Making Government Science Work for Canada and the World[1]

A Legacy of Excellence at the Canada Centre for Remote Sensing (CCRS)

The authors and contributors to this document and the editor are named on the following Author's Page as well as in their respective sections or Subsections.

The Executive Summary and Lessons Learned follow the Author's Page

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[1] The original title of this work referred only to Canada. In a telephone conversation on January 7, 2019 Dr. Ade Abiodun - one-time CCRS Post Doctoral Fellow and later a senior official in the United Nations remote sensing and space program suggested that the word "World" be added to recognize the contributions CCRS made beyond the borders of Canada. As ever, Ade was convincing and the title has been changed! His story is in Section 3.6.2.

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Author's Page

This document that details how to do science in Government for the benefit of the country and its citizens is the result of a volunteer effort. Authors listed below are those who have written material for this work. Except for Dr. Morley, names are listed alphabetically. This work was initiated by Dr. Morley and is a tribute to him.

A note on the use of the term "Dr." Many of the people referred to and many of the authors have earned PhDs. That is the nature of a research-based organization. We have tried to use the term "Dr." the first time someone's name is mentioned or in a list of those named as seemed appropriate. To use it throughout the document everywhere someone's name is mentioned seems to be distracting to the flow for the reader. Our apologies in advance if someone with a PhD believes that they are not accorded appropriate respect with this approach. Those marked * are deceased.

Authors and Editors: Chapters and Sections

Dr. Lawrence "Larry" Morley*
Dr. Frank Ahern
Ralph Baker
Dr. Josef Cihlar
Dr. Ian Crain
Roy Dixon
Howard Edel
Tom Feehan
Carolyn Goodfellow
Dr. Laurence Gray
Dr. Alan F. Gregory
Florian Guertin*
Dr. Bob Hawkins
Michael Kirby
Keith Langley
Dr. C.E."Chuck" Livingstone
Tom Lukowski
Wally McColl
Dr. Heather McNairn
Jennifer "Jenny" Murphy
Dr. Bob O'Neil
Peter Paul
Dr. R. Keith Raney
Dr. Dianne Richardson
Dr. Bob Ryerson
Dr. Vern Singhroy
Dr. Karl Staenz
Dr. Murray Strome
Dr. Philippe Teillet
Dr. Thierry Toutin
Dr. Ridha Touzi
Lori White
John Wightman

Contributors

Contributors are those who have provided a limited amount of material including anecdotes, papers and material written some time ago and "re-purposed" for this. Names are listed alphabetically. Those whose work is cited but who did not prepare material used directly here are not listed as contributors.

Tom Alföldi
Bill Bruce*
E.A. "Lee" Godby
Paul Hession
Shannon Kaya
Les Whitney

Editor-in-Chief

Dr. Bob Ryerson
Box 1125, Manotick, Ontario
K4M 1A9
bryerson@kimgeomatics.com

Editor's NOTE: Each author is responsible for his or her contributions and any opinions expressed therein. As editor I have only sought authors, organized the material and performed an edit for clarity and consistency in grammar and format.

Executive Summary and Lessons Learned

Bob Ryerson

ES1. Executive Summary

We the authors of this history and "how-to" guide freely contributed our time and knowledge to its creation. Why? Because we appreciate that what we accomplished together was something special: something that no other group anywhere in the world accomplished no matter their size or budget. We want to explain not only what we did, but how we did it to provide some guidance for others in government who seek to apply science to meet the future needs of Canada and Canadians. This short summary is intended to whet the reader's appetite and provide an overview of what the Canada Centre for Remote Sensing accomplished – and why. The summary ends with the lessons learned – lessons that are as relevant today as they were when first applied by CCRS.

One of the best explanations of how so much was accomplished comes in Section 5.5 – the conclusion of the Section on RADARSAT by Dr. Keith Raney, a former Chief Scientist at CCRS and arguably the world's leading radar scientist in the period this history covers. His explanation:

> "Long-term enterprises become successful only to the extent enabled by the steadfast leadership of their management, sustained by enthusiastic quality staff, and high level support. Leadership and senior management need to be willing to accept risks, when the road ahead is well prepared, and the benefits of success are clear. RADARSAT-1 is a good example. The all-important user advisory groups set up by management (inspired by Larry Morley) in the early 1970s became essential resources leading to a remarkably responsive satellite SAR launched two decades later. The CCRS SAR-580 program that provided radar data products and user-oriented analysis techniques were an essential component in developing and expanding a knowledgeable user base, both in Canada and world-wide."

Former Scientist and Director Dr. Bob O'Neil elaborated on the conditions for success in Section 6.5.3 when he stated that "CCRS hired people with a range of backgrounds with two common attributes: pride in what they did and the drive to meet what sometimes seemed like unattainable goals."

This history of the Canada Centre for Remote Sensing (CCRS) was written at the suggestion of the late Dr. Lawrence "Larry" Morley, who has rightfully earned recognition as one of Canada's all-time leading scientists and engineers. In 2014 Dr. Morley was inducted posthumously into Canada's National Science and Engineering Hall of Fame: he was one of but sixty members. He was the founding Director General and led CCRS from its inception until the 1980s. Dr. Morley always said "Canada was made for remote sensing" given the limited budget of CCRS and the enormous size of the country we were setting out to monitor and help map. While this document has been written as a history, along the way it also outlines how to do effective science in government. This is as Larry intended: as with most work done by CCRS two objectives have been met with one output.

CCRS was known world-wide as a world-class organization that consistently punched well above its weight in the important area of earth observation. It served as the model for a number of countries and how they approached remote sensing and the geospatial sciences. We the authors believe that the CCRS organization "model" is more widely applicable than to just remote sensing and related fields. The organization – from management structures to the library – was built to foster innovation. As is explained in Section 6.4, innovation was not something that was just hoped for, or that we relied on luck to achieve. Innovation was built into our organization's DNA.

This is the story of CCRS – both what it did, how it did it and, most importantly, the lessons learned that might be usefully applied by Government in other areas of science and technology. There is a great deal of focus on supporting and international activities inasmuch as they were, in retrospect, critical to the long term success of CCRS and the growth of the industry that CCRS nurtured. It is believed that it is particularly important to emphasize these supporting activities since most scientists and science advisors tend not to give them the attention that they deserve if the goal is to create a successful and sustainable science-based activity to support the national interests of a country.

This history is not just about CCRS. It recognizes the important roles of industry, academe, other levels of government and other government departments with which CCRS worked as a truly national centre of excellence. At the same time we also agree with the point of view on the important role of government in innovation espoused by Dr. Mariana Mazzucato in her *TED Talk* filmed in June of 2013 that was titled "Government – Investor, Risk-taker, Innovator." We recommend viewing her presentation as a point of departure before reading this work:
http://www.ted.com/talks/mariana_mazzucato_government_investor_risk_taker_innovator

The accomplishments of CCRS and its staff are truly amazing in both their scope and importance. Almost every page identified yet another leading edge development or a first in the field: there are far too many to list them in this summary. For this executive summary we have extracted some of the most significant achievements and activities in the following table. For each we have identified the section where further details can be found.

The reader will find that some topics are covered more than once from different perspectives. For example a specific technology may be described by the scientist or engineer who invented the technology as well as by the applications scientist who used the technology. We believe that these different perspectives give a more rounded and complete view.

Following the table are the more than sixty lessons learned that have been extracted from this work. We hope that the Lessons Learned over the next pages will be widely and wisely shared across government.

Some of the Significant Achievements and Activities of CCRS and Its People[2]

Awards and Accolades

- In 2011 CCRS was the first organization outside of the US to win the prestigious William T. Pecora Award, the highest honour in the field of remote sensing for an organization. Over 35 accomplishments are cited in Section 8.2.3.[3] The nomination letter begins with the following paragraph: "I am nominating the Canada Centre for Remote Sensing (CCRS) for the 2011 Pecora Award. CCRS has contributed in a major way to the understanding of the Earth over a period of forty years through the development of important technologies, innovative applications and policies, as well as major contributions to the international community. It has worked successfully with the USGS and NASA as well as other agencies and industry in the USA and elsewhere. Cooperation has been its hallmark."
- CCRS employees have won hundreds of awards for contributions in the field. Section 8.2 documents some of the most important.

Advisory Structure

- To truly understand the organizational genius of Larry Morley, Lee Godby and University of Waterloo professor and management consultant Don Clough, one need only look to the Canadian Advisory Committee on Remote Sensing - CACRS. The Committee and how it functioned as an inclusive truly national advisory body was responsible for much of the success Canada enjoyed in the field. Section 2.2.
- CACRS provides a useful model for guiding science in government. Section 2.2.
- There are two significant new programs that came out of CACRS Recommendations: the development of the airborne radar program; and RADARSAT. Sections 6.7.2 and 5 respectively.

[2] Editor's Note: Text boxes are used throughout this document to provide additional information. Some of them are longer than one page and many are split between two pages. This may not be ideal in terms of format, but it does mean that fewer pages are wasted.
[3] Several of these are repeated in this table.

Active on the World Stage

- Larry Morley was the individual who did more than anyone to make the world's remote sensing community a global village based on cooperation and sharing. Section 2.1 and Appendix F.
- The CCRS Library provided world-wide access to the first searchable data base of English and French publications in remote sensing and by so doing became the world's go-to source for information in the field. Section 6.3.
- Canada's first cooperative agreement with the European Space Agency was initiated by CCRS for ESA to gain access to the Convair-580 SAR. In a 1985 assessment of the relationship with ESA, Canadian participation in the ESA ERS program was viewed as "a major asset" primarily because of the role of the Canada Centre for Remote Sensing. CCRS was described as "the leading body in remote sensing. It had a good team, the necessary resources and long experience". "The same report noted that MDA, which had been awarded the prime contract for providing the SAR data processing technology at the two ERS satellite stations in Europe, had become a leader in the field. Section 7.8.
- The Convair-580 aircraft and the systems on board were used to provide SAR imagery, share our experience, and demonstrate our excellence in Asia, Africa, the Middle East, Latin and South America, and, of course, Europe. Sections 6.5.6 and 6.7.2.
- CCRS was a founding member of the Committee for Earth Observation Satellites (CEOS) and played a pivotal role in data calibration, standards, and the like – helping Canadian industry (such as MDA, PCI and others) along the way. Section 3.6.3.4.
- As a result of the award-winning GlobeSAR program additional sources of groundwater were found in Jordon. The Syrian refugee camps in eastern Jordan currently rely on this water. Section 6.6.6.
- CCRS had both bilateral and multi-lateral relationships around the world. Section 3.6.

Responsive to National Priorities

- Key issues faced by the government of the day were always kept top-of-mind by CCRS management – and scientists. For example the thread of protecting sovereignty has run through CCRS and remote sensing from their beginning in Canada. There was also an early focus on thermal imagery for assessing heat loss in buildings in response to the energy crisis in the early 1970s, while climate change became top of mind in the 1990s. Sections 6.5.3 and 6.6.10.
- CCRS worked with a wide range of other federal departments and agencies as well as the provinces and academe. Sections 3.1, 3.2 and 3.4.
- In the massive budget cuts of 1994-95 the only program in all of Government to obtain substantial new funding was the space program which obtained some $800M over the next decade or so and most of that was earmarked for remote sensing or earth observation (EO). CCRS wrote much of the EO justification and the industry CCRS worked with provided support. Sections 2.3.4.2, 3.3.2.6, 4.3 and 6.6.1.

Relationships with Industry

- Dr. John MacDonald, founder of high tech success story MDA, was quoted as saying "it was from Larry Morley that we learned how to build a high tech company in Canada." MDA got its start working with CCRS. Section 3.3.4.5.
- CCRS was considered so effective in its development of industry that it was studied to gain insights into how science could lead to commercial success. Section 3.3.1.
- CCRS contracting and related policies led to international success for several companies including PCI Geomatics and Intera. Sections 3.3.4 and 3.3.3.
- MDA has sold the Geometric Image Correction System (GICS) technology derived from MOSAICS for CCRS to many satellite ground stations around the world for satellite missions such as Landsat, SPOT, ERS-1&2, MOS, NOAA AVHRR, JERS, RADARSAT, Envisat and others. The GICS technology became the de facto world standard, and MDA the leading provider of Earth observation satellite ground systems with market share estimated as high as 90%. Section 7.5.

High Impact

- The CCRS Convair-580 Synthetic Aperture Radar research aircraft and work by CCRS scientists on polarimetry provided the proof-of-concept and scientific backing for an **estimated $10 billion investment by Japan, Europe and Canada in radar remote sensing satellite systems.** Unlike most other countries, we in Canada used aircraft to prove and develop concepts before launching spaceborne systems – a cautious but effective Canadian approach. The CCRS Convair-580 Synthetic Aperture Radar research aircraft flying laboratory is a symbol of how we approached scientific research: cautiously and in support of our economic, environmental, and foreign policy goals. Sections 6.5.6 and 6.7.2.

- During the 1990s the GeoAccess Division's Atlas of Canada web site routinely ranked among the top Government of Canada sites in terms of yearly visits by users. Section 6.10.
- In 2006, as part of the centenary celebrations of the Atlas of Canada, the Royal Canadian Geographical Society recognized the Atlas with its Gold Medal award. The Canadian $100 banknote was produced to celebrate the same centenary. Section 6.10.2.

National Leadership

- CACRS was originally set up as a national advisory body including all sectors and regions of Canada. Section 2.2.
- The Canadian Remote Sensing Society led by Larry Morley was the first national society anywhere with remote sensing in its name. Section 3.5.2.
- "The ground breaking work by CCRS supported many a graduate thesis and advanced many a career…and has most certainly yielded dividends." Section 6.6.3.9.4.

Efficient and Well Managed

- The Auditor General could find nothing to criticize! The ultimate stamp of approval on how CCRS was managed and the results obtained came from a study involving the Auditor General and a report of the Auditor General of Canada. Section 2.3.2 and 3.3.1.
- The GeoAccess Division was a part of CCRS for just twelve years. Over those twelve years what began as a collection of orphans that no-one other than CCRS seemed to know what to do with became an award winning unit that everyone coveted. This is largely as a result of the solid management team that was assembled and the belief of the staff that what they were doing was important for Canada. And it was important. Section 6.10.
- While CCRS developed a wide range of new technology, CCRS used generic off-the-shelf computer hardware and software where possible to avoid designing costly special purpose systems, and by so doing reduced the on-going operation and maintenance costs. Section 7.2.

Technology Developments

- CCRS did a significant amount of the world's basic research in civilian radar remote sensing. Section 5 and 6.7.2.
- Working with CCRS MDA developed the first digital SAR image – forever revolutionizing the use of SAR data. MDA became the world's largest producer of SAR processors. Sections 3.3.2.6, 3.3.3.6, 5.1.2, and 7.6.In the 1976-1979 time frame CCRS developed the Digital Image Correction System (DICS), the first operational facility to produce geocoded imagery from Landsat MSS data. Section 7.4.
- The CCRS Colour Image Recorder was the world's first high-resolution digital film recorder system. Section 7.7.
- The Polarimetric Work Station developed by Dr. Touzi of CCRS has been adopted in Canada and in many countries around the world (India, Brazil, China, France, Russia, and Argentina, among others) as a user-friendly tool for efficient exploitation of polarimetric satellite SAR information provided by various satellite and airborne SARs. Section 6.7.2.4.3.
- CCRS developed methods to use SAR data for individual ship detection. Section 6.7.2.4.3.
- The pioneering research into image analysis algorithms by CCRS and the rest of the RS community in the 70s and 80s formed the basis for today's practical applications from point-and-click photography to the "vision" capabilities of autonomous vehicles. In particular the CCRS work led to a successful export industry. Section 6.8.2.2.
- Data from the US's flagship Landsat Thematic Mapper sensor had serious problems (striping in the data) that the US could not solve. It was CCRS scientists Frank Ahern and Jenny Murphy who developed a solution to the problem. Their approach was subsequently adopted world-wide – including by the US. Section 6.8.2.5.1.
- CCRS successfully received and processed the first Landsat-1 image and made it available to the U.S. The

image was rushed to Ottawa from Prince Albert in time to be shown at the 12th ISPRS Congress held from July 24 - August 04, 1972. Section 6.9.2.
Leading Edge Applications • CCRS led the Great Lakes Land Use Mapping Project – the world's first large area project where information derived from existing map data, satellite data, airborne data, and census data were incorporated together in a GIS. Section 6.6.3.3.2. • CCRS worked with Statistics Canada to produce the first real-time pre-harvest operational crop area estimation done anywhere. Section 6.6.3.6. • An operational crop monitoring system was developed with and for the Canadian Wheat Board. It was later taken over by Statistics Canada which received a government-wide award. (See Section 6.6.3.5.) • The unique CCRS approach to monitor rangeland condition won an award for Drs. Ron Brown and Frank Ahern for the English speaking world's most outstanding paper in remote sensing in 1983. (Section 6.6.3.7 and 6.6.3.1.2. • CCRS was a major contributor to the BOREAS Program. Canadians have benefited from improved weather forecasts resulting from a better understanding of the energy exchange over the vast boreal ecosystem. Section 6.6.10.4. • CCRS was an early player in the area of climate change and national monitoring. Section 6.6.10. • CCRS's contribution to Canadian agriculture is measurable and remarkable." Section 6.6.3.9.4.
Technology Transfer, Education and Visibility • CCRS was active in technology transfer and the development of training materials used at home and abroad. Sections 3.1.7 and 3.2.4. • CCRS had an active marketing and public awareness program. Section 6.2.

ES2. Lessons Learned

ES2.1 Introduction

This is believed to be the most important section of this work. The lessons learned over the history of CCRS provide both positive advice and some advice on how not to do things with regard to science policy and implementation of that policy in government. The lessons learned are identified in the next nine Subsections. The topics considered are:

- Management and leadership (not the same thing!);
- Advisory bodies;
- Working with industry, academe and government agencies;
- Identifying opportunities;
- Innovation and problem solving;
- Building research capacity;
- Putting innovation into operation;
- Understanding politics and politicians: and
- International relations.

One of the interesting aspects of re-reading hundreds of papers, advisory reports and meeting minutes concerning CCRS was the realization that the early leaders of CCRS knew that they were forging a new way of doing science in government – and that other organizations might learn from studying CCRS. This was clearly stated in Canadian Advisory Committee on Remote Sensing (CACRS)[4] reports, for example. And while many did learn from CCRS, we hope that this document will lead to many more gaining insights from what amazing things CCRS accomplished and how it did so.

[4] Pronounced KACK-ers.

ES2.2. Management and Leadership

- To ensure knowledgeable management and leadership, all levels of management and the leadership should have experience relevant to the discipline.

- Leaders should be expected to lead, not just manage.

- To ensure succession planning in both management and leadership, efforts should be made to identify potential managers and leaders among the engineers and scientists involved in the program. (At CCRS many people identified as having management and/or leadership potential went on to become Directors, Directors General, and Assistant Deputy Ministers in organizations in governments across Canada. A number of others became leaders in industry.)

- Secondments, participation on interdepartmental committees, mentoring and formal training can be used to further staff development and expand the impact of the organization.

- All projects and programs must be on time, on budget and there will be no surprises.[5]

- There should be no fear of failure…such fear limits the potential for success.

- While failure can be tolerated, both project managers and senior management should know when to cut losses – and not be afraid to do so. A project selection and review committee of senior scientists and their managers chaired by a member of the leadership team will help in this regard.

- Management should have plans in place to rapidly absorb extra budget should funds become available. At the same time, it is wise to know what projects or programs might be sacrificed should there be calls for budget reductions.

- Everyone in the organization is important and should believe that their role is important.

- Management by walking about is important. Leaders and senior managers should be seen and should be available on an informal as well as formal basis.

- Management should keep in mind that Research Scientists are promoted based largely on publications and related metrics. Technology transfer and operational applications of science are sometimes best left to those not in the Research Scientist category.

- Constant reorganization and changing linkages and mandates tend to result in reluctance to embrace changes – even beneficial changes.

ES2.3. Advisory Bodies

- To ensure that widely-based and appropriate advice is received, a broadly based advisory body should be established at the outset to provide advice to government.

- To avoid hearing only limited advice, the main advisory body should meet annually with its constituent working groups that cover the key areas within the discipline including technical areas, potential users, industry, researchers, and appropriate levels of government. (This may be done at a relevant national symposium.)

[5] Editor's Note: These are the words of the late Florian Guertin who gave so much to CCRS – and this document.

- In that some science and industry policy may be related to national security and industrial development, some elements of the advisory body's deliberations may have to be held in secret.

- If the research involves natural resources or other areas that fall mainly within the jurisdiction of the provinces, as CCRS work did, then the provinces and territories must be fully engaged in the advisory structure.

- As science and research lead to new ideas, evolution and change in advisory bodies and their working groups should be both expected and accepted as the norm.

- Advisory bodies that advise the scientific level as well as the political level are more effective than those that advise the political level alone.

ES2.4. Working with Industry, Other Government Agencies and Academe

ES2.4.1. Introduction

How CCRS worked with those in industry, other government agencies and academe is one of the keys to its success. Words like collaboration, partnership and technology transfer were all part of the vocabulary at CCRS. By and large CCRS listened to its stakeholders both through advisory structures and bilaterally. Furthermore CCRS was generous in sharing success, and paid strict attention to its mandate and those of its partners to ensure cooperation. Here industry, other government agencies and academe are grouped together inasmuch as certain elements of working with others cross these sectoral boundaries.

- The organization should actively build and maintain links with partners and stakeholders in industry, government, and academe as well as with key international partners.

- By partnering with outside organizations, including those engaged in R&D, one can leverage work for broader application to a much wider community. CCRS was able to exert an influence far out of proportion to its small size.

- Words like collaboration, partnership and technology transfer should be part of the essential vocabulary of everyone in the organization.

ES2.4.2. Industry

- Government can be an effective beta client for industry's commercialization activities.

- Do not compete with industry: allow industry and the advisory body to decide what is or is not competition.[6]

- Industry should be fully engaged in advisory bodies.

- Recognizing that industry will, in the end, likely be the agent to make the science operationally useful, mechanisms to involve industry in technology transfer should be in place from the start. These may involve industry employees being embedded in or seconded to government, government staff seconded to industry, incubators, or other mechanisms including Public Private Partnerships.

- In that governments should not be involved in selecting winners and losers, mechanisms to engage industry should be open and transparent and involve independent evaluations of proposals.

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[6] This was a bone of some contention. The Ontario Centre for Remote Sensing was accused of unfairly competing with industry, as were some of the other provincial centres.

- Project reports, not just scientific papers, should be readily available to Canadian industry to lead to commercialization for the benefit of Canada (and the taxpayers who paid for the research).

- To obtain the best result for the dollar expended and to avoid "low-ball" bidding all requests for proposals should indicate the dollar amount set aside for the contract and proponents should be encouraged to make innovative use of the funds available to maximize the return on the expenditure. Such an approach leads to innovation and reduces the potential for less competent "low-ball" bidders winning contracts that they cannot complete or which yield results that they are unable or unwilling to commercialize.

- If industry or other governments have benefited from the R&D done, benefits should be quantified and brought to the attention of the political and senior bureaucratic levels – preferably by industry or the other levels of government most involved.

ES2.4.3. Working with Other Government Agencies

- If the research involves natural resources or other areas that fall mainly within the jurisdiction of the provinces, attention should be paid to cooperation and the development of mechanisms to transfer technology to the lower or other levels of government.

- If the research will serve, or can be expected to serve, another government ministry or agency, the nature of relationships and responsibilities should be formalized to maximize the potential benefits. These agreements may include cost-sharing, secondments, how credit is shared, and how results and benefits are calculated.

- Joint projects with other levels of government and other government agencies or ministries tend to amplify expertise.

ES2.4.4. Working with Academe

- Education is a provincial/territorial responsibility – a Federal agency must be mindful of that fact.

- Academics from universities and colleges should be fully engaged in advisory structures.

- Researchers in academe should have access to data and the necessary information for both research and education.

- Beneficial working relationships with academe can take many forms including hiring summer or co-op students, secondments during professorial sabbaticals, or government scientists serving as adjunct professors, thesis examiners, visiting faculty members, or advisors on program structure and/or content.

- Agencies may find it useful to contract research to academics (e.g. funding graduate student research), or contract education and training associated with international activities of the government agency.

- Government scientists participating in research teams involving academics can be an important way to share and further research.

ES2.5. Identifying Opportunities

- To ensure success, work must contribute to the needs and priorities of the government (See Section ES2.9 below.) and, ideally, other levels of government, industry and the international market.

- New government or other funding programs (including international opportunities to which Canada has access) should be evaluated as to their relevance to the organization's activities.

- Creating positive relationships with the media and publicizing successes should be a key activity supported at the highest levels. While perhaps once seen as unusual in a science-based organization in Government, public awareness and marketing should be part of any science program. Such activities will lead to the widest possible understanding of the science and/or technology to ensure that serendipitous applications have a greater chance of being identified.

- There may well be opportunities to contribute to foreign policy, trade and/or international development: these opportunities should be explored.

- All of the above imply that a broadly-focused and technically and scientifically aware marketing activity is required.

ES2.6. Innovation and Problem Solving

- A research and development organization must be a safe place for new ideas: calculated risk is to be encouraged.

- Do more with less – every time. One way to accomplish this is to ensure that every project or activity has more than one potential beneficiary and more than one purpose – i.e. projects should be planned to produce multiple outputs to meet multiple objectives with the same input.

- Build on the verifiable research of others – but do not do "me-too" research (research that simply proves that someone else was right in their conclusions).

ES2.7. Building Research Capacity

- Not every area of needed expertise can be covered by a Canadian – you may have to hire some people from other countries to put you "over the top."

- If the research involves natural resources or other areas that fall mainly within the jurisdiction of the provinces, consideration should be given to how or if research capacity should be built up[7] to meet provincial and territorial needs.

- A diversity of scientific backgrounds of staff can lead to a broader range of potential solutions to research problems.

- A diversity of cultural and linguistic backgrounds of staff can lead to a broader range of potential international markets, as well as a wider range of approaches to scientific questions.
- Budgets must be predictable from year to year to allow for multi-year projects.

- Capital budgets are easy to cut, but such cuts may lead to failing infrastructure in the future.

ES2.8. Putting Innovation into Operation

- **The value of a new technology comes not from its creation, but rather from its use.**

[7] Built up here implies the full range of activities that might be envisioned – how research capacity is organized, strengthened, structured, or enhanced.

- Recognizing that there is no one appropriate approach to operationalize an innovation, various ways may be used including allowing industry access to scientists through some form of collaborative mechanism (such as an incubator), licensing, transfer mechanism to address other levels of government, etc.
- Ensure that the required suite of technology development tools and relationships are available when and as needed. For example, CCRS had sensor development expertise (scientific, engineering, and technological), test and demonstration capability, applications development expertise and wide connectivity with government and private sectors within Canada and abroad to keep its work relevant and cutting edge.
- To ensure that appropriate companies are engaged to further operationalization of the science governments should try to work with companies that have had success in commercializing R&D.

- Researchers often want a perfect or near-perfect solution. Even the near-perfect solution is often too expensive to implement: industry (or users) should be engaged early in the process (ideally at the beginning) to allow earlier commercialization and early use of the resulting technology and by so doing, be first to market.

ES2.9. Understanding Politics and Politicians

- Obtaining or maintaining financial support for a government program requires the support and interest of the political level. Linkages must be shown between the program and the important issues of the day as outlined in Minister's letters, Speech from the Throne, or policy announcements. These issues may be creating a clean and sustainable environment, job creation, increased exports, etc.

- Members of industry and academe including those active in broadly-based advisory bodies and working groups can contribute to increased visibility, awareness and understanding by the political level through outreach activities, pro-active media coverage, meeting with parliamentarians, etc.

ES2.10. International Relations

- A world-class organization must be both outward-looking and highly competitive.

- International activities must benefit international partners as well as Canada.

- Recognizing that science and the markets to apply innovation from science are international, identifying sufficient funding for international activities is critically important.

- To stake out an interest in a new or developing market for a new area of innovation, it is important to establish a leadership position in the international community. This may be done by volunteering to chair and host a new international committee or working group, lead a technical standards body, or serve as a host repository for information. This may be done through the UN, a development bank or independently. On a much grander scale, one might develop an international training institute or facility – much like the International Space University or the former ITC in the Netherlands.

- Virtually every new technology and its application must be considered in the international context in terms of the science, its application, and the market, including the potential for development assistance through Canadian and international mechanisms.

Table of Contents

Foreword

This history of the first forty years of the then demonstrably world-class Canada Centre for Remote Sensing (CCRS) provides a set of useful lessons for those wanting to develop science policy that will lead to success. At the same time it is meant to convey the excitement of a new field and how the Government of Canada played a key role in the field's development – in Canada and world-wide from 1971 to the early 2000s.

The story of its formation, accomplishments and contributions to Canada and the world is one of hard work, some luck, a few brilliant leaders, and what a team from government, industry, and academe working together can accomplish. CCRS had brilliant leaders, top-notch scientists, a number of what can only be described as "characters," and a shared belief that Canadians could do more with less…and we did. In 2003 four scientists at CCRS wrote a description of why and how CCRS accomplished so much – they titled their two page document "*History Lessons – The Mouse that Roared*." That document, written more than thirty years after the founding of CCRS (and more than fifteen years ago), is reproduced in full in Section 2.4.1. It is used to introduce the approach to management, technology transfer and external relations at CCRS that proved so successful for so many years.

I have been asked two questions about this history.

1. Why do it?

The first is easy to answer. CCRS had success doing world-class science and technology development within government working with partners in industry, other federal departments and agencies, other levels of government, and academe. The model was copied all over the world – and could be applied once again. Our first leader, Dr. Lawrence Morley (Larry to those of us who had the privilege of working with him) thought that the story of that success was worth telling and some years ago began a committee to mobilize both resources and interest. This is a direct result of that initiative. Furthermore, as science is being "re-born" in government, and as we understand the importance of science and technology in industry policy, how CCRS obtained advice, how it evolved and how it was organized and managed will be instructive to governments today.

2. Why should you do it?

I admit some bias. I was part of the CCRS team. I was hired in the first group of applications scientists in 1973 and was involved in the field even before CCRS was officially established. I later became Director General. But what qualifies me to write a history – and this history in particular? I can provide nine answers to this question – the last being most important. I have:

1. Already written a short history of remote sensing in Canada for the book "***Mapping a Northern Land***" (Sayn-Wittgenstein, 1999);
2. Served as a scientist, Section Chief, been a member of the Management Advisory Committee and have been Director General;
3. Access to a great deal of material in my personal library;
4. Formal education in history – a distinction I earned along with several degrees in geography and remote sensing;
5. Written and edited a number of books on and in the field;
6. Benefited from having been in the field from near the beginning;
7. Spent quite a few years as an outside observer while trying to help other countries replicate the success of CCRS;
8. Maintained a library of material that seems to have largely disappeared – summaries of advisory committee meetings, research documents published by the organization, newsletters, symposium proceedings, public relations materials, press clippings on the Centre's work, and thousands of slides;

9. Been fortunate as word of this project got out to have had over thirty former colleagues volunteer to contribute their writing and send me copies of papers, reports and other documents; and
10. Most importantly, after the establishment of the CCRS History Committee by Larry Morley, there was a lot of discussion … but no-one else seemed willing to do it!

I have used some of the organizational structure and much of the prose provided by Larry in his 1991 overview of the field "Remote Sensing Then and Now." That dramatic 30 page document is well worth reading for anyone interested in the field. It conveys both the excitement and the ups and downs associated with the establishment of CCRS from a vantage point that no-one else had. Indeed, it provides an entirely new perspective even for those of us who participated in the events being described. As for the present document, depending upon the section, I am either editor or author. In most cases I have been a very light editor inasmuch as the contributors are generally known for their ability to write clearly and well. The authors of, and contributors to, each section are identified in their sections.

Some areas have not been covered as well as others – and some have not been covered at all. Unfortunately, as time has marched on many of those who would have helped have passed on while others have been burdened by ill health. We are fortunate that several key figures in the field contributed material before they passed on – notably Larry Morley and my longtime colleague and friend Florian Guertin. The depth of coverage has depended on whether I could find authors ready and willing to describe the areas in question or whether I could access sufficient resources to fill in gaps myself. In all cases we the authors have tried to provide references to the original work that provides the backbone to this effort. In some cases, in the words of one of the co-authors: "the material is…very uneven in terms of too much (often technical) information or too little information." In areas where there is perhaps too much information we have decided to leave it for others to reduce it as needed for the intended purpose. Technical detail or material not central to the narrative is often placed in a text box.

I was going to thank the librarians working in Natural Resources Canada, but the five boxes of the materials deposited there by Larry to help in the writing of this history seem to have disappeared and I fear that many of the seminal publications are only kept in personal libraries, if they have been kept at all. Luckily, as my wife will attest, I have long been a "pack-rat" and have kept a personal library of many symposia proceedings, CACRS Reports, scientific papers, newsletters, and several thousand slides. (Fifty-six boxes at one count!) I have drawn heavily on these materials. Library and Archives Canada have agreed to accept eight boxes of these documents.

Like CCRS itself, this document owes its being to the inspiration of Larry Morley and its creation to the more than thirty co-authors who gave their time and knowledge to its creation. My co-authors deserve a hearty "Thank you!" for their wonderful and thoughtful contributions.

A word on acronyms: The Canada Centre for Remote Sensing (CCRS) worked in the area of space and technology where acronyms were (and are) in common use. We have attempted to introduce each acronym where it is first used as well as in the alphabetical listing of acronyms at the end of this document.

Bob Ryerson
Manotick, Ontario
June 2019

1. Introduction

Bob Ryerson

There are many reasons and many ways to look at CCRS – the Canada Centre for Remote Sensing. We begin with the assumption that CCRS was somehow "different" and worth studying – a close look at CCRS may be instructive from a number of standpoints. For example, one could look at how it evolved, what it contributed and what lessons might be learned from a study of it over time. The comparison of the Canadian Advisory Committee on Remote Sensing (CACRS) vs. other advisory bodies may be instructive. Perhaps there may be interest in CCRS as an example of the evolution of science in government, or the very positive relationship that formed between industry development and government science, or how a federal science and technology organization interacted with the provinces, industry, academe or other government departments. The management structure and approach, seen by many of us as ahead of its time, may also be worth studying. Perhaps someone may want to compare CCRS to other government organizations in Canada or elsewhere to see how this one relatively small organization propelled Canada to a leadership role in the field internationally. For many of these topics there may also be an interest in assessing how CCRS was viewed by those who worked in or with it.

This history is intended to answer all of these questions. By so doing we are reflecting on one of the basic tenets of CCRS: meet a number of objectives with one output. A corollary of that is another basic principle: do more with less.

The value of this history has already been demonstrated. In 2017 the Government of Canada established the Space Advisory Board to provide advice on what Canada should be doing in the area of space. The Board asked for input and advice. Material assembled, organized and written for this history was brought together in a 28 page response to the Board and some of the suggestions made in that response have found their way into the Board's report and, we hope, into government policy. We hope that many more government policies will be informed by this document.

Certainly a small book or monograph may be written on each of the topics of interest noted above. In 1991 the founding Director General, the late Dr. Lawrence (Larry) Morley wrote a summary from his perspective that ran to almost 30 pages of fascinating material. A number of years ago now, Larry[8] called a meeting of former CCRS employees to explore the creation of a history of CCRS. This document is the result. In the last year of an extraordinary life Larry assembled five boxes of his writings, historical material and other documents pertaining to the history of CCRS. Several people including Les Whitney, volunteered to be the custodians of this treasure, but Larry thought it best to give the material to the Library at Natural Resources Canada where it would be properly cared for. Regrettably these materials seem to have been disposed of as not being of value or interest. Luckily we have some of the papers he wrote courtesy of Tom Alföldi, Lee Godby, Les Whitney and the editor.

Of course, the topics listed above and Larry's paper do not begin to cover the research reported in many thousands of pages of scientific papers and books published and/or contributed to by CCRS scientists over the years. The value of the research and impact can be seen from the higher than would have been expected number of CCRS scientists who reached the highest level for a scientist in Government – Research Scientist Level -5.

Our challenge then is to organize this document as well as the material we have obtained according to themes or topics that will allow future studies to more easily access the information that we either collect or identify in existing materials to build THEIR chapters and assessments. With this background six themes have been identified that may be instructive to those engaged in science in government. The

[8] A note on names: Dr. Lawrence Morley was always accorded his earned title of "Dr." in public. But to us at CCRS, one-on-one, he was Larry. In most cases he will be referred to as either Morley or Larry, depending on the circumstances. The reader should be assured that the use of the familiar "Larry" is a sign of respect – and what he would have wanted us to use here.

seventh theme provides a list of significant events, decisions and appointments as well as kudos received by both the organization and the employees. In a number of cases, an inanimate object (a sensor, an image analysis system, an airborne laboratory, etc.) was feted, not the person who created it. This too says volumes about how the organization worked. But CCRS staff did win more than their fair share of awards at home and internationally.

The first theme (covered in Chapter 2) deals with the overview of CCRS's formation, advisory structures, and approach to management. The second theme, in Chapter 3, covers relationships: relationships with provinces, industry (including CCRS's role in helping to build an industry from virtually nothing), academe, other federal agencies, scientific organizations and international relationships. The third theme "Mergers, Acquisitions and Closures" deals with the additions and deletions of significant elements of the organization over time with an explanation from those involved in why they happened as they did. The fourth theme – RADARSAT – is a wonderful story of scientific and engineering brilliance coming together to address issues of national importance. The fifth of the instructive themes is simply called "Science and Services." Under this theme we address the CCRS approach to innovation and the various programs including the airborne program, satellite data reception, applications development, sensor development, methodology development, systems, and technology transfer. The library and the Remote Sensing, On-Line Retrieval System (RESORS) and the CCRS marketing activities are also discussed here as enabling or supporting activities.

The sixth theme is called the "kudos, geography and people theme." It details a small sample of the awards and kudos received over the years by the organization and its people. This theme also covers the "geography" of CCRS – the many buildings and homes of various CCRS sub-groups. Some of these buildings were functional by design and others had to be significantly modified to accommodate a growing and evolving organization. Many wonderful anecdotes revolve around these buildings and their eccentricities – not to mention the eccentricities of those of us who, in general, took great delight in inhabiting them. Some of the personalities are also brought out in this more informal chapter.

The final section brings together the lessons learned over the years organized by topics including: management, advisory bodies, working with industry, working with academe, identifying opportunities, innovation and problem solving, building research capacity (and the importance of capital budgets), putting innovation into operation, understanding politics and politicians, and international relations.

While not a theme *per se* in this document, underlying much of what is written is the concept of "leadership." In the words of Tom Lukowski:[9] "as described throughout this document, CCRS was an organization dedicated to furthering the field of remote sensing in all of its many facets. This was not just limited to development of technologies and the exploitation of data. It was also very much leadership, both in Canada and in the world-wide remote sensing community. This included the sharing of knowledge and the assistance to others in these fields. Examples of this leadership are highlighted throughout the document. Admittedly, although the contributions of CCRS were "limited" by resources and capabilities, they were significant both on the Canadian and international stages as is clearly demonstrated."

[9] Personal Communication from Tom Lukowski, May 11, 2018.

2. Formation, Advisory Structures, and Approach to Management[10]

Larry Morley and Bob Ryerson[11]

2.1. 1960-1966 Pre-CCRS, Good Luck, a US Partner, and Canada's Needs[12]

2.1.1. The Beginning[13]

The following narrative unveils the development of remote sensing in Canada almost as a novel – with many twists and turns before the end result arrives. Section 2.1.4 contains a brief chronology of the key events that led to the formation of CCRS. Throughout this document we use text boxes to provide technical information or additional material that provides context, background, or some of the more complex descriptions of the science and technology. In the next section three text boxes are used to provide such additional background. First there is additional material on some of the early players as taken from Morley's history. Second is information on the studies and work leading up to the formation of CCRS given in the words of Dr. Alan F. Gregory, one of the early leaders of the field. Third is some commentary by Ralph Baker on the background to Morley's interest in the field.

Following World War II Canada was deeply involved in the "development and application of aerial photography, photogrammetry and airborne geophysics to the mapping, resource development and environmental monitoring to its very large and remote territory." (Morley, 1991) Sayn-Wittgenstein (1999) also provided background to the emergence of remote sensing from photo-interpretation. Many of the first scientists involved in the field in Canada, including the first Canadian to earn a PhD in the field (Peter Murtha at Cornell in the early-mid 1970s) and the first to earn a PhD in Canada (Bob Ryerson at Waterloo in 1975) worked with photographic interpretation and the precursor of expert systems – not the more complex imagery that was to come later.

"The term 'remote sensing,' first used in the United States in the 1950s by Ms. Evelyn Pruitt of the U.S. Office of Naval Research, is now commonly used to describe the science – and art – of identifying, observing and measuring an object without coming into direct contact with it. This process involves the detection and measurement of radiation of different wavelengths reflected or emitted from distant objects or materials, by which they may be identified and categorized by class/type, substance and spatial distribution."[14] Even during the early 1960s, virtually all of the work in remote sensing using advanced systems and satellites was done within the US military. While heat-sensing scanners, U-2 aircraft, and even satellites were being used, Morley, a civilian geophysicist, was interested in but had no access to such systems.

As he states in his 1991 paper, Morley's scientific and technical background was well suited to lead the development of remote sensing in Canada. What remained to propel further development was what Morley referred to as "chance." The "chance" came in 1962 when he served "on a United Nations Mission on 'photo-geology and airborne geophysics' at the Geological Survey of Japan with William Fischer, chief photo-geologist with the U.S. Geological Survey (USGS)." Fischer told Morley that the U.S. Department of Defence would soon be de-classifying a lot of remote sensing technology and that he was hoping to get the USGS involved. That started the more serious interest in the field. "In 1963, the

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[10] Much of this section is based on a paper titled "Remote Sensing Then and Now" prepared in 1991 by Dr. Morley for the CCRS web page. It has been provided by Tom Alföldi who led the CCRS Web Page Project. The paper is in the resource materials assembled for this work.

[11] With much of Section 2.1 based on Dr. Morley's writing, he is listed as senior author. Ryerson wrote the remaining elements.

[12] The description prepared by Dr. Morley in 1991and used as the basis for Section 2.1, reads like a suspense novel with interesting twists and turns. We have tried to keep as much of the exciting prose as possible while providing additional context or editing as it appeared to be required. The material in this section in "quotes" is taken from Morley (1991) unless otherwise stated.

[13] An outline of major meetings, Cabinet Committee decisions and Cabinet decisions leading up to the creation of CCRS is given in Section 2.3.

[14] Source: https://www.nasa.gov/audience/foreducators/k-4/features/F_What_is_Remote_Sensing.html

Environmental Research Institute of Ann Arbor held the first unclassified international symposium on remote sensing. Steve Waskurak from the GSC attended and brought back much valuable information. As soon as Bill Fischer returned from this mission, he set to work on the idea of using satellite imagery for photogeology and later became a force for leading the U.S. into its National Remote Sensing Program."

The benefits of allowing some freedom in the R&D work that government scientists pursue was highlighted by Morley as being important in Canada's success in remote sensing. "The Geophysics Division was able to pursue R & D in remote sensing, even though aerial methods were considered quite "flakey" at the time for geological applications. We set up a Remote Sensing Section with Alan Gregory as its head. He had been conducting the original experiments in the development of the airborne gamma ray spectrometer which we considered to be a type of remote sensing. He went on a fact-finding mission to several laboratories in the U.S. which we knew were doing development work on remote sensing and returned with much valuable information and contacts which were used to point the direction in which we should be moving in Canada."

A number of individuals from across Canada contributed to both fostering interest and building a case for remote sensing. As is often the case, some of the early champions (including Dr. Morley himself) were open to some ridicule. As recently as 2007 a retired former Director in the GSC told this author that the "interest in remote sensing was misguided and it should have been a division within the GSC." The following text box describes some of the events and people that shaped the development of the field.[15]

Some of the People and Events Shaping a Canadian Remote Sensing Program
(From Morley, 1991)

"During this period[16] there were two persons in Canada who had been working with remote sensing in Canada within the classified area. One was Trevor Harwood, a geophysicist with DRB[17] and the other a geologist with Acadia University, the late 'Harky' Cameron.[18] Cameron was an ex RCAF navigator who had maintained his connections with the RAF and was able to get access to PPI radar images taken over Nova Scotia by the RAF Vulcan aircraft based at Goose Bay, Labrador. They were taken at altitudes of 30,000 feet and each one covered nearly half of Nova Scotia in one image. These images showed dramatic 'linears' which Cameron interpreted as major geological faults. The geological 'establishment' did not think much of his interpretation and nicknamed him "Faulty Cameron" which discouraged him from publishing. It is interesting to note, however, that his interpretation now stands as 'self-evident.'

Trevor Harwood and Moira Dunbar, both of DRB, studied floating ice in the Canadian Arctic using aerial photography and remote sensing. This was, and still is, a subject of great concern to Canada, both from the point of view of unauthorized passage of foreign vessels through the N.W. Passage as well as providing information for safe surface navigation. Harwood organized the first infrared line-scanning survey of a test area in the Arctic which demonstrated the possibility of ice reconnaissance during the Arctic night. The Ice Branch had been conducting ice

[15] Note that text boxes are often split between pages. In some cases this is because text boxes are more than one page and in other cases this has been done to reduce the number of pages in this document.
[16] Editor's Comment: We believe Morley was referring to the late 1950s up to the early1960s.
[17] Defence Research Board
[18] To show the many inter-connections in the remote sensing field John Wightman, the founder of the College of Geographic Sciences (COGS) and a leading figure in remote sensing noted that he "studied geology under Harky Cameron and was his lab assistant at Acadia University in the 1950s. When he was away I even taught some of his classes. With his military connections (See Text Box in Section 2.1.1.) Professor Cameron working through DND and the Nova Scotia Research Foundation managed to get a ride in a U-2 to manage a "near space" view and photography of Nova Scotia, New Brunswick, the tidal action in the Bay of Fundy, as well as, the ice patterns in the Gulf of St. Lawrence from 60,000 feet. He used some of the first TIROS image data to plot the spring break-up and ice movement in the Gulf in the early 1960s – long before the concept of RADARSAT." John Wightman, Personal Communication April 9, 2017.

reconnaissance flights for several years during the summer, but had no information on winter coverage as they were using visual observation methods.

Both Harky Cameron and Trevor Harwood found interested listeners in the Geophysics Division of the GSC to any information on remote sensing which they felt could be revealed at that time. I vividly remember Trevor telling me in 1962 "the Americans have a dedicated C 130 and are 'shoveling' millions of dollars into it in the form of all kinds of remote sensing devices." I was very impressed with this because of my obsession with airborne methods of data gathering. It was also frustrating because of not having access to this information.

The break came in 1963 when the Environmental Research Institute of Michigan obtained permission from the U.S. Department of Defence to hold an open conference on remote sensing. A wide variety of both operational and experimental sensors ranging from infrared and multispectral scanners to side-looking radar and passive microwave imaging devices, scatterometers and laser sensors were discussed. Our only problem was to get our hands on some of these devices. Whereas the data from these sensors were de-classified, there was still a restriction on the sale of instruments. Steve Washkurak, a technologist with the Geophysics Division attended this conference and returned with much valuable information which he passed on to the division scientists in our regular Friday afternoon informal seminars.

Help came in 1964 from Dr. Robert Uffen, the newly-appointed chairman of the Defence Research Board (DRB). He was able to arrange the purchase by DRB of the state-of-the-art infrared line scanner from HRB Singer which was making these instruments for night-time aerial surveillance to be used in Vietnam. This scanner was then installed in the NRC/Flight Research North Star Aircraft by Lee Godby's Magnetic Airborne Detector (MAD) group. They had been doing development work for DRB on aircraft demagnetization systems for use with the rubidium vapor magnetometer, a supersensitive magnetometer used for airborne submarine detection. The Geophysics Division had been collaborating with the MAD group on the development of an airborne magnetic gradiometer for mineral exploration and continued this collaboration with the infrared line-scanner. This scanner provided the first opportunity in Canada to carry out de-classified remote sensing experiments. It was used later by the Canada Centre for Remote Sensing for many years. It was even loaned back to DND at the time of the Pierre Laporte kidnapping to search for cottages in the Laurentians where he may have been taken for hiding. It was in November when most cottages would have been closed up for the winter. Any cottage showing a heat target was therefore a suspected hideout.

This collaboration with the MAD group turned out to be very valuable to the future remote sensing program as their magnetic work for DRB was completed and five bright young engineers, including Lee Godby, later transferred over to the newly-formed Canada Centre for Remote Sensing (CCRS), providing much-needed electronic and computer expertise.

At the beginning of 1964 Morley and others in government thought that airborne remote sensing (before they had thought of space) “could become a big and important activity for Canada for obtaining information for managing our resources and environment, especially because of our vast and relatively inaccessible land and continental shelf territories.” The next question was how to organize and promote the idea across government departments. As Morley stated “the 'knee-jerk' response of we civil servants was to set up an interdepartmental committee.” Because of the lack of senior support, this was done at the working level. After a year of “deliberation” they recommended to the government the establishment of an aerogeophysical and remote sensing institute with a government-wide mandate. Since the committee was at the working level the recommendation went up to more senior officials. Some were supportive but eventually it was caught up in “interdepartmental wrangles” such as which agencies had the mandate to operate aircraft. The question of mandates was to arise again and again as the program developed and over time Morley developed ways around this and many other problems that arose. Nothing more happened and “the committee languished for a couple of years, becoming only a forum for the exchange of scientific and technical ideas which began to seem more and more like pipe dreams when a dramatic thing happened.”

Bringing Remote Sensing To Canada[19]
Alan F. Gregory

My interest in and contribution to the CCRS history is in the period before the Program Planning Office and CCRS were created. My work, research and instrument design with Larry Morley during the years before he invited me to join his Geophysics Division at the Geological Survey of Canada in 1958 is quite relevant. That work with and for Larry began in 1950, the summer after my graduation as a geologist. I worked for Eldorado Mining and Refining, at that time owned by the Government of Canada. I was then a party-chief of a two man party investigating the radioactivity and geology of radiation anomalies detected by the GSC Canso as it flew over a broad area in which my party and others were working. Over the following years, I formed the opinion that Larry was the finest director of research that I had worked with in my career, including my university advisers: he was the spark that made the GSC the home of Canada's first active remote sensing centre as well as the visionary behind the creation of CCRS.

In 1954, I was still with Eldorado working in the winters on my Ph.D. thesis at the University of Wisconsin and in the summers on a helicopter survey in Manitoba which evolved later into research on flight parameters and design of instruments with Atomic Energy of Canada, then in Eastview (Vanier). They were building scintillation counters for both GSC and Eldorado with gamma-ray attenuation research by Larry and me. When I finished my thesis in 1958, Larry invited me to join his Geophysics Division where I analyzed geophysical surveys and extended my thesis research on the attenuation of gamma-ray spectra in air.

1958 was a wonderful time to be working in government science. The spirit of co-operation between different departments was exemplary. Such co-operation extended to universities and commercial enterprises also. If equipment was not available from GSC resources, it was borrowed from those who were more fortunate. Or, work was performed co-operatively in their facilities. It was in this heady environment that plans for extending studies into other frequencies of radiation began to develop in the Geophysics Division. In 1963, Larry appointed me as Head of the Remote Sensing Section. After a slow start, mainly because we had only a few scientists to work on aerial photography, radiation and geological surveys. In 1964-65, I organized a classified aerial infra-red survey of parts of Ontario and Quebec in conjunction with HRB Singer with US military aircraft from a US base in Massena, NY, and lots of US and Canadian security. I think Lee Godby purchased the same detectors for NRC the following year. With Larry's support, I began lecturing at Canadian Universities and publishing papers on remote sensing on our work at GSC.

My first lecture on remote sensing was at the University of Waterloo in February 1964. Most of 1964 was spent on preparing for Operation Grenville, a summer-long geological mapping program using planes and a helicopter to reach lakes and large outcrops that were isolated to overland transport in a large area of western Quebec. It was all knitted together at the end of summer (and spring 1965) with aeromagnetic maps by Hugh Wynne-Edwards of Queens and me. In November 1965, I went on a month-long tour of military, industrial and Federal remote sensing facilities across the USA as recommended by Bill Fischer. During that trip I attended a briefing by the famous Dr. Werner Von Braun and his team. The thesis of his team’s briefing was that collecting scientific data on a voluminous scale was not justified except where practical priorities had been assigned. Practicality was a watchword for Larry’s team.

I prepared a report which Larry said senior officers thought had an exciting potential. In December 1965 my team of four geologists with varied interests such as bedrock, soils, land cover and water, flew to the secure facilities of HRB Singer to analyze the images that had been acquired the previous year. A classified report was prepared and a secure meeting was held at GSC, attended by Canadian security staff and Lee Godby.

I was unhappy at the way GSC was changing personnel and joined Carleton University’s Geology Department leaving formal remote sensing behind. In early 1968, EMR contracted me to cooperate with Ray Moore, Director of Surveys and Mapping to draft a background paper for senior officers and make a scientific visit to Washington

[19] Much of this material was in a series of e-mails sent to the editor on June 12th and 15th, 2018. The remaining material is drawn from a document titled "Prelude to CCRS" which Dr. Gregory wrote in 2003 as requested by Tom Alföldi of CCRS.

again. In December 1968, I spent 3 days in briefings at USGS and NASA. During the winter months and early 1969, I revised the draft of the Moore/Gregory paper and added the comments by other members of the committees. The revised version of "Satellite Observation of Canadian Resources" was delivered to EMR in late January, 1969. That draft was vetted by senior officers supporting the Privy Council and the Cabinet.

In July 1968, Assistant Deputy Minister Dr. J.M. Harrison wrote to Dr. W. T. Pecora, Director of the USGS requesting his support for me to review the EROS program in depth. I was directed to consider: "Applications of resource satellites, launch and orbital data pertinent to Canada, types of instrumentation and their resolutions, the role that Canada might consider in a resource satellite program" (letter of 16July1968 from Harrison to Pecora). In response, Fischer arranged meetings with over two dozen specialists concerned with the EROS program at USGS and the ERS program at NASA, as well as at RCA, the Environmental Science Services Administration, the Institute of Policy Studies at George Washington University, the State Department, the Space Council and the Congressional Committee on Science and Astronautics.

The Washington trip occurred in August 1969 and I was to visit the Canadian Embassy before the other more than twenty offices arranged by Fischer. Four specific objectives regarding USGS satellite ERTS were given to me by Dr. Harrison: 1. launch and orbital data pertinent to Canada; 2. type and resolution of instrumentation; 3.Design of readout stations. I also learned about the NASA EROS satellite which was in competition with ERTS for federal funds and appeared to have stronger support. I came back to Ottawa with a lot of data for a report and found that I was a member of Interdepartmental Committee on Remote Sensing (ICRS) and the Robb Committee. The Robb Committee was to plan and recommend an organization to carry out a Canadian program of remote sensing from satellites. It was chaired by Dr. E.J. Robb of TRW Canada who had suggested the establishment of the Project Planning Office. The Robb Committee consisted of Dr. Robb, Dr. R.E. Barrington and J.H. Crysdale (Department of Communications), E.A. Godby (NRC), Dr. Morley, N.S. Benvie (EMR Personnel Branch) and myself.

I retired from Carleton in June to concentrate on consulting geology and geophysics, including remote sensing and I set up an office in the basement of my home. In April, I signed a contract with an exploration company run by a friend from my Athabasca days. In June, I was consultant for the EMR committee on RS chaired by Larry and, later, the committee of senior officers which replaced this lower level committee. The new body included Dr. John Chapman of Communications as well as Morley and Harrison. In July1969, this committee was renamed the Interdepartmental Committee on Remote Sensing (ICRS) under Dr. J.M. Harrison, ADM (Research).

The ICRS solicited briefs from interested Canadian scientists and engineers. I moved my office from home to Richmond Road. In the same month, the Cabinet Committee on Science, Technology and Industrial Research approved the proposal to establish a Program Planning Office (PPO) with Larry as Director. Until this office was staffed and funded there was little for a consultant to do, so my family and I went to our cottage near Cape Cod. While there, I was requested by the Canadian International Development Agency (CIDA) to write a background paper suggesting how remote sensing might assist developing countries. On September 10th, the newly mandated ICRS and Remote Airborne Sensing Committee acquired airborne sensing as their charge. A small group of secondees was contributed to PPO to staff the start of operations.

On September 24, 1969, I attended a two-day conference at Princeton University on "Aerospace Methods of Evaluating Earth Resources". At a private meeting with Arnold Frutkin, head of International Affairs for NASA, I learned that NASA might welcome Canadian participation in ERTS but with warnings that the satellite was experimental with poorly defined benefits. I spent much of my time with Larry and Liz Lloyd, executive assistant, on priorities for PPO in offices at #8 Temporary Building and was present when ICRS and Remote Airborne Sensing approved Larry's program and budget for 1970-71. In December, I flew to Washington to attend updates on RS research at NASA, USGS and US Coast Guard and Geodetic Survey and reported back to Harrison and Larry that no decision had yet been made as to which agency would lead the US program to develop remote sensing satellites.

During the year, the paper "Satellite Observation of Canadian Resources" was edited and augmented by government scientists and was distributed as background for the ICRS and Remote Airborne Sensing Committee. Just before Christmas, the committee appointed six working group leaders to support the PPO. I was the leader of the Geology Working Group, members of which were to become knowledgeable about ERTS data and help spread that through members in their disciplines. I helped Larry organize CACRS at Montebello and from there on for some years I served as secretary of CACRS. Of course eventually my staff at Gregory Geoscience made a number of contributions. Harold Moore and I presented a paper at ASPRS in 1986 that won First Prize for Practical Papers and which was based on the work of Harold's 'Mapping Division' of Gregory Geoscience and our development of the

'ProCom-2,' a system we designed to overlay hard copy image transparencies on map data. The same technology was later used by the Surveys and Mapping branch of EMR to save the branch millions of dollars in the cost of map revision throughout the Canadian north. (See Piwowar, 2000)

Throughout this account we refer to the importance of leadership. The leadership of Dr. Morley was built in part on his background as a naval officer in World War II, and in part on his scientific background. As Al Gregory has explained in the text box above, Larry Morley was regarded as "the finest director of research that I had worked with in my career." The following text box provides some insight into the background that provided the foundation of Morley's interest and success in remote sensing. Dr. Morley's intelligence, dogged determination, and ability to get things done certainly shine through in the account provided in the following text provided by Ralph Baker, also an early leader in remote sensing.

Larry Morley: Some Comments on the Foundation of His Interest in Remote Sensing
Ralph Baker[1]

I was the NRC project scientist responsible for the fitting and operation of the North Star from 1963 when we obtained the aircraft until 1970 when I left Flight Research. I must admit to having had very little interest in Continental Drift – or anything else in the tectonophysics field at that time. I was a hardware developer first, charged with providing the most sensitive, at the time, airborne magnetometer possible. Larry Morley's efforts funded the Atlantic crossings of the North Star/magnetometer system. Larry was definitely a man with vision - and I am certain that his experience with the North Star magnetometer data influenced his enthusiasm for the airborne SAR-580 precursor to RADARSAT.

Larry is now credited with showing that magnetic striping of the moving ocean floor "proved" continental drift. He first proposed this in the early 1960's via a letter to the Journal of Geophysics and was answered by a rejection suggesting he would better to make this suggestion at a cocktail party. Larry framed that letter.

Unfazed, Larry managed to get EMR to fund many Atlantic crossings in the mid 1960's by NRC's-Flight Research North Star – using the magnetometer to record the changing field. (The concept, that the mid-ocean ridges are continuously pushing up magma or lava that then becomes magnetized by the earth's ambient field as it freezes on both sides of the ridges, relies on the fact that the earth's magnetic field reverses every now and then, thereby producing alternately magnetized stripes of ocean bottom. The time period between magnetic reversals is just long enough to produce 'stripes' on the order of hundreds of miles wide. Continental drift is slow!)

Bullard and Vine, in the UK, published similar information first using magnetic data obtained, I think, from New York University. The Theory was then credited to Bullard and Vine - but, and this matters - Larry is now given official joint credit with them - most observers seeing him as the real originator. Tuzo Wilson initially openly derided Larry's theory (Larry was a student of Wilson's at U of T) but Wilson did eventually change his mind when the magnetic data were published, and he publically praised Larry' theories. I didn't meet Wilson until after he had changed his mind. A personal letter from Tuzo Wilson to Morley was among the papers provided by Lee Godby for this work.

The best layman's mention of this whole thing, including Larry's part in it, is in Bill Bryson's book "A Brief History of Nearly Everything" - a very readable best seller. In 1962 -3, when Larry proposed his theory, geophysicists really believed that the ocean bottom was not the 'youngest ' rock on Earth but the oldest. They had a reason - a proof derived from ocean bottom sampling around the world by ships dragging the bottom (typically 15,000 feet deep) for samples. These draggings picked up many rocks which were subsequently carbon dated and found to be very, very old - much older than we now know any ocean floor to be!

After continental drift became the perceived wisdom, it was suggested that these rocks were the result of repeated ice-age scouring of the older continents, the ice carrying the rock out over the frozen oceans and later dropping them as the ice melted.

People are seldom heroes at "home". Long after Larry was known to be the first in all this, Bullard and Vine came to Carleton U to talk about continental drift. Larry was flabbergasted when his boss, an ADM at EMR who had even helped fund the NRC work, suggested that Larry would find their presentation exciting!

[1]This personal account was written by Ralph Baker, the first Chief (and later Director) of the Data Acquisition Division of CCRS and who retired as Deputy Director General of CCRS. Ralph worked with Dr. Morley before CCRS was formed. This material was provided in an e-mail to Bob Ryerson on December 19, 2016.

It is also "worth remembering that there were two other champions as well as Larry when the Centre started. There was Charlie Smith, the ADM at the time who was very positive and J.J. Green, our minister then who was even more positive. I believe the very idea of CCRS depended on Green's enthusiasm. Green moved on, but Charlie was still there when we went for the Convair and, while he authorized me to find a suitable aircraft and start the deal, he set up a committee to stamp approval on the final choice and price when we went to Treasury Board."[20]

This involvement of senior officials and the political level has been a hallmark of how successful remote sensing programs have developed around the world – often involving Canadian consultants and those from developing countries who spent time at CCRS.

2.1.2. Leap into Space[21]

The dramatic thing that happened was that in 1966 Bill Fischer of the United States Geological Survey convinced Bill Pecora the Secretary of the Department of the Interior to sponsor an Earth Resources Orbiting Satellite (EROS).[22] The plan was to use the same satellite bus as RCA made for NASA's experimental meteorological NIMBUS program. Secretary Pecora managed to get approval for funding the satellite as an Interior initiative

Morley invited Bill Fischer to come to Ottawa to "meet privately with senior EMR officials and John Chapman ADM of the Satellite Communication Branch of Eric Kieran's newly-formed Department of Communications. After the success of the Alouette and International Satellites for Ionospheric Studies (ISIS) programs Chapman had also become interested in satellite remote sensing. The meeting was held at the Royal Ottawa Golf Club. Jim Harrison ADM/EMR and John Chapman, Yves Fortier, director of the GSC and Sam Gamble, Director of the Surveys and Mapping Branch were present." (Morley 1991) In describing the meeting Morley noted that Fischer showed some dramatic pictures of the Earth taken by astronauts. Chapman then made an offer that was to dramatically affect the development of the field in Canada: he "offered the Prince Albert Radar Laboratory as a readout station for EROS. It contained an 84-foot diameter parabolic tracking dish which was no longer needed as the ionosphere experiments, for which it had been erected, were complete." Apparently "Fischer was pleased with the idea, as this station would be able to read out data for the whole of North America. At that time, no plans had been made for the readout of EROS." (Morley 1991)

The EROS "leap into space" was abruptly terminated by the US Bureau of the Budget after NASA complained that EROS would be an experimental space project, and as such was within their mandate. Morley noted (1991) that "Mandates are very important in the government service." The development of the entire remote sensing activity was to pay careful attention to this and many other lessons that were learned over the course of Morley's pre-CCRS career. His ability to constantly learn from and take advantage of what was going on around him made him unique in government service – and a wonderful mentor for those who worked with him.

[20] Personal Communication from Ralph Baker, April 24, 2018.
[21] This is the title that Dr. Morley used in his 1991 paper for this section following the stirring words "when a dramatic thing happened."
[22] Later the Israelis built a satellite with the same initials: Earth Resources Observation Satellite.

While EROS was cancelled, NASA was expected to provide an alternative program which they did in 1969. The new program was the Earth Resources Technology Satellite (ERTS). The payload was at least in part the same as was proposed for EROS. It "would consist of three bore-sighted, RCA, very high-resolution return-beam vidicons. Each vidicon would have its own optical filter, one for the near infrared band, one for the red and the other for yellow, corresponding to the three emulsion layers on camouflage film used during the war (i.e. WW II) and found to be especially useful in airborne experiments to map vegetation." In addition it was also to have a "new sensor, the multispectral scanner designed and made by Hughes, Santa Barbara. A vibrating mirror focused the earth scene onto an array of solid state detectors arranged in five clusters, each cluster being sensitive to a different wave band, making five channels ranging from blue to the far infrared. The sensor was to have a ground resolution of 80 metres."

NASA's involvement created a problem for the nascent Canadian remote sensing program: "how to get the same deal with NASA on ERTS as we had with Interior on EROS, particularly as NASA originally had no plans to share their program internationally." With experience in successful cooperation with NASA on the Alouette and International Satellites for Ionospheric Studies programs, John Chapman went with Morley to visit NASA's Assistant Administrator to "propose that Canada read out ERTS at Prince Albert." Morley states that "we were politely told 'it would be foolish to invest in a readout and ground data handling facility as it would be too large a risk for Canada. It was costing NASA $40 million and besides, they could cover most of the Canadian landmass from their three readout stations in Alaska, Goldstone, Arizona and Wallops Island, and New Jersey. Furthermore ERTS would carry an on-board tape recorder which could record any data beyond the range of the three readout stations.' It was clear to Morley that the US did not want to have a foreign country reading out data from the satellite. Chapman appealed to the President Nixon's Scientific Advisor but to no avail."

It was at this juncture that luck came into play again, although the "luck" was backed by a certain degree of resolve by those in Canada interested in the question of gaining access to satellite imagery. As background, Morley noted that "Canada had a strong tradition, as did most states, of keeping the control of aerial photography and mapping within the country. We did not like the idea of having to purchase imagery of Canadian territory from a foreign country nor of having a foreign country acquire imagery of Canadian territory without advance permission. Such a concept was in violation of the Chicago International Convention which required any state wishing to acquire air photography of another country to first get permission. NASA took the position that in this case, the U.N. Treaty on the 'Peaceful Uses of Outer Space' applied - in which any state was free to conduct any activity in space provided it did no harm to other states (particularly in the case of falling debris)."

The highest levels of the bureaucracy became involved. In effect they began to play what would later be called the 'sovereignty card.' "The Deputy Minister of Communications, Alan Gottlieb and his legal advisor, Charles Dalfen, at first wished to make diplomatic objection on the grounds that the U.S. would be able to obtain exclusive information on the location of potential mineral and petroleum deposits in Canada by means of this satellite and might give advance information to U.S. exploration companies. By orbiting a resource satellite and taking imagery of Canadian territory, the U.S. would be invading our sovereign rights. In EMR, we took the view that it would be preferable for Canada, and indeed the international community, to gain knowledge of the technology which would allow us to better control the use of the data. To that end, Harrison, Gregory and I presented a paper at the International Astronautics Federation held in Brussels in 1971, in which we recommended that an international legal regime for the operation of remote sensing satellites, including the transfer of technology, be established. We suggested the establishment of an international network of readout and ground data handling centres and even supplied a map showing the possible locations of such a network. This aroused a lot of hostility from one of NASA's assistant administrators. Its publication was delayed for four years because the editor misplaced the manuscript and failed to notify me of this."

"Luck raised its head on the question of Canada's reading out the ERTS satellite in March, 1969. NASA's Chief Administrator was on a tour of the countries active in space to seek technical contributions towards their "Post Apollo Program" which was the development of the Space Shuttle. When he came to Canada, he addressed a meeting of about 50 senior scientific administrators and politicians held in the Centre Block of the Parliament Buildings. After delivering a briefing on the re-useable shuttle concept he was asking Canada, as he had asked several other nations to consider how they might contribute. (Canada eventually responded to this request suggesting we contribute the remote manipulating system, later to be known as the CANADARM). During the question period I had the temerity to ask if NASA would allow Canada to read out their proposed ERTS satellite at Prince Albert. To my surprise he immediately replied "yes". While it did take another two years to reach a written agreement, we were definitely on our way. Whatever happened within NASA, I do not know, but within a few months, it became their policy to encourage other states to read out ERTS and to pay a fee of $200K per year per station for the privilege of doing so." Others to whom we have spoken suggest that part of the interest that the US had was politically motivated: they were using satellite imagery access as a carrot. Still others have suggested that the US space industry was interested in selling satellite receiving stations and related technology to other countries. In any case, according to Morley, "after a year of negotiations with NASA and the U.S. State Department 'an exchange of notes' on the Canada/U.S. Earth Resources Agreement was finally signed."

2.1.3. The Program Planning Office (1969-71)

The next step in the long march to satellite remote sensing in Canada was to "reach an agreement on the organization and funding for an agency to implement the remote sensing program." Only after this agreement was in place could work begin to get the Prince Albert facility – eventually known as the Prince Albert Satellite Station or 'PASS' – ready for data reception.

As Morley noted, while it is relatively easy for a government to create a new agency, it is almost impossible to do so from the position of a division chief[23] in a branch of one department to do so. The failure of the committee referred to in the previous section is a case in point. "The solution was found in the suggestion by a consultant E.J. Robb from TRW, the U.S. Aerospace giant. He suggested going to Cabinet to ask for the establishment of an Interdepartmental Planning Office for Remote Sensing. This we did, and at the same time asked for an initial budget of $550,000 to do advance planning for the readout of ERTS and for the establishment of a Remote Sensing Centre - this was approved - to have a life of two years, at the end of which, an organizational and operating plan was to be submitted to Cabinet." Note that $550,000 in 1969 is roughly equivalent to $3.6 million in 2016: a senior scientist's annual salary was well under $20,000 at that time.

In early 1969, a document was sent to Cabinet by Energy Mines and Resources "recommending the establishment of an Interagency Committee on Resource Satellites and Remote Airborne Sensing, supported by a Program Planning Office to set up technical working groups, prepare program forecasts for resource satellite and remote sensing programs and to plan and recommend an organization to carry out these programs." It was with the funding of the Program Planning Office that Morley carried out his 'dog and pony shows' – the first signs of the marketing that was to long remain a focus and differentiator of CCRS from other scientific organizations at that time. It was at one of these 'dog and pony shows' held in Guelph, as I recall, that I (Ryerson) decided that I wanted to work for Dr. Morley – his enthusiasm was infectious. From the beginning marketing, public awareness and support of industry's sales were recurring themes that surface in almost all aspects of CCRS activities as will be seen throughout this document.

2.1.4. Formation: Chronology of Key Events and Decisions[24]

This section provides a short summary of the many steps along the road from 1967 to 1973 that led to the formal creation of the Canada Centre for Remote Sensing (CCRS) as a Centre within Energy Mines and Resources Canada. Looking back the many documents, meetings, and approvals necessary appear

[23] The term "Division Chief" would today be a Director at the Executive EX-1 or 2 levels in the federal government. By the time Ryerson became Director General in 2002, the leaders of the substantive Divisions were at the EX-2 level.

[24] This material is taken from Section 4.1. "Historical Highlights" on pages 14-15 in the 1973 CACRS report. We have reproduced the wording and punctuation as the information appeared in the actual text.

daunting. This section also includes a few other key milestones in 1972-73 that resulted in the organizational and advisory structures that were to lead to success for the next three decades.

Eventually the importance of remote sensing and the responsibility for it in EMR (and later Natural Resources Canada (NRCan)) was built into the Act governing the department. Specifically remote sensing was noted as one of eight general duties of the Minister.

> *"In exercising the powers and performing the duties and functions assigned to the Minister by section 5, the Minister shall:*
>
> *(g) promote the development and use of remote sensing technology."*(Department of Natural Resources Act, 1994)

May 27, 1967. Meeting of representatives from EMR, NRC, Forestry, Defence Research Board, Agriculture to discuss Canadian participation in the EROS project. The following tentative costs were estimated: Feasibility Study $20,000; Modification to Prince Albert Facility $250,000; Tape Recorder and Tapes $75,000; Leased scanner for printing pictures $90,000; Extra staff to print and distribute photos $30,000, Total over three years $765,000.

May 23, 1968. Meeting of Interdepartmental Committee on Remote Sensing of Earth Resources from Aircraft and Satellites was convened by L.W. Morley to discuss advantages of joint programs. 16 representatives from 8 gov't agencies attended.

May-July 1968. Preparation of First Draft of background paper: "Satellite Observation of Canadian Resources."

September 1968. Report on US earth resources satellite programs by Dr. A. F. Gregory (consultant) following intensive reviews and discussions in Washington.

November 20, 1968. Meeting of the Interdepartmental Committee on Remote Sensing was chaired by Dr. L.W. Morley to initiate planning for a Canadian program in remote sensing.

February 26, 1969. Completion of Final Draft of Background Paper for Memorandum to Cabinet.

June 20, 1969. Liaison meeting to hear and discuss brief s from representatives of government, industry and universities concerned with organizing a Canadian program of remote sensing. 14 briefs were received comprising of 6 from federal government agencies, 7 from industries and consultants and 1 from university.

July 22, 1969. Cabinet Committee on Scientific and industrial Research recommended that EMR should be the responsible agency for coordination and funding of "Resource Satellites – Canadian Research Program and should establish an ad hoc interdepartmental committee to steer the program. The Program Planning Office was officially established with Dr. L.W. Morley as Director.

October 8, 1969. First meeting of the "Interdepartmental Committee on Resource Satellites and Remote Airborne Sensing" was chaired by ADM, Science and Technology.

October 28, 1969. Second meeting of the Interdepartmental Committee, at which it endorsed a program of participation with the USA in the NASA Earth Resources Technology Satellite (ERTS) Program.

November 24, 1969. Memorandum to Cabinet from EMR re "Proposed Projects for Resource Satellites and Remote Airborne Sensing 1970-71," requesting that the Cabinet Committee on Science and Technology consider four urgent projects: (1) hyper-altitude aircraft experimental earth sensor operation;

(2) research and development on remote sensors; (3) study of incidence of cloud-free areas; (4) study of data reproduction system for resource satellite data. Total Funding: $550,000.

November 28, 1969. Cabinet Committee on Science and Technology agreed that $550,000 funding to be made available, as per memorandum on November 24, 1969.

December 11, 1969. Cabinet confirmed decision of November 28, 1969.

December 24, 1969. Third meeting of Interdepartmental Committee approved appointments of Chairmen of seven *ad hoc* working groups in (1) Forestry, (2) Hydrology, Oceanography, Limnology, Fisheries and Meteorology, (3) Data Reproduction and Distribution, (4) International Cooperation, (5) Sensor and Data Systems, (6) Remote Airborne Sensing, and (7) Geology.

February 14, 1970. First Montebello meeting to form the Working groups of the Program Planning Office.

March 5, 1970. Fourth meeting of the Interdepartmental Committee set (1) the functions of a Program Planning Office (PPO) to serve as its secretariat, (2) terms of reference for user groups, and (3) the membership of 14 user groups (extending the 7 groups of the December 24, 1969 meeting. These working groups are sub-committees of what is now[25] called the Canadian Advisory Committee on Remote Sensing.

April 3, 1970. Fifth meeting of the Interdepartmental Committee considered the next submission to Cabinet (April 18, below.)

April 18, 1970. Memorandum to Cabinet from EMR re: "Resource Satellites and Remote Sensing: Collaborative Programs with the United States", proposing a three year experimental program of remote sensing from aircraft and satellites related to the ERTS-A satellite, to be launched on March 22, 1972. A proposed Memorandum of Agreement between EMR and NASA was appended to the memorandum. The proposed program included (a) ground receiving station at Churchill, Manitoba, (b) continuation of experimental airborne remote sensing program, (c) continuation of sensor development, (d) facilities in Ottawa for computer correcting, reproducing and distributing data, (e) partial financing of regional interpretation centres. A three-year forecast of expenditures was included.

May 1, 1970. Cabinet Committee on Science Policy and technology gave approval for EMR to negotiate a memorandum of understanding between EMR and NASA, as requested in the April 18 memorandum.

May 7, 1970. Cabinet confirmed the May 1 decision.

May 20, 1970. External Affairs transmitted text of proposed memorandum of understanding to State Department (U.S.) and informally to NASA.

January 16-20, 1971. Second Montebello meeting to review reports of the Working Groups.

February 1, 1971. Beginning of "Systems Integration Contract" with Computing Devices of Canada to produce a data processing facility to process the data from the ERTS-1 satellite.

February 1, 1971. Treasury Board Memorandum re: "Change in Organization" authorizing the establishment of the Remote Sensing Centre as a new organizational element of EMR, as proposed in the paper "Organization for a Program in Remote Sensing of the Surface Environment", by a task force

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[25] Now in this context is 1974.

organized by Dr. L.W. Morley. (The Centre was subsequently renamed Canada Centre for Remote Sensing, with Dr. Morley appointed as its founding director.)

March 31, 1971. Submission of Working Group Reports. (2) Agriculture and Geography. (3) Atmospheric Constituents. (4) Cartography and Photogrammetry. (5) Forestry and Wildlife. (6) Geology. (7) Ice Reconnaissance and Glaciology. (8) Water Resources. (9) Satellite and Ground Station Engineering. (10) Sensors.

April 1, 1971. Canada Centre for Remote Sensing officially established.

April 21, 1971. Memorandum to Cabinet from EMT re: "Earth Resources Survey (ERS) Agreement" reviewing international policy aspects of the proposed agreement with the U.S. (April 18, 1970). Included were drafts of a proposed exchange of diplomatic notes, with annexed arrangements between EMR and NASA.

May 14, 1971. Agreement with NASA signed.

June 23, 1971. Memorandum to Cabinet from EMR re: "A Program for Remote Sensing of Earth Resources and the Surface Environment", seeking approval for (a) an increase of capacity for the Air Photo Production Unit (APPU) and the National Air Photo Library (NAPL) of the Surveys and Mapping Branch of EMR, to handle the additional load of the Remote Sensing Centre, (b) an airborne remote sensing program, (c) conceptual studies of an internationally shared resource satellite system and other remote sensing systems. The Memorandum recommended a supplementary budget to cover item (a) and a "B" budget for FY 1972-73 to cover other items as "an integrated remote sensing program to be undertaken in 1972-73. It also recommended the replacement of the *ad hoc* Interdepartmental Committee by a senior Inter Agency Committee to be chaired by the ADM, Science and Technology, EMR. It also contained forecasts of expenditures for three optional programs.

July 1, 1971. The CFASU[26] formed and became operational.

July 29, 1971. Record of Cabinet decision, approving (a) the supplementary budget to increase the capacity of the APPU/NAPL; (b) the FY 1972-73 "B" budget for the integrated remote sensing program (including an expansion of the airborne sensing part of the program); (c) the new Inter Agency Committee on Remote Sensing (IACRS); and suggesting (d) shifting the temporary Prince Albert Receiving Station (PASS) from Prince Albert to Churchill.

November 30, 1971. Purchase of Falcon Fanjet Aircraft.

January 4, 1972. Meeting of the Inter Agency Committee on Remote Sensing (IACRS) at which terms of reference for the Canadian Advisory Committee on Remote Sensing (CACRS) were approved, and at which the first partial "cost recovery" or "shared funding" formula was approved (whereby CCRS may charge Federal government user agencies for airborne remote sensing).

January 17, 1972. Submission of an "A" Budget for FY 1973-74, establishing the CCRS "A" budget activity level at about $6.5 million and 104 man years, a minimal datum for on-going activities.

February 22-24, 1972. First CACRS (third Montebello) meeting at Montebello, PQ.

March 1972: "A" level budget of $5,431,000 and 60 man years[27] approved by Treasury Board.[28]

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[26] Canadian Forces Airborne Sensing Unit
[27] The term "man years" was later replaced by the term "Person Years," or "PYs."
[28] The $ budget at that time would not include the cost of staff, only operating and capital expenses. The equivalent in 2018 dollars would be $33,154,000.

May 1-22, 1972. Tests of HISS radar in the Arctic.

July 6, 1972. Treasury Board Memorandum (961) entitled: "The Canada Centre for Remote Sensing" submitted providing three options:

> Option 1: $6.916 million and 104 man[29] years, the amount recommended by Cabinet in June 1971 and requested by DEMR as its "A" level budget which includes $450,000 in grants for regional centres, and 3 may years and $35,000 to provide personnel to supervise the operation of PASS.
>
> Option 2: $5.431 million and 60 man years, the amount suggested by Treasury Board Staff. As mentioned previously, this option is considered non-workable in terms of the limit of 60 man years and will, therefore, not be considered further.
>
> Option 3: $5.431 million and 84 man years. This option, though workable, does not include grants for regional centres, is technology frozen and does not attain the objectives outlined in the Cabinet memorandum of June, 1971.

July 23, 1972. ERTS launched.

July 26, 1972. First imagery of Canada received by CCRS.

July 27, 1972. First ERTS image presented to Honourable Robert Stanbury, Minister of Communications, at the International Society of Photogrammetry Conference held in Ottawa.

January, 1973. Establishment of Applications Division of CCRS, and initiation of a concentrated program in applications research and development.

January 29, 1973. The "Preliminary Assessment of the Remote Sensing Program" was published by the Program Evaluation Office, of Energy Mines and Resources. It contained a "Summary of Program Priorities" as follows:

> 1. Develop applications or uses of remote sensing data and markets for their uses. This can be done on the basis of projects to define individual application/market; or as a package of applications for a single market.
> 2. Estimate potential benefits at each phase of the program; the first of these estimates is required by March 1974.
> 3. Maintain satellite and airborne data to support studies required, and to familiarize users with the data obtainable.
> 4. Develop sensors and platform, primarily for airborne sensing, related to acquisition of data for sues having potential benefits in new and existing programs
> 5. Investigate long term alternative system configurations

July, 1973. By early July six scientists had begun to work in the Applications Division – three each in the Applications Development (Jean Thie, Tom Alfoldi, and Bob Ryerson) and Methodology Sections (Ian Crain, Dave Goodenough, and Fred Peet).

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[29] It would be some years in the future when the term "man years" was replaced by "person years" or "PYs."

2.2. The Successful Canadian Advisory Committee on Remote Sensing (CACRS): Structure, Evolution, and Results[30]

Bob Ryerson

2.2.1. Introduction

To truly understand the organizational genius of Larry Morley, Lee Godby and University of Waterloo professor and management consultant Don Clough, one need only look to CACRS. The Committee and how it functioned were responsible for much of the success Canada enjoyed in the field and provides a useful model for guiding science in government. The committee and its working groups were inclusive – every individual with an interest in the field was invited to be involved. Virtually every major development in the field in Canada over two decades or more started as an idea expressed at one of the working groups, sub-committee, or specialty group and, eventually, at the annual meeting.

The following sections review how CACRS was started, how it was governed and performed, and how it changed over time. The section closes with an outline of the key recommendations that were made and the significant impacts of the recommendations. One of the most important impacts was the attention that was paid to publicizing the applications and beneficial uses of remote sensing – again another useful lesson.

2.2.2. The Beginning

For governance, Morley drew on a combination of his experience from before his interest in remote sensing as well as some of the early problems encountered in the remote sensing program's development. "The governance, management and committee structure of the Planning Office were all based on the model of the NRC Associate Committee on Geodesy and Geophysics" on which Morley served in the 1950s and 1960s. He believed that this NRC committee, among other things, had "spawned Canada's very successful participation in the 1957 International Geophysical Year which, in many ways, set the stage for Canada's venture into space." One might also argue that it led to Canada's prominent position in mineral exploration. Morley believed that it was this organization that led to the program becoming a truly national one. He believed that most of the appropriate technical and scientific organizations and individuals in Canada were consulted and involved a in the NRC Associate Committee on Geodesy and Geophysics. The approach has been well summarized by Dr. Bob Hawkins: "CCRS had the whole spectrum of technology development tools early on and that was a strength. We had sensor development expertise (scientific, engineering, and technological). We had test and demonstration capability. We also had applications development expertise and wide connectivity with government and private sectors within Canada and abroad to keep our work relevant and cutting edge. Spacex and Tesla have the same basic model."[31]

CACRS was "established in January 1972 to effect the development of a national program in remote sensing." (CACRS Report, 1973, p 1) "The purpose of the Canadian Advisory Committee on Remote Sensing is advising and assisting the Government of Canada, through the Minister of Energy Mines and Resources, in meeting the objectives of the National Program on Remote Sensing of the surface environment by assessing national needs, promoting research and development, by diffusing remote sensing technology into Canada, and by assisting in the coordination and evaluation of programs to ensure a high level of national benefits relative to the cost of remote sensing." (ibid)

Similar to the NRC Associate Committee on Geodesy and Geophysics, there were a number of sub-committees called 'working groups', each one of which had between 10 and 15 representative members from both federal and provincial governments, from industry and universities.

[30] Section 2.2 is primarily based on official CACRS reports from 1973 to 1986, as well as some materials from the author's previous writing.

[31] Personal Communication: Dr. Bob Hawkins, September 17, 2018.

"Its advisory[32] duties shall include:

- Coordination of existing and proposed new programs and recommending priorities;
- Advising on remote sensing platforms:
    - Satellite systems,
    - Aircraft systems,
    - Balloon systems;
- Sensor development;
- Data processing;
- Cataloguing, reproduction and marketing of data;
- Regional involvement;
- Research grants and contracts.

It will assist:

- By generating requests for airborne remote sensing surveys;
- By carrying out on-going evaluation of existing projects;
- By organizing conferences, seminars and training courses for the diffusion of remote sensing technology into Canada." (CACRS 1973, p. 1)

The Committee was called on to "establish such working groups as it may deem necessary to carry out this work." (ibid)

2.2.3. The Working Groups and Advisory Structure

The key to success was the openness of discussion and the quality of the ideas brought forth for discussion as recommendations by the many groups and individuals involved. Those involved included technical and application-oriented working groups, specialty centres, academics, provincial and territorial representatives and industry. A further strength was the early and continuing emphasis on ensuring that CACRS remained relevant. While it was the Minister of Energy Mines and Resources who officially received the advice and assistance, it was the Canada Centre for Remote Sensing that was the recipient of advice and that usually acted on the advice – or had to explain why it did not. Assistance was provided by everyone involved in CACRS. It was truly seen as both important and one's patriotic duty to provide the best advice and assistance where needed. Every recommendation was subject to discussion and debate in the crucible of both working group meetings and the CACRS plenary session – often referred to by those of us who attended it as a bear pit session.

The working groups and others reporting to CACRS for 1973 are listed in Table 1.

Table 1
Canadian Advisory Committee Working Groups and Key Participants Reporting for 1973[1]

Working Groups	
• Oceanography	• Geography
• Atmospheric Sciences	• Cartography and Photogrammetry
• Hydrology	• Future Earth Observation Satellites
• Limnology	• Data Re-transmission
• Agriculture	• Reproduction and Marketing
• Forestry, Wildlands and Wildlife	• Sensors
• Ice reconnaissance and Glaciology	• Data Handling and Satellites
• Geology	

[32] The underlining of the words "advisory" and "assist" was present in the original text. Punctuation has been added in the bullets to be consistent with current practice.

CCRS	
• Historical Highlights • Data Acquisition Division • Applications Division • Data Processing Division	• Cost Benefit Studies (1973) • Review of Environmental Policy (Environment Canada) was reported on under CCRS in 1973
Specialty Centres	
• Canada Centre for Inland Waters	• Forest Management Institute
Provinces	
All provinces were represented except Nova Scotia	

[1]The 1973 report from the meeting held in Montebello, Quebec February 18-21, 1974 was the fifth annual meeting to review and plan the national remote sensing program – but only the third constituted as "CACRS." Three committees were struck to examine and consolidate recommendations: Provincial Representatives Study Group, Discipline Oriented Study Group and Technology Study Group.

Generally, working group leaders were selected from the various federal government departments where the required disciplinary expertise existed. Eventually CCRS employees (usually a senior scientist or engineer) were selected as the Secretaries of the working groups and this provided a direct link into CCRS. As one might expect, this designation of a CCRS representative for each group came as a result of a recommendation. Morley estimated that more than 140 scientists and engineers were involved in these initial working groups, each of which, in the first year, met four or five times. Morley later said that while it "seemed like committee 'overkill'… we desperately needed lots of help to meet the ERTS (later re-named Landsat) launch date of July 1972. They were indeed 'working groups' and they had two jobs: firstly to educate themselves in this new technology, and secondly to do their part in preparing for the onslaught of data from ERTS - to reproduce, distribute and interpret the useable images of the 1500 or so scenes of Canada which the satellite was to record every day, seven days a week." One of the observations made forty years later at a meeting on what is now called "Big Data" is that from the outset remote sensing has had to deal with amounts of data that were unknown in even the most complex IT environments.

After the first year each working group met once or twice a year, often hosting a series of presentations relevant to the mandate of the working group. The group would agree on recommendations that would then be presented to the plenary meeting held annually. Two of the first better attended meetings were held in 1974 and 1975 at the Chateau Montebello – a luxurious hotel east of Ottawa. Following criticism for such extravagance the following meetings were held at "the spartan facilities of an old airbase in Arnprior. CACRS meetings took on a certain charm. No-one could have been accused of attending the meetings to enjoy the luxury of the antiquated plumbing, draughty rooms and questionable heating." (Ryerson, 1999, p 432) But the beer and wine flowed (paid for by the attendees – NOT the government!), as did the ideas. The ideas and camaraderie made the meetings – especially the early ones – quite memorable.

Looking Back at a Memorable Meeting
Paul Hession

Some CACRS meetings were still being held at the Arnprior Federal Study Centre (FSC) in the 1979-1983 time periods. The facilities there were memorable partly for the contrast that they represented between CACRS' very forward-looking agenda and the remnants of the FSC's early 1950s mandate as a Federal Civil Defence Staff

College delivering special courses in atomic/biological/chemical warfare defence. There was also an unmistakable ambience of early Air Force tradition lingering in the Mess facilities – harkening back to a foundational era before the advent of earth observation satellites.

Despite the somewhat anachronistic character of the FSC, the facilities worked well, and – in hindsight – represented a medium for the "passing of the torch" between generations of aerospace science. Although CCRS was breaking new ground in the application of satellite observation of the earth, CACRS discussions were hosted at the premises of the FSC – which, in turn, were physically surrounded by the familiar technology of airborne data acquisition platforms.

This description was prepared in response to a question asking former employees about memorable meetings or events. As noted elsewhere, Hession served in the Canadian military after graduating from RMC and has since held senior positions in both government and industry. Personal Communication, Paul Hession, May 27, 2015

The fact that remote sensing was a brand new field meant that it attracted those who wanted to work in an exciting new field where rapid advancement was possible. It also attracted some whose abilities fell well short of being able to meet the objective of being world leaders. The former went on to be recognized on the world stage, while the latter were soon weeded out, often after making an outlandish presentation or intervention at CACRS. Some of these interesting people and interventions are profiled (some anonymously!) in Section 8.4.

2.2.4. Overview of the Performance of CACRS

In retrospect, Morley concluded that these working groups "performed beautifully… with the result that Canada was fully ready for the launch of ERTS – probably even more so than the U.S. itself as we were a smaller, more tightly-knit organization." (Morley, 1991) Having participated in these early events and looking back from 45 years into the future, this author agrees with Morley's assessments with regard to the success being spawned by the advisory committee structure and how it functioned. The degree to which CACRS guided us within CCRS can be seen by the early CACRS Reports kept by this author. The areas where there were any recommendations related to my responsibilities or interests are highlighted and these provided a rough outline of my work for the year ahead in that I knew that I would have to have a report on what we did to answer each and every recommendation. One colleague suggested that the CACRS recommendations were the "Ten Commandments for CCRS." In 1981 there were 71 recommendations – 62 were to be acted on by CCRS.

While issues of national importance were generally the focus, the provinces were to play an increasingly important role. As John Wightman said in 2017 "CACRS gave the provinces a voice at the table and helped the provinces learn from each other – recalling that Ontario, Alberta and Manitoba were ahead of the others. CACRS helped get the other provinces going and made a contribution, and the provinces made a contribution to the federal program as well."

While many issues of importance were brought to the committee, and while in many cases consensus was reached, there were cases where issues were not resolved. For example at the 1975 meeting there was some discussion on having a national scientific and technical society for remote sensing. Those involved in the discussion included representatives of the newly formed Canadian Remote Sensing Society, the Remote Sensing Committee of the Canadian Institute of Surveying, the Association Québécois de Télédétection and the Ontario Association of Remote Sensing. No consensus was reached and the issue of a single voice for the professionals involved in the field of remote sensing in Canada has continued to be a bone of contention to today, although recent cooperation saw the Canadian Remote Sensing Society led by Dr. Monique Bernier and the Canadian Institute of Geomatics led by Dr. Rodolphe Devillers working together in an attempt to get an ISPRS Congress for Canada.

Much of the factual history of remote sensing in Canada is found in the widely circulated CACRS reports. From 1973 to 1981 detailed reports on the meetings were published that totaled 1270 pages – or an average of 141 pages of very small print for each year. From 1982 through 1985 executive summary reports, including key recommendations and summary reports from both CCRS and the provinces, were published in both English and French. These reports were an average of 40 pages in English. The author also had access to the full report for 1984, and the "Canadian Eyes Only" background materials for the special 1984 meeting held in March of 1985 on marketing Canadian remote sensing capabilities.

Not only did CACRS have an impact on what CCRS did from year to year, as noted in more detail in Section 2.2.6, the CACRS meetings and the detailed reports that came from them can be seen as the source of inspiration for virtually every significant new idea or program in remote sensing in Canada from the early 1970s into the mid-late 1990s. The importance of CACRS to the RADARSAT program is clearly detailed in Chapter 5. CACRS proposed new programs, modification of existing programs and solutions to issues and problems that beset Canada and its nascent remote sensing program. One of the true strengths of Canada's remote sensing program including CACRS and the leadership of CCRS was its ability to respond to issues of national importance and to do so quickly and effectively

2.2.5. CACRS Changes Over the Years

CACRS was unique for a government-inspired advisory body: it changed with the times, and did so to reflect what was important to the government of the day. It goes without saying that what is seen as important to the government of the day is what gets funded. With regard to funding, CCRS Management had an uncanny ability to find and exploit new sources of support – whether it was a program to fund unsolicited proposals from industry (See Section 3.3.1.) or recruit scientists. What was perhaps most impressive about CACRS was that it reflected the ability of the CCRS leadership to assess what was GOING to be important. In at least a few cases the CACRS meeting focused on a single issue. For example the March 1985 meeting opened by Minister Bob Layton (reported in the 1984 report) focused on marketing remote sensing in Canada and internationally. Another meeting focused on technology transfer. Still another had as one of its primary foci radar – leading to RADARSAT.

The following Table shows what changed year to year in terms of who or what groups were involved in reporting, how the organization of CACRS was modified, and what invited reports or position papers were given in each year. These papers or reports were often harbingers of what was to become important in the future. Trends that can be observed are discussed following the Table.

Table 2
Changes by Year in Canadian Advisory Committee on Remote Sensing (CACRS)
Working Groups and Key Participants

Year	Change
1974	• Specialty Centre added: Ocean and Aquatic Affairs – Pacific Region; • All provinces reported…and but for the occasional budget limit on travel by specific provinces, full participation continued.
1975	• The name "Specialty Centres" was changed to "Specialty Groups" with the addition of an industry association. Those added were: o Atmospheric Environment Service, o Canadian Association of Aerial Surveyors (CAAS), o Lands Directorate, o Canada Centre for Inland Waters (CCIW), o National Aeronautic Establishment (NAE).
1976	• The CCIW, CAAS and NAE were not present and never did reappear; • There was an invited Report from the Ontario Association of Remote Sensing and another on the need for a remote sensing training centre in Canada; • The European Space Agency gave a report on its future plans; • In addition to reports of working groups there were Position Papers prepared on four key topics by senior CCRS staff. These were on Oceans, Water, Land and Vegetation. There were then workshops held on each topic and reports were written on recommendations that resulted from the discussion.

1977	• CCRS reports were no longer given by the three operating divisions, but rather by topic: Applications Development, Satellite Program, Airborne Program, Research and Development, Support Services, SURSAT Program and Landsat-D program. • An Engineering Applications Working Group was added. • The name of the Limnology Working Group was changed to Water Resources and other more minor name changes were made to other Working Groups. • There were invited reports from the UBC Faculty of Forestry, the Forest Fire Research Institute, the Nova Scotia Land Survey Institute, and Intertech Remote Sensing – the new remote sensing services firm owned by Innotech and Intera.
1978	• The Forest Fire Research Institute joined the Specialty Groups. Lands Directorate, Forest Management Institute, and Atmospheric Environment Service participated in their fourth consecutive CACRS meeting; • Saskatchewan did not participate; • CCRS hired two unilingual Francophones under a government program with the intent of providing better service to French-speaking Canadians; • There were invited reports on education, on the problems of Landsat in forestry, and on a suggested approach to environmental monitoring centres; • The CCRS report was given on: o Applications Development, o Data Acquisition, Processing and Dissemination, o Applied Research, o Scientific and technical Support, and o Management and administration; • One of the working groups (Ecosystemes terrestre – formerly Forestry and Wildlife) gave its full report in French.
1979	• The Provinces and Territories were brought together under a new sub-committee called the Interprovincial and Territorial Advisory Sub-Committee to CACRS – IPTASC (Pronounced IP-TASK); o Northwest Territories did not report, nor did Saskatchewan. • Of the specialty groups only Lands Directorate and Atmospheric Environment Services reported; • CCRS reported on Landsat, Availability of aircraft for leasing, the airborne program, SURSAT, Landsat-D simulation, Digital Image Correction System, and the Preparatory Program of the European Space Agency; • There were no reports from the data Reproduction and Marketing WG, nor from the Forestry, Wildlife and Wildlands WG; • Invited reports dealt with CARCRS re-organization and Technology Transfer. • Those on re-organization: o A review of the functions and organization (By E.A. “Lee” Godby, CCRS and A/Chair of CACRS); o The Educational Viewpoint (Dr. Phil Howarth, U of Waterloo); o A proposal for re-organization (Victor Zslinszky, Ontario Centre for RS). • Those on technology transfer: o Reflections on the Movement of Remote Sensing to an Operational Stage (in French by Herve Audet, Quebec Centre for Remote Sensing); o Remote Sensing Technology Transfer Program, Dr. Josef Cihlar, CCRS.
1980	• There were no reports from the Data Reproduction and Marketing WG, the Forestry, Wildlife and Wildlands WG, nor from the Geoscience WG; • To effect better communication with the federal Inter Agency Committee on Remote Sensing or IACRS (Pronounced EE-yackers) the executive summary of the 1980 meeting was tabled at IACRS; • While the focus of the meeting was on provincial input, there were no reports from Northwest Territories, Yukon, and Saskatchewan.
1981	• The focus of the 1981 meeting was the Future of the National Remote Sensing; Program under the Chairmanship of Frank Hegyi, Director of the BC Forest Service’s Inventory Division; • The Minister was represented by A.E. Collin, Associate Deputy Minister;

	• 71 recommendations were made – of which 62 could be handled by CCRS and 9 were referred to IACRS; • A "new feature" was a panel of major remote sensing companies who gave industry's view; • The Data Reproduction and Marketing WG did not report; • There were no reports from Newfoundland and Labrador; • The only specialty centre present was the Petawawa National Forestry Institute.
1982	• 1982 was the first year that only the executive summary of the meeting was published and widely distributed: • The summary, (including the CCRS report and recommendations) was published in both English and French for the first time; • From the summary available it was not clear which working groups, specialty centres or provinces/territories reported; • There were a number of exhibits from provinces and federal agencies; • Leaders of ten companies involved in remote sensing discussed three topics: o Is the sale of satellite data a commercially viable activity in Canada assuming the availability of Landsat-type products? o How could industry operate such a commercial activity, taking into account the R&D nature of the present Canadian government program? o Are the new initiatives leading towards more industrial involvement in the Canadian RS program? • The meeting focused on new initiatives in the national program including: o Landsat-4 data reception and production including Thematic Mapper (TM) data; o The development of a new analysis system (LDIAS) to handle Landsat-4 data; o Plans for reception of ESA's ERS-1 satellite; o Progress made in the Canadian radar satellite program (RADARSAT); o The development of MOSAICS, a processing tool to enable the combination of data from different sources; o The Technology Enhancement Program; and o Increased industrial participation in the national remote sensing program.
1983	• There were two foci for the 1983 meeting – economics and the newly announced funding for a space program; • The panel discussion on presentations on the economics of remote sensing included: o Internal review of CCRS activities (by Phil Lapp); o Economic studies of RADARSAT (Oliver Kent, Price Waterhouse); o The Canadian Space Program (Mac Evans, Ministry of State for Science and technology; and o Economic studies of remote sensing in BC (Frank Hegyi), Quebec (Claude de Saint-Riquier), and Ontario (Larry Morley); • The Auditor General (AG) looked at CCRS over the past year and provided a positive report – something that is not usually the case. The AG did recommend that there should be a national goal setting exercise for remote sensing. CACRS suggested that CCRS set goals for itself and these be reviewed by CACRS; • Workshop topics on economics and benefits looked at Oceans and Ice and Crop Monitoring, and regionally for Atlantic Canada, Quebec, Western Canada and Ontario; • From the summary available it was not clear which working groups, specialty centres or provinces/territories reported; • The exhibits expanded from previous years; • There were 41 recommendations – 34 for CCRS and 7 referred to IACRS.
1984	• The 1984 report was produced in English and French but unlike the previous two years, it provided 65 pages in English with more details on reports by working groups, IPTASC (provinces and territories), CCRS, specialty groups, and recommendations; • The focus of the meeting was marketing of remote sensing generally, and RADARSAT and the export market specifically. A 23 page marketing plan was

	presented for discussion; • Part of the discussion was for Canadian eyes only and it led to the approval of aggressive international marketing plan believed to be unique at the time; • All of the technical and applications working groups provided reports; • Neither Northwest Territories nor PEI reported; • The Minister of the time, Robert Layton, gave the banquet speech.
1985	• The 1985 report was again produced in English and French with comprehensive summaries of the reports by working groups, IPTASC (provinces and territories), CCRS, specialty groups (including the Atmospheric Environment Service, the Petawawa National Forestry Institute, and, for the first time the Institute of Ocean Sciences, and Statistics Canada. • The focus of the meeting was "the future." A number of respected experts offered comments on various aspects including the need for wide swath radars from space, the value of artificial intelligence, the potential of narrow band spectrometers (hyperspectral), the usefulness to monitor global change, the importance of remote sensing in ocean management and the current operational use of remote sensing in forest inventory and management. • There were reports from the Canadian Remote Sensing Society, the Ontario Association of Remote Sensing and the Association Quebecoise de Télédétection; • For the first time Universities and colleges reported, including U of Alberta, UBC, U of Manitoba, Universite de Sherbrooke, Waterloo and the Nova Scotia Land Survey Institute. • To encourage greater industry participation one day of the meeting was specifically set up for industry • The meeting was held under the cloud of the requirement to reduce budgets and "was not as upbeat as the previous one" but it did "explore innovative ways for involving industry for maintaining the thrust and benefits of the airborne program while reducing costs to government."

Over the first fourteen years of its existence CACRS, like a living organism, was continually changing and evolving. There were cosmetic changes such as the change of venue from a luxury hotel to the spartan conditions on a retired World War II air force base, as well as those that were more important. The more important changes included the varying (but always topical) foci of the meetings, the range and number of participants and participating bodies, and changes in the composition and areas of interest of the working groups. In the later years there were also changes in how and by whom the advice was received, and actions taken. The trends noted from the beginning to 1985 were the following:

- The provinces became more and more important, and eventually the territories were added to form a major sub-group within CACRS.
- CACRS started out with a combined tactical and strategic focus, but over time became more strategic and future looking. As a result the discussions moved from being organized around the divisional structure of CCRS to being organized by topics.
- Over time the meetings and advisory structure became somewhat more formal and often featured reports on recommendations by study groups tasked by the previous meeting.
- The focus on identifying the benefits of the remote sensing program began at the outset and continued.
- New working groups were formed based on the focus of the meeting and priorities of the government of the day.
- As the years passed and as industry became more important, industry (especially) and academe became more important players.
- Specialty Centres were added and subtracted based on the influence of an individual, the importance of remote sensing to the organization, and the focus of the particular meeting. As industry groups and academe became involved "Specialty Centres" became "Specialty Groups."

- Meetings became more focused on important topics of the day and those that appeared to likely be important in the future, rather than on a grab-bag of topics of interest to the participants.
- Following 1976 French became increasingly visible in and important to CACRS, recognizing the linguistic reality of Canada and the contributions of French-speaking scientists, academe, and agencies of the Quebec government and Quebec industry. Our Francophone colleagues were becoming increasingly important players in Canada's remote sensing activities.
- With the development of the Canadian Space Agency, the relationship with the space program took on more importance. The biggest change to CACRS came in 1988 when it became a much smaller Advisory Council with far less visibility for its working groups. That smaller group reported directly to the Minister. The Chair of CACRS at that time was Dr. John MacDonald, founder of MDA. Interestingly enough, over the first two years of this new arrangement MacDonald did not meet with the Minister even once – only one sub-group of the Council met with the Minister. (Ryerson, 1999) With the changes and the removal of direct and visible impact in helping to steer CCRS and the national remote sensing program the interest in participating in working groups waned.

CACRS became much less relevant. Some observers would say that the change in CACRS was the beginning of the end. Eventually the concept of a national remote sensing centre was effectively killed, as is detailed in Chapter 4: Mergers, Acquisitions and Closures.

2.2.6. Recommendations from CACRS

2.2.6.1. Introduction

From 1973 to 1985 over 1000 recommendations were made by CACRS. Most of them, especially in the beginning, were serious, thought-provoking and useful suggestions on what CCRS and the Government of Canada should be doing in remote sensing. At the outset the strength of CACRS, and the bear-pit sessions that discussed the recommendations generally ensured that self-serving recommendations of one interest group or another were left on the cutting room floor.

As can be seen by a quick examination of the Table in Appendix A, recommendations often surfaced in one year in a vague and incomplete fashion. In some cases the recommendations would simply fade away. In others, the more interesting here from the point of view of history, the recommendation would lead to a more detailed position paper or study by an existing working group or a new group structured to examine the idea. These were the recommendations that often led to major new activities or a significant change in the direction of remote sensing in Canada. RADARSAT, the technology transfer program, a number of technology and application developments, marketing activities, and changes in how CCRS did things came from recommendations that grew from a vague idea to an implemented program. There were other recommendations that were made that were not taken up at the time but which in hind-sight should have been – and later were addressed independent of the original CACRS recommendation.

Over time, as the community grew and became more visible, recommendations became more focused on the wishes of the various interest groups involved. Even so, in general the recommendations continued to be future looking and focused on the broader needs of Canada rather than on the hobby horses of individuals with an axe to grind.

2.2.6.2. Understanding the Recommendations in Appendix A

We believe that it is neither necessary nor useful to reproduce in this study all of the recommendations made in the period we are examining CACRS – from the beginning to 1985. Appendix A provides a summary of those that are believed to be among the most notable in the study of the history of CCRS and, more generally, remote sensing in Canada. What we have assessed in Appendix A as the major recommendations for each year are presented together, and for each specific recommendation the page number in the annual report and/or reference numbers are given.

To avoid confusion we have simplified the organization of recommendations in Appendix A so that they are presented in roughly the same order as they were presented in the annual reports – whether presented together or scattered over 100 pages. This avoids any further imposition of this author's bias associated with assessing the relative importance of recommendations.

Over the years the way in which recommendations were reported and categorized changed. At the outset they were organized in one place in the report by who would act on the recommendations, i.e. by the organizational units of CCRS. At other times the recommendations were organized by source – which Working Group or other body proposed them. In some cases the recommendations were scattered throughout the report – and only those recommended for attention came to the fore. Some were actually rejected in the CACRS Plenary Session: needless to say, those do not appear here. Still others were made that suggested action by CCRS that was not legally possible since it fell within the legal mandate of some other agency or group, or was far too costly to be considered by CCRS. Some of the more costly recommendations were rejected by CCRS as being impractical at the time. Those with some merit and broad support usually did eventually lead to Treasury Board submissions asking for an increased budget, and many of those led to successful activities including, as noted below, the airborne radar program and RADARSAT.

Many recommendations as written in the CACRS reports are preceded by explanatory text to set the context, and thus some tend to be quite verbose. In Appendix A we have attempted to reduce the verbiage while maintaining the intent of the recommendation. As noted above, we have selected only those that appear to be most relevant when studying the history and evolution of CCRS. In some cases the same recommendation was proposed by two or more different groups or under two different topics. For example in 1973 there was a recommendation under the topic "airborne" that CCRS develop "an all-weather imaging system," and another recommendation under sensor development suggested giving "priority to microwave systems…because of specific limitations in the Canadian Arctic (long periods of darkness and cloud cover)." Where there appears to be duplication we have tried to indicate that inasmuch as such duplication tends to emphasize the perceived importance of the recommendation, as does repeating of a recommendation over a period of years – such as the recommendation that CCRS should offer services, reports and advice in both English and French.

Housekeeping items (such as CCRS should ensure it has sufficient trained staff to meet peak demands for data) are usually not included in the summary table. Similarly what are considered to be generic (and in some cases obvious) recommendations such as "data should be delivered faster," "calibration of sensors should be improved," or "all scanner data should be geometrically corrected as far as possible" are omitted. Also omitted here are those recommendations that called for a budgetary increase without any context. The rationale for generally omitting monetary requests is twofold. First, for most line items we lack the context of what the base budget was and thus do not know if the request was a minor augmentation or perhaps a doubling of the budget. Secondly, inflation can lead to an under-appreciation for the specific "ask." For example, using the Bank of Canada's inflation guide, a request of an additional $250,000 for sensor development in $1973 would be equivalent to $1.3 million in 2016. In any case, the reader is referred to the original sources for a more complete view.[33] We recommend that the reader simply scan the table in Appendix A to get a sense of the both the consistency of some issues always arising as well as the changes that occurred in what was considered important.

In the last column of the Table we have attempted to indicate whether the recommendation was completed or acted upon and when. In some cases the recommendation was acted upon immediately with immediate results. In others the action either took longer to take, or required more thought and support (and in many cases future and more specific recommendations) and results did not come as quickly. In still others no action was taken and no impact (positive or negative) resulted. The reasons for a lack of action often included one or more of the following:

- There were often legal reasons why CCRS could not respond to a particular recommendation:

[33] Arrangements have been made with Library and Archives Canada to take possession of the ***CACRS Reports*** and the many of Proceedings of the ***Canadian Symposia on Remote Sensing***.

- The recommendation dealt with a topic that fell under another Department's mandate;[34]
    - The recommendation dealt with a topic that fell under provincial jurisdiction. For example, under the British North America Act, 1867 (later re-named the Constitution Act, 1867) education was a provincial matter. CCRS could not become actively involved in education. (See Section 3.2 for further detail);
    - CCRS did not have a mandate to apply the technology in an operational manner – it could only do demonstrations;
    - CCRS could not sell technology – but it could license it under some circumstances;
- The cost was too high:
    - For some recommendations the lack of funds was used as an excuse by CCRS management;
    - In many other cases there were no funds available since the benefits were judged to be too low to justify the costs;.
    - In the case of good ideas, revised and better recommendations would come along in a future year and for these additional funds were sought and often obtained. CCRS developed a good reputation for finding additional sources of funding;
- In some cases the recommendation was returned to the Working Group to ask for elaboration or a more detailed explanation or justification;
- Some recommendations were anticipated and answered virtually as they were being proposed – such as the cancellation of the contract with the company that was failing to meet its obligations in processing ERTS data;
- Some recommendations were overtaken by events – whether new processing tools, new media for the archive, etc.; and
- Some recommendations were simply not technically feasible at the time. In some cases such recommendations returned after technology caught up to the concept proposed.

Section 2.2.6.3 provides our assessment of the most important recommendations from 1973 to 1984 and their impact.

2.2.6.3. An Overview of the Impact of CACRS Recommendations 1973-1985

2.2.6.3.1. Introduction

As noted above, a Summary of CACRS Recommendations and the resulting activities they led to are given in detail in Appendix A. Of particular importance here are the recommendations that, in retrospect, led to some of the greatest programmatic successes of CCRS, set the stage for that success, or that led to continuing financial support.

The key impacts that have come directly from CACRS recommendations can be divided into five areas: significant new programs, new research areas, application areas that should be developed, activities and policies to support the broader use of remote sensing, and programs to support the development of the Canadian remote sensing industry. The last two groups of recommendations may well provide useful guidance today for scientific organizations in government.

2.2.6.3.2. Programs

There are two significant new programs that came out of CACRS Recommendations:

- The development of the airborne radar program; and
- RADARSAT.

Clearly the multi-billion dollar RADARSAT program and the follow-on RADARSAT Constellation Mission (RCM) were children of both CCRS and CACRS as is detailed in Chapter 5. Another important

[34] Here it must be noted that anything to do with remote sensing research and technology was legally under the mandate of CCRS according to the Act that gave the Department its mandate – be it , for example, remote sensing of agriculture, oceans, or ice.

area encouraged through CACRS and initially a topic of CCRS research has recently grown in importance: the development of airborne laser systems.

2.2.6.3.3. Research Areas

The significant new research areas that resulted (beyond support for radar programs and the applications areas noted in the following Subsection) included:

- Development of applications;
- Laser bathymetry;
- Atmospheric correction;
- Field spectroscopy;
- Development of on-line data distribution systems;
- Developing the linkages between image analysis and geographic information systems; and
- Improved software for image analysis.

The early focus on applications led to the creation of the Applications Division which quickly developed a world-class reputation. Atmospheric correction and field spectroscopy work led to more quantitative and confident use of satellite and airborne imagery. The laser bathymetry and image analysis work led to operational systems which Canadian industry has sold around the world. The development of on-line distribution systems led to early Canadian leadership in the wider distribution of geo-information via the Internet through the National Atlas of Canada.

2.2.6.3.4. Application Areas

Before CCRS had an Applications Development Section, there were calls to focus on a number of application areas. At the outset these included:

- Crop information systems;
- Land use mapping; and
- Forestry.

These topics provided the early foci of the Applications Development Section as well as direction for part of Methodology Section. As detailed in Section 6.6.3 CCRS projects in these areas were the first in the world to operationally demonstrate applications in large area land use mapping (Great Lakes Basin) and near-real-time crop area estimation (Potatoes in New Brunswick). The industry's role in supporting these and other developments of applications is shown in Section 3.3.

Other application areas were championed by CACRS that led to applications development work on:

- Ice;
- Oceans;
- Rangeland;
- Soils;
- Geology;
- Geo-botany;
- Hydrology; and
- Environmental monitoring (that grew into research related to climate change).

Over time the Applications Development Section grew from two scientists and a section head into several sections with more than forty professionals – both government employees and contract staff who served as a national centre of remote sensing applications expertise for Canada. As is detailed in Section 4.7 in 2002-2003 the Assistant Deputy Minister of the day decided that CCRS was to focus only on areas within the mandate of the home department, Natural Resources Canada. This effectively led to undoing thirty years' worth of work developing a broadly-based national centre of expertise. In effect work on agriculture, oceans, ice, soils, rangeland, and land use ended at CCRS and the limited budget was cut further. A number of the key scientists in these other areas went on to work in other departments including several authors of this document and many others.

2.2.6.3.5. Activities and Policies to Support the Broader Use of Remote Sensing

Early CCRS management and CACRS members recognized a basic truism associated with remote sensing: the value of remote sensing came not from the creation of the data or the sale of the data, but rather from its use. There were therefore many recommendations over a number of years that were aimed at increasing the use of remote sensing – and hence its benefits. The importance accorded this suite of recommendations is reflected in the fact that there were fifty-one such recommendations over a period of 13 years and almost all of them resulted in concrete action by CCRS. Those that did not lead to action by CCRS were often ones that suggested doing things outside the legal mandate of CCRS. As noted above, CCRS could not, for example, carry out education activities or provide grants in support of universities.

What was uncommon for that time was that a major focus was put on public awareness and marketing – something that was at that time (and still is) highly unusual in a science-based organization in Government.

The recommendations on activities and policies to support the broader use of remote sensing for which there were significant concrete actions included those that called for CCRS to:

- Develop a technical information service (library);
- Carry out cost benefit studies following the generally accepted guidelines put forward by Treasury Board;
- Focus on operational demonstration projects that involved users;
- Establish a user liaison team;
- Document successful case histories;
- Establish a marketing unit;
- Produce training materials, brochures and the like;
- Develop low cost image analysis systems;

(The above eight recommendations were made before 1976. There were then supporting recommendations for the next decade.)

- Develop a technology transfer program;
- Convince Treasury Board to use results of data being used as a measure of success, not the value of data sold;
- Produce brochures on operational RS techniques; and
- Facilitate scientist exchanges with industry.

The above suite of recommendations led to a number of benefit cost analyses which helped both justify the program and guide CCRS to new application areas where the technology could be of most benefit. These recommendations also led to the establishment of a marketing and user assistance unit[35] (See Section 6.2), on-going attention to operational projects, and the requirement to document successful work in user-focused case studies, not just scientific papers. One might argue that the publicity generated helped keep the benefits of remote sensing in the public eye, leading to continuing public and political support. When that publicity was reduced (and eventually ended) public and political support also was greatly reduced.

2.2.6.3.6. Programs to Support the Development of the Canadian Remote Sensing Industry

From the beginning industry was seen as an important element in the national remote sensing program, as discussed here and in several other places in this document. There were two roles seen for industry. First, industry would develop technology for CCRS which the companies could then export. Second, industry would commercialize the applications research at CCRS and offer services. The idea expressed by Morley at the beginning of CCRS was that the taxes paid by the companies and their employees would be what would justify the continued funding of the Centre – they would "pay for" the Centre. The recommendations on activities and policies to support the development of industry included those that set

[35] Ryerson, author of this section, headed the User Assistance and Marketing Unit and the follow-on Industrial Co-operation and Communications Section for a total of eleven years.

the stage for the development of products and services that industry might sell to those that directly benefited from their application, whether in Canada or abroad. Those that helped set the stage included suggesting that CCRS:

- Should change the focus from experimental to operational RS;
- Should not compete with industry;
- Ensure closer liaison between its operational units and industry; and
- Should ensure that more commercial organizations are represented on CACRS Working Groups.

Those recommendations that more directly supported industry included ones that directed CCRS to:

- Foster the development of low cost image analysis systems including PC-based software for image analysis;
- Support Canadian industry involvement in foreign satellite programs;
- Contract out routine production and distribution of ERTS imagery;
- Support industry with adequate funds to produce an advanced imaging radar;
- Provide technical assistance to the service industry;
- Provide a directory of RS-related facilities available in industry, government and universities;
- Produce a brochure or video to inform potential international buyers, especially in developing countries, of the services available from Canadian private industry; and
- Inform CIDA of Canadian (government and industry) expertise in remote sensing and land evaluation and rangeland applications.

The CCRS response to these recommendations is given in Section 3.3.2.

By 1984 26 % of all WG members were from Canada's remote sensing industry – an industry that did not exist ten years before. The degree to which industry became involved in CACRS is reflected in the 1984 meeting whose focus was on the development of a strategy for the support of industry in the domestic and international market. The industry and marketing strategy provided much of the focus for the User Assistance and Marketing Unit, as is further discussed in Section 6.2. The Unit was later renamed the Industrial Co-operation and Communications Section and refocused in 1990 when the sale of satellite data was outsourced to industry as a money-saving measure.

While CACRS was important to the strategic positioning of CCRS, many of the important innovations came from the simple requirement to make things work and make them work at low cost – always an issue at CCRS where the organization was trying to do what the US was doing but with less than 10% of the budget. This led to the relatively inexpensive reception of satellite data, corrections to make imagery useful (removal of spurious lines caused by eccentricities of the sensor, for example), creation of special enhancements, geometric correction of imagery, etc. Many of these innovations led to commercial success, most notably the success MDA had in selling satellite receiving stations. At one point MDA had over 90% of the global market for remote sensing satellite receiving stations. Total export sales of just satellite receiving stations by MDA were estimated by some to be well over $120 million by the late 1980s.

2.3. Management

2.3.1. Introduction

Bob Ryerson

How CCRS was managed, and the evolution of management over time provides an interesting study in science management in government. The next Subsection begins with an outline of some of the factors that contributed to the complexity and difficulty of management as seen by one of the first scientists to be hired. Further detail on various aspects of management are then covered, as are the changes over time and the structures that were put in place over time to facilitate the management of a complex world-class organization.

2.3.2. Approach to Management
Bob Ryerson and Ian Crain

In its first decades CCRS was ahead of its time in terms of management. Employees with the potential to grow were encouraged to do so by obtaining training, serving in acting capacities at higher levels, or by serving on departmental or interdepartmental committees. Training in aspects of management was encouraged…this was important inasmuch as CCRS functioned on the basis of projects and the projects had to be managed. And there was the belief that managers should understand that which they were managing. A key player in developing the approach to management was Frances Macdonnell, who was the Head of Personnel through the early days of rapid growth. In today's private sector world she would be seen as the VP of Human Resources – she had that much impact in hiring and encouraging training. One of the other early contributors to the success CCRS, Paul Hession, said that Francis impressed him "as a most passionate human resource manager whose mission was to make certain that all CCRS employees knew they were working in a very special place." (Hession, Personal Communication to Ryerson, May 27, 2015) Another aspect of the initial creation of CCRS was the diversity of academic backgrounds of the staff. In hindsight the diversity of backgrounds of staff led to a broader range of potential solutions to research problems given the different perspectives staff had.

At CCRS we were encouraged to take calculated risks and teamwork was emphasized. In today's vernacular it was a "safe place for ideas." The reader should keep in mind that in the late 1960s and early 1970s in general the "boss" (often a veteran from World War-II) decided what you should do, how you should do it and then told you to do it. This was not the CCRS way. There was one aspect that was consistent with common management practice at the start of CCRS: from the outset until the early-mid 2000s the Directors General and senior management were experienced in the field or in related fields. The idea that any manager could manage anything did not appear at CCRS in the period we are examining. The concept that seems to have gained prominence in some industries and government, that a good manager could manage anything, was not one that was endorsed by CCRS. The fact that CCRS leaders truly understood what they were leading and managing, led to better management, more coherent (and more successful) requests for financial support, and more interest in partnering by provincial groups and industry. It also tended to keep scientists "on their toes" to know that the Director General knew the field.

The strong positive opinions of CCRS scientists on the approach to management at CCRS were brought out in the response by CCRS scientists to the 1989 Lortie Task Force Study of Science in Government. That response is provided in its entirety in Appendix D.

Another aspect that made CCRS unique was the willingness of management to fill important gaps with people from outside Canada, much as has been done with the concept of Canada Research Chairs in academe. For example, once the decision had been made to focus on radar, it was clear that more depth in radar was needed in CCRS. CCRS went to ERIM to bring on board one of the top radar scientists in the world. That scientist, Dr. R.K. (Keith) Raney, became Chief Scientist at CCRS, and was the Chief Scientist of the RADARSAT Project Office. He is widely seen as one of the fathers of RADARSAT. He has also been (and in some cases still is) the mentor for a number of other CCRS scientists who have built international reputations. Dr. Raney has written Chapter 5 of this document. Dr. Ridha Touzi, a native of Tunisia who studied in France also joined CCRS. Dr. Touzi is also a contributing author.

The ultimate stamp of approval on how CCRS was managed and the results obtained came from a report of the Auditor General of Canada (AG). Usually the reports of the AG are negative – they find all manner of issues in how Government agencies and Ministries are managed – or mismanaged. In the case of CCRS, the thorough review done in the 1982-83 time period by the AG was positive in tone. (CACRS, 1983) The positive AG report reflected well on all of CCRS and is today seen as one of the highlights of then Director General Lee Godby's career.[36]

[36] Personal Communication by e-mail from Lee Godby, May 8, 2018.

The following text box provides a personal view on management from the early years by one of the first scientists hired by CCRS.

Science Management in the Early Years
Ian K. Crain

This text box refers to the first two years of CCRS - the development period. The early days of CCRS (1973-4) held much potential to be a management nightmare. One component of the Centre was moved more or less intact from an existing airborne sensing unit at the National Research Council – complete with its organizational structure and established management culture

At the same time there was a major recruitment campaign for scientists, mainly for fresh PhDs straight from university in various scientific disciplines including Theoretical Physics, Geophysics, Mathematics, and Geography. At the time there were degrees and courses in Remote Sensing at but a handful of universities – the first PhD was not granted until 1975. Some of these recruits would later become professors and teachers of Remote Sensing and GIS. One of the four earliest recruits, I was the exception to the rule, as I was employed in the Energy Mines and Resources Computer Science Centre, and had previous experience in geophysical data acquisition (airborne) and processing with the Geological Survey of Canada.

In short, the new recruits (and many more followed) who were to research satellite imagery, were young, self-motivated, independent-minded, with a wide range of personalities, and precious little experience in teamwork or even the concept of the "boss."

The organizational structure was divided into Airborne Sensing, Applications, Data Processing, and Administration. From the outset there was an embryonic Library which would later become a major national and international resource for information. A small section dedicated to Human Resources was led by Francis MacDonnell, who was an international-level concert pianist who, by her own admission, was not especially keen on dealing with people.

The physical surroundings were not a typical government office: it was a former factory that produced women's undergarments in an industrial area in the East end of Ottawa. It featured uneven floors, rudimentary offices, many without windows, and basic furniture. There were no nearby shops or food sources and no public transport. However, there was ample free parking!

Initially there were no on-site computer facilities, only an awkward input terminal arrangement to connect to the distant EMR Computer Science Centre. There were no satellite data for experimentation and analysis, only some simulated images collected by aircraft. The Airborne Sensing Division was located in an old hangar at the Ottawa airport, a dozen or so miles away, and other staff were at the under-construction satellite receiving station in Prince Albert Saskatchewan.

To add to the fun, the Government had just introduced a "merit pay" scheme for scientists (replacing a simple stepwise increment system) in which a fixed pot of money for salary increases was divided up according to perceived "scientific productivity." Given the very small pool of scientists at CCRS, all of whom believed they were high performers, a certain amount of competitiveness ensued, pursued with more enthusiasm by some than by others.

Given the lack of eateries in the neighbourhood, there was a canteen lunch-room of sorts. Given the range of personalities, backgrounds, scientific specialties, (not to mention eating habits), and potential for competitiveness the CCRS cafeteria at times resembled the cafeteria scenes on the comedy series "Big Bang Theory." The primary difference being that there were no female scientists in those early days.

So none of the above – staff split into three separate locations, established group vs. a hodgepodge of new enthusiastic recruits, rivalry inducing pay system, questionable working conditions – boded well for smooth sailing. But somehow in the end it seemed to work out well.

At the top, the Director General, Larry Morley confined himself to promoting and defending the organization to the higher-ups, ensuring funding, and international liaison. He employed an Associate Director General, Lee Godby who took care of the day-to-day administration. The Director General did not involve himself (visibly) in research priorities or specific projects, but somehow still directed things. This was a rare talent.

Initially the Divisions were headed by Division Chiefs who were at the senior Physical Scientist[37] Level 5. Reporting to them were Section Heads, usually at the Physical Scientist Level 4. Division chiefs were recruited who were experienced with government research management or industry research. They had a steadying effect (most of the time) on this rambunctious lot. Together they introduced a project-oriented management system, rather than a hierarchy, with some modest level of project planning and progress reporting against benchmarks, with only the necessary levels of paperwork. (A sort-of matrix management approach). There were few if any meetings. Some of these early Division Chiefs were Joe MacDowall, Murray Strome, Ralph Baker and Ed Shaw.

Part of a commentary on management usually includes some words on internal communication. In the early years the different Divisions were much more likely to actually meet and discuss their activities at national and international conferences than at CCRS HQ. Not ideal, but it seemed to work.

An on-site computer was acquired and was available for research analysis, and was well managed. One bone of contention was that scientists could not access the system until mid-morning. Since the formal hours of work were from 8:00 a.m. to 4:00 p.m. one of the scientists insisted that they should be allowed to work from 10:00 until 6:00. The Division Chief denied the request – which the highly productive scientist ignored. Eventually data from the satellites (ERTS later re-named Landsat) were routinely produced. Research and application development products began to flow and the Centre gained a reputation for disproportionate productivity in scientific results, and the development of useful applications.

One of the enabling factors in this success was the Library, under the leadership of Brian McGurrin. It became a significant national, and then international source for literature on Remote Sensing. The User Assistance and Marketing Unit became the main point for the sale of imagery for applications across Canada, while the Applications Division led the development of projects with and for CIDA and IDRC.

CCRS was different in other ways too. While it was clear who “the boss was,” it was also clear that every team member was important and every team member was made to feel important. And this was in 1973! The following text box illustrates this with a simple set of examples.

Cafeterias, Lunch Rooms and Excellence: Experiencing Camaraderie and True Leadership at CCRS
Bob Ryerson

The cafeteria at the original building at 2464 Sheffield Road set the tone. It was not uncommon for the Director General and Associate or Deputy Director General to sit with whoever was having lunch and have a conversation about all manner of things. At one long table one often found Lee Godby (Deputy DG) having lunch with Bob Hamelin (head of the stock room and the CCRS driver), Roy Butler (Personnel Clerk), Post-Doctoral fellows Seymour Shlien or Pak Chagarlamudi, young scientists like Tom Alföldi, Bob Ryerson, Ian Crain, Fred Peet and Dave Goodenough, or Frances MacDonnell (Head of HR). Everyone was respected for what they brought to the table – and everyone brought hard work and a desire to do what was right for the Centre and for Canada. Everyone was made to believe that his or her role was important. Management by walking about – being visible, was a central element of how CCRS was managed.

In other buildings this sense of lunch-table camaraderie also held true – whether at Data Acquisition’s Limebank Road facility, at “The Hangar” where the Airborne program was housed, or the Applications Division’s Belfast Road location. It was in these early years that a tradition of having pot-luck lunches began. Every Christmas there were Christmas Party Pot Luck Lunches. Those at Belfast Road featured Librarian and music aficionado Brian McGurrin’s “name that tune” challenge – where he would play a few snippets of a musical piece and we had to guess the name. (Everyone wanted to be on Jean Game’s team – her musical knowledge was encyclopedic!)

[37] Editors Note: This is a job classification in the Government of Canada. Eventually the Division Chiefs were re-named “Directors’ and were classified at the Executive or EX level 1 or 2.

At many social events there were skits performed by staff. Such events were often organized by Jenny Murphy whose British humour was quite evident. At one Christmas party one of the skits played on the frequent absence of a Director who always seemed to be flying off somewhere in a hurry. A scientist ran across the room, up onto the stage trailing a long line of airline tickets while saying he was late for his flight – and then he turned to the crowd imitating one of the mannerisms of the Director. The crowd laughed – including good-natured "frequent flyer" Director.[38] The fact that CCRS employees were comfortable in such kidding, and that the leaders accepted it with a good laugh, was yet another indication of the team-environment fostered by CCRS management – and staff.

Several pot luck lunches were so large they had to be held in Camsell Hall, the main Natural Resources Canada auditorium. The first event of this size was a Christmas Pot Luck Lunch held in the early 2000s. Another was in November 2009 celebrated the career of popular Marion Normoyle, who began as the Secretary to the Director of the Applications Division at Belfast Road and was for many years the Executive Assistant to Director Dr. Bob O'Neil. Another was in January 2012 for the retirement of Kathy Laity, another popular support person who had spent virtually her entire career in CCRS. Both of the ladies feted deeply appreciated the send-off. If memory serves correctly, three former DGs attended Marion Normoyle's send-off.

The text box on the following pages shows what two Section Heads and two scientists thought in 2003 about how CCRS was managed and the role its staff were encouraged to play. CCRS employees had a shared belief that Canadians could do more with less…and we did. The two page document "History Lessons – The Mouse that Roared" was written more than thirty years after the founding of CCRS (and more than a dozen years ago). It is used to more fully introduce the approach to management, technology transfer and external relations at CCRS that proved so successful for so many years.

History Lessons – The Mouse that Roared[39]
Tom Alföldi, Willy Bruce, Shannon Kaya and Tom Lukowski
(Written in May, 2003)

Positioning and Vision
A basic fact realized early on at CCRS and still true today is that CCRS is not NASA. We never, however, thought ourselves 'second best' to anyone. Our challenge and our strength came from recognition that our areas of focus have always needed to be tuned to broadly understood priorities of government, most often expressed for practical purposes by funding opportunities. CCRS has arguably been 'issues-driven,' largely successfully, over much of its 30 year history, recognizing that we could not 'do it all' and what we did had to contribute to externally expressed/endorsed needs and priorities. By actively building and maintaining links with partners and stakeholders in government, industry and academia as well as with key international partners, CCRS was able to exert an influence far out of proportion to our small size. In this way, CCRS became, in effect, Remote Sensing Central for Canada and a model for the management of remote sensing programs in many other countries where the US model could not be duplicated due to limited S&T funding and breadth of need.

Maturity
Developments in earth observation have been similar to those in other areas of rapidly expanding and developing technology. CCRS management and staff have shared the understanding that while specific applications mature

[38] Extensive travel was what one expected at that time. After all, CCRS people were in demand around the world for the work we were doing and our travel was often done in support of our nascent industry's export activities as well as foreign aid. It should also be noted that at that time Public Servants did not get airline points – and anyone who travels a lot will attest that travel takes a toll on one's health and family life.
[39] This short piece captures the view of CCRS leadership from the point of view of both senior and relatively junior staff. It was written by the named authors as a contribution to the new strategic plan for remote sensing being developed by the Director General at that time. Tom Alföldi was the first Applications Scientist hired at CCRS. He retired as a Section Head, as did the late Willy/Bill Bruce. At the time Shannon Kaya was a relatively junior Environmental Scientist who later left CCRS to join Environment Canada, while Tom Lukowski was a scientist who also left CCRS. Alföldi, Kaya and Lukowski gave their permission to use this material.

from R&D to operations through technology transfer, the organization as an innovation laboratory cannot allow itself to 'mature' in the process. A factor that countered the tendency for stagnation at CCRS was the extent of 'connectedness' and influence that CCRS maintained in the domestic and international contexts. CCRS was 'expected' to lead and innovate. While CCRS could not DO everything, it was important that CCRS was aware of what was being done as broadly as possible to be able to take advantage of synergies. There are many cases where CCRS scientists were able to develop innovative and important applications based on work done in other fields elsewhere that were not themselves priorities for CCRS. This synergy was actively nourished by the foresight and high level of competence of CCRS scientists who were able to operate and cooperate in an environment that nurtured innovation, personal initiative, and scientific exploration.

Brand Recognition
The importance of brand recognition has been evident with virtually every international visit to CCRS. The modest reality clearly comes as a surprise to most visitors who know us by reputation. Our visibility, active scientific engagement and commitment to voluntary leadership at the international level has created a 'whole' that has been much more influential on the development of remote sensing in Canada, Canadian industry and international earth observation programs than the sum of our 'parts'. The quality of CCRS contributions to the international 'brain trust' in earth observation has been recognized over and over again (e.g. GlobeSAR-1 & -2). We have often lacked the resources to compete with our international counterparts but our greatest successes have come both domestically and internationally when we have been able to lead by example and forge impressive and durable partnerships. Our success has been evident in the numbers of scientists and engineers from outside CCRS (universities, governments, and industry in Canada and outside our borders) who have sought to work with us cooperatively or as visiting scientists in our laboratories. The contributions of these folks to programs at CCRS and throughout the world have contributed directly to many of our successes.

Sustainable and Deployable Capacity
At the heart of CCRS' success has been the ability and eagerness of staff to provide informed and authoritative guidance and direction to management in relation with needs, opportunities and priorities. The relationship between bench scientists and management has always been a close one based on a fundamental recognition of the importance of peer vision in building and sustaining success. CCRS scientists were 'out there' and engaged both domestically and internationally. As a result, CCRS scientists were able to lead and to inform our decision-making process. CCRS scientists were our primary routine points of contact for stakeholders, partners and clients. Staff shared in the vision of CCRS management in large part because they helped shape it and therefore eagerly "represented" the Centre. A benefit of this intimate and informed involvement was a science staff that could reliably anticipate changing needs, issues and priorities and a management model that was based on shared responsibility and flexibility. While the CCRS science core has always been small in comparison with other comparable organizations internationally, we have maintained a critical mass of competence that, through its intelligent and focused deployment allowed us to have a shaping influence in the development of earth observation over the past 3 decades.

We are the mouse that roared.

2.3.3. Evolution of Management Structures over Time
Bob Ryerson, Murray Strome and Florian Guertin

In many bureaucracies the arrival of a new leader results in a re-organization. This did not happen in CCRS during the period under discussion. Looking back at the early organization of CCRS and the changes that occurred until the end of the period being examined, it all seemed to make sense: there never seemed to be a change for change's sake. The management structures could more correctly be viewed as having evolved over time with the occasional more dramatic change that was brought about by external forces – such as dramatic changes in budget or the addition of more responsibilities.

The usual state of gradual evolution is attributed to the fact that seven of the eight leaders of the organization (see Table below) were either from within the organization, had been in the organization in the past, were closely involved with CCRS as a user of remote sensing or through participation in CACRS. What was deemed important to the leaders was the effective and sensible management of the organization so that it would meet its objectives. Eventually external pressures resulted in the effective end of CCRS as a national centre.

Directors General of CCRS[1] for the First Forty Years
Dr. L.W. Morley, 1971-1980 Mr. E.A. Godby. 1980-86 Dr. L. Sayn-Wittgenstein, 1987-1995 Dr. E. Shaw, 1995-2001 Dr. R.A. Ryerson, 2002-2005 Dr. M. D’Iorio, 2005-2006 Mr. S. Salter, 2006-2010 Mr. D. Bancroft, 2010-2013
[1] From Ryerson 1999 and personal communications with Mssrs. Shaw, Salter, D’Iorio, and Bancroft.

The first operating divisions were Data Processing Division (DPD) under Dr. Murray Strome and the Airborne Data Division under Ralph Baker. They were in place by 1972 with the previously noted launch of ERTS and purchase of the Falcon aircraft. The Applications Division was approved in January 1973 and staffed under Division Chief Joe MacDowall by July 1973. Murray Strome replaced Joe MacDowall in August of 1974 as the Chief of the Applications Division and MacDowall left CCRS. Ed Shaw took over the reins of the DPD at that time.

Division Chiefs Strome and Baker started as Research Managers while MacDowall was at a similar senior level in the Physical Scientist job category. Sometime before 1980 the senior managers of CCRS were re-classified in the Executive category. In the words of Murray Strome “It was at a time when the Government decided that ‘a manager was a manager was a manager’, and that a manager's education and discipline experience were completely irrelevant: a manager whose career experience had been, for example, in the prison system could manage scientists just as easily as one with a scientific background.” The fact that CCRS never subscribed to this view is in large measure why it was successful for so many years. From the beginning CCRS hired managers who knew the field. Succession planning was based on training people from within who expressed an interest in management, or through recruiting experienced people from outside who held similar views on the need for what could be called knowledge-based management. CCRS senior management was also not afraid to remove managers who did not perform up to expectations…something altogether too rare in most bureaucracies.

Later, the Airborne Division became the Data Acquisition Division (DAD) and the satellite receiving stations were moved into DAD. The Data Processing Division became the Digital Methods Division when the satellite data processing activities were transferred from Sheffield Road to the Prince Albert Station for the launch of Landsat-4 in 1982. When the Major Projects Office was created in 1987/88 the Methodology Section, that started life in the Applications Division, was transferred to this new unit and the Digital Methods Division was then renamed the Systems Technology Division whose work is described more fully in Section 7. At this point in the mid-1980s the Applications Division consisted of Applications Development, User Assistance and Marketing, Technology Enhancement and the Library.

Through these changes into the mid-1990s the basis of Management stayed much the same. There was a Director General and under the DG (or Deputy DG – until that position was eliminated) there were several Division Chiefs or Directors. There were dramatic changes to the structure of CCRS caused by external factors, primarily budgetary or the decision to add more responsibilities to CCRS – or in the early 2000s the removal of responsibilities. These are briefly discussed in Section 4 “Mergers Acquisitions and Closures.”

2.3.4. Internal Committees and their Evolution
Bob Ryerson

2.3.4.1. Introduction

Once CCRS was staffed up in 1973 the CCRS management structure was similar to that found in many government organizations of that time. The Director General Larry Morley had beneath him the Associate Director General E.A. "Lee" Godby. The operating Divisions were each headed by a Division Chief who reported to the DG through the Associate DG. Some of us who worked at CCRS at the time thought of Larry as the "Outside Guy" and Lee as the "Inside Guy." As noted in the text box above, Larry dealt with the external issues – funding, international, long term strategy, and the like, while Lee managed the day-to-day operations. The success of CCRS was a testament to how well they worked together.

Management in the Government of Canada through most of the period being discussed here was done through a series of Committees at each level. In Energy Mines and Resources/Natural Resources Canada the Deputy Minister chaired a Committee made up of the Assistant Deputy Ministers (ADMs), while each ADM chaired a committee made up of the Directors Generals who reported to the ADM as well as a finance officer and other senior advisors. Each DG then chaired an internal committee for the branch. The meetings of these committees were held in a sequence from the highest level to the lowest to allow the discussions or directions from the more senior committee to cascade down through the organization.

2.3.4.2. Management Advisory Committee (MAC)

The first internal committee within CCRS was the Management Advisory Committee commonly referred to as "MAC" (pronounced "Mack"). The committee was composed of the Director General, Associate or Deputy Director General, Division Chiefs (later Directors), and the heads of Administration and Personnel. Over time the individual in charge of marketing joined the Committee, Administration was replaced by Finance, and the regular attendance of Personnel ceased.

The Committee met weekly to address the key issues of the week – be they items that came from the meeting of the Director General with the ADM the day before, other requests from higher up, or solving the on-going problems of management or operations that one found in a rapidly growing and highly visible organization. MAC would often assign small projects to staff that would lead to presentations to MAC on important research, a new technology, or on what some company was doing. The day after the MAC meeting Divisions would have their management meetings chaired by the Chief or Director involving Section Heads (later called Section Chiefs) and in turn Section Heads/Chiefs would often gather their staff together to report what direction or useful information came from the higher level committees. As in all organizations there were also informal contacts that exchanged information across the organization. And, as in other organizations, these informal contacts often seemed to work faster in passing on information than the formal structures.

While MAC sometimes gave the vibe of being a democratic operation, it wasn't. Every so often there would be an argument when the Director General made a decision that ran counter to the Committee's advice. The Committee of the day often pushed back and would note that the decision ran counter to their collective advice. On several occasions the DG of the day ended the discussion by saying "this is an Advisory Committee, NOT a Management Committee. I heard your advice but do not have to take it." Sometimes that would lead to a short explanation for the decision, sometimes it did not.

Over the course of a year there were certain reporting requirements that guided what MAC focused on at different times of the year. This included the preparation of the year-end report to the ADM, writing the report for CACRS, responding to the recommendations from CACRS, preparation of the conference plan (which scientist was to go to which conference), and preparation of requests for new money in the annual Budget process. These events had a certain rhythm over the year, were expected, and could be prepared for.

More interesting were the requests or questions that came “out of the blue.” This included questions like “how might your program be able to use money from a fund related to industry development?” or “might you be able to find and hire a Francophone scientist if you were given access to a free budget to hire entry-level French-speaking scientists?” Early on CCRS was one of the most successful organizations in all of Government in identifying how and why it should benefit from some new funding program – be it the winter works programs that saw several provincial agencies started, the Unsolicited Proposal Fund developed under the leadership of the late Dr. Peter Meyboom that led to contracts with MDA and many others, or the programs developed to hire young francophone scientists that started the successful and long careers of both Monique Bernier and Christian Prevost among others.

Eventually these discussions on funding focused more on what should be cut next or what CCRS should give up doing to react to the budgetary pressures that were encountered from 1994 onwards. The most dramatic decisions faced by MAC over the period being discussed were related to Budget Day 1994. On that day a very sad and emotional ADM Hugh O’Donnell announced to a gathering of all staff that there would be a 40% cut in budgets and staff and a reduction of Executive level positions from around 30 to 11 in Geomatics Canada. At the same time he announced a program that allowed anyone over the age of 50 with ten years of service to voluntarily retire with no penalty. I (Ryerson) was the first person to make it to the front of the auditorium to volunteer – I had planned on leaving government to enter the private sector and this made it much easier to do so when I turned 50.

While the budget woes of 1994 impacted CCRS in a negative way, there was some positive news. The only program in all of Government to obtain new funding was the space program which obtained some $800M over the next decade or so and most of that was earmarked for remote sensing or earth observation. Why this happened is quite simple: industry and academic leaders were informally encouraged to send letters to cabinet members and MPs on the Government side of the house. We later learned that the space program in general and remote sensing in particular were the hottest topics by the metric of the number of letters received. Public relations, cclose ties to industry and marketing paid off.

The first casualty of the budget cuts was the airborne program. In effect the SAR-equipped Convair was transferred to Environment Canada (and in part paid for by the new space money) and the rest of the airborne program was eliminated. (An unconfirmed rumour has it that one of the DC-3 aircraft ended its life as a chip-wagon somewhere in Northern Ontario – it was actually sent to a college in Sault Ste. Marie.) However, scientists in the airborne program were retained – most of the required personnel cuts were absorbed through voluntary retirements and departures of staff. The other major casualty was the capital budget which was used to update and maintain various systems, including the receiving stations. This became a major problem for future managers inasmuch as the ground receiving stations were held together “with duct tape and binder twine” as future Director Ian Press described the situation to the Director General of the day. The capital budget problem for CCRS was exacerbated in the early 2000s when the sector’s individual branch capital budgets were merged into one. Further discussions of the ramifications of these budget cuts are found in Section 4.

2.3.4.3. Project Selection and Review Committee (PSRC)

The Project Selection and Review Committee (PSRC) was unique to CCRS. Almost all work in CCRS was done as a project and it was the PSRC that approved projects. At the outset it was chaired by the Associate Director General Lee Godby and involved a number of key scientists, one from each Division. The impact of a project across all parts of the Centre was an important part of the deliberation. A clear result was much better communication, integration, and understanding of the whole. The tough reviews made for better projects. Members of the committee over the years included such well-known scientists and section heads such as David Goodenough and Florian Guertin. Godby “chaired the committee and had a major influence. He made sure that each project was realizable, and had well defined objectives within the mandate of CCRS and adequate resources. This strongly encouraged the project leaders and their project members to remain well focused. Regular project-based financial reports were provided to the project leaders; this helped in controlling resources and in identifying the risk of discrepancies. I believe that the concept of computer-generated financial reporting was proposed by Jean-Claude Henein early on for PSRC. This was ahead of its time. In the 1970s at the departmental level financial reporting was still very much a manual bookkeeping affair done by financial officers."[40]

Through the mid-1980s presenting a new project to PSRC was a nerve wracking experience. Those of us who were project leaders soon learned that one had to be well-prepared with a clear idea of what we were doing, why, and with what anticipated result and how much it would cost. We also had to have some form of outside support or an indication that what we were doing would be broadly useful. A natural byproduct of the philosophy of doing more with less – which can also be expressed as meeting multiple objectives with the same output, forced us to have a clear idea of the impact of the project beyond the demonstration.

Primarily at the urging of J-C Henein, projects led by scientists in the Applications Division (of which he was then Director), were expected to generate materials useful for outreach and education. The intensity of the meetings and questioning can be best described as being similar to a Master's Thesis defense. One could expect detailed probing of weaknesses featuring hard questions by people who either knew the subject area or who made the effort to learn about the subject. Larger projects were subjected to an on-going review or gating process to evaluate progress. Over time the process became somewhat less confrontational, less stressful and, in some respects, perhaps less useful as a filter to ensure that all projects were well focused and well managed.

[40] Personal communication from Florian Guertin, November 18, 2017.

3. Relationships

CCRS consciously fostered relationships across several dimensions. These included the normal cross-sector relations with academe and industry, as well as with the provinces, other federal agencies, internationally, and with professional and technical societies. As Bob Hawkins has noted, "by partnering with outside R&D organizations, we were also able to leverage our work, particularly in applications, to a wide community so that publications and cooperation multiplied our effort."[41] This section explores these relationships introduced by the Editor, but also from the eyes of those with whom CCRS had relationships. One of the interesting facets of these relationships is that there were often exchanges and secondments of academics to CCRS or CCRS staff to industry, academe and other government agencies. Through these interactions CCRS was continually re-inventing itself.[42]

3.1. Provinces

3.1.1. Introduction

Bob Ryerson

Federal-provincial relations are almost always an important consideration in any activity undertaken by the Government of Canada. Provinces are even more important in remote sensing inasmuch as the provinces have responsibility under the constitution for natural resources – the sector where it was assumed remote sensing would play a major role. Furthermore, to ensure that the provinces could reap the benefits of remote sensing, developing regional or provincial interpretation centres was an early and continuing focus for CCRS.

CCRS interest in establishing regional or provincial centres broadly influenced what was done in the provinces. Indeed, in the initial proposal for the Ontario Centre for Remote Sensing it was stated that "the policies and organization that are suggested have also been influenced by the publicly stated policies of the Canadian Centre for Remote Sensing, which include the policy of strong support for regional centres as they are established." (Collins *et al*, 1972) These policies were elaborated upon at CACRS meetings as well as at presentations Dr. Morley gave, including one to the university community at the University of Guelph in 1971 attended by the author, then a PhD candidate at the University of Waterloo.[43] Similar observations on CCRS support for regional centres were made by Professor Angus Hamilton of UNB in his report for the Council of Maritime Premiers. "The Canada Centre for Remote Sensing (CCRS) has, since its formation, been advocating the establishment of provincial or regional centres. Although it is never stated explicitly, it is implied that the Centres should focus their efforts on developing applications for Landsat imagery rather than on air photography. …Two such centres have been in operation for some time the Alberta Centre for Remote Sensing (ACRS) in Edmonton and the Ontario Centre for Remote Sensing (OCRS) in Toronto."

Obtaining funding for such centres was difficult. The 1972 request by CCRS for $450,000 in grants for regional centres was not approved. In the end the only support found in the budgets of the 1970s by CCRS came from what was then called the "Winter Works Program," best known in Ontario for hiring the unemployed to remove elm trees felled by Dutch elm disease. A number of individuals were hired with Winter Works funding at centres across the country. Several of them became well-known figures in the field, including the late Dr. Simsek Pala of the Ontario Centre for Remote Sensing.

The first provincial remote sensing centre was established in Manitoba in April of 1973 (see next Subsection). Others started that same year were in British Columbia (in July) and Ontario (on September 18) under the leadership of Victor Zsilinszky. Also established relatively early on was the Alberta Center for Remote Sensing under Cal Bricker and the Quebec Centre under Hervé Audet. The provincial centres

[41] Personal Communication: Dr. Bob Hawkins, September 17, 2018.
[42] This author was employed by CCRS for a total of 26 years and in that period was seconded to another division within CCRS for a year, was seconded to Statistics Canada for 18 months, had several short secondments to the UN, and saw several changes in titles and duties. Such moves were common and kept ideas and staff fresh.
[43] Mike Kirby, author of Section 3.3.3 and Carolyn Goodfellow, author of Section 3.2.4.3 were also students in remote sensing at Waterloo at that time.

often helped coordinate airborne sensing flights in their jurisdictions and thus worked closely with the CCRS Airborne Sensing Unit. They also often worked with those responsible for the production of satellite data and some worked on projects with Applications Division staff (See Section 3.1.7 below.) All but the centre in British Columbia operated with some success for many years. As can be seen in the descriptions of the provincial centres in the next several Subsections, each province had its own approach to how the centre would and should operate.

The federal government had certain responsibilities in research in areas like agriculture, forestry, geology, and the like. However, as noted above, the constitution states that provincial agencies have the primary responsibility for the management of these resources. It should not be surprising then that in addition to connections with provincial centres CCRS also established close working relationships with a number of provinces through its applications work related to resource management.

As is explained in Section 3.1.6 resource managers were early participants in a number of CCRS Applications projects and were early users of the CCRS Airborne Program. Eventually provinces were seen to be so important to the goal of having remote sensing data used that a special program was developed that focused on developing expertise and activity in the provinces and territories that did not already have a functioning centre of remote sensing expertise. The program, called the Technology Enhancement Program (TEP), led to other centres being established in other jurisdictions. The TEP is described in Section 3.1.7.

The following Subsections describe in varying detail the development and activities of four provincial centres in Manitoba, Nova Scotia, Ontario and Alberta.[44]

3.1.2. History of the Manitoba Remote Sensing Centre
Roy Dixon

In February 1974 the Manitoba Remote Sensing Centre (MRSC) was established to provide a coordinating role in the use of this technology. Jean Thie was instrumental in developing the policy that was presented to Treasury Board regarding the creation of the MRSC. William G. Best was appointed as Manager of the MRSC. Roy Dixon was chosen as a Remote Sensing Technician responsible for supplying information about the technology of remote sensing to user agencies. The Centre acquired a Zeiss/Jena Intrepretoscope with a 15x enlarging feature, two person viewing capability, and scale matching feature. The Intrepretoscope was ideal for interpretation work in forestry, geology, geography and city planning.

In 1975 a technical information service (TIS) was established to provide reference material on techniques and methods available. Over 600 articles and papers were catalogued. The MRSC entered into an agreement with the Canada Centre for Remote Sensing (CCRS) which allowed access to a library of documents available through CCRS.

Methods for analyzing satellite data acquired by the Earth Resources Technology Satellite (ERTS-1) became available with the loan of two instruments by CCRS: a Spatial Data Systems density slicer and a Spectral Data Color Additive Viewer. Education and training demonstrations were given on the operation of these instruments at the MRSC.

In 1976 the MRSC commenced projects for Provincial Government clients. The projects included a land use study near Brandon Manitoba, a rangeland study using color infrared photography and a road location from Berens River to Pigeon River. In-house seminars were offered to departmental staff as well as college and university students.

From 1977-79 the MRSC continued education and training but increasingly became more involved in projects for various government agencies. A large project involved mapping barren ground caribou

[44] These four were ones for which authors were found or for which material was available to write a profile.

habitat in northwestern Manitoba using Landsat principal components to generate the land cover types. In 1978 the MRSC became responsible for the Supplementary Aerial Photography (SAP) Program. SAP acquired 70mm vertical aerial photography from a camera mounted in a Cessna aircraft. Departmental clients included: Agriculture, Highways, Municipal Affairs, and Natural Resources. Hartley Pokrant was the program manager.

In the early 1980's the MRSC continued to work on remote sensing projects for various clients within the Manitoba Government. In 1982 the MRSC became involved in a Technology Enhancement Program (TEP) in co-operation with the Canada Centre for Remote Sensing (CCRS). The purpose of the program was to test operational remote sensing technology for natural resources management programs. Eight projects were initiated in close liaison with resource management specialists. CCRS loaned MRSC an image analysis system called the DIPIX ARIES II which was used to analyze digital Landsat satellite imagery. Hartley Pokrant was transferred from the SAP program to remote sensing. In 1984 the success of the program resulted in MRSC purchasing three DIPIX image analysis systems for project work. Fifty-eight projects had been completed by the end of 1985 which indicated the MRSC had shifted from its coordinating role to an operational agency in its second decade of operation. In 1986 MRSC completed 16 projects varying in size and complexity. Close liaison was maintained with CCRS for identifying applications, new developments and future programs to enhance the use of remote sensing technology in Manitoba.

On October 22, 1987 the Crop Information System (CIS) was officially launched with a ribbon cutting ceremony. The CIS was a joint venture with CCRS and the Canadian Wheat Board (CWS) to provide users with a quick and reliable method for obtaining acreage and yield assessments of major crops around the world. In 1988 the CIS commenced in April, and ran through to September. Advanced Very High Resolution Radiometer (AVHRR) National Oceanographic and Atmosphere Administration (NOAA) satellite imagery from the wheat growing areas of Canada and Russia were processed into weekly composites using software developed by CCRS to produce cloud free images. Ten day composites were compiled for CCRS. Two staff members were added to MRSC. Gerry Lux was transferred from Topographical Mapping in 1987 and David Busch was transferred from Surveys. Projects using SPOT and Landsat imagery were carried out for several clients across Canada. The CIS was successfully carried out during the 1989 crop season. There were over 600 satellite images of the Soviet Union, 200 images of Canada and 52 global images processed. In 1989 MRSC became a member of the RADARSAT program. An agreement was reached to purchase two complete sets of RADARSAT imagery of the provincial landmass when the satellite was launched in the mid-1990s.

W.G. Best retired in 1990 and Hartley Pokrant was selected as Manager of the MRSC.

The MRSC became a partner in the Radar Data Development Program (RDDP). The RDDP provided a framework to carry out projects to familiarize users with the characteristics of radar data. The MRSC coordinated and assisted on project work with other provincial government agencies. Remote Sensing project works in the 1990's had shifted from developmental to operational. Landsat and SPOT imagery were being used on a routine basis to generate land use land cover for a variety of clients. Pat Hurlburt was transferred from Topographical mapping to remote sensing in 1992.

In 1997 Manitoba had the flood of the century and RADARSAT data were instrumental in coordinating resources to combat the flood. A serious flood also occurred in the Czech Republic the same year and MRSC staff members were asked to go to the Czech Republic to train staff in the use of RADARSAT data for mapping and monitoring their flood.

In 2000 Hartley Pokrant was offered a position with the Information Technology Branch, Manitoba Conservation, and Roy Dixon became Manager of MRSC. Roy Dixon retired in 2007 and Gerry Lux is the current Manager of MRSC. Remote Sensing Technology is considered an operational technology used by many departments within the Manitoba Provincial government. Work is also currently being done for Statistics Canada and is called the Canadian Crop Assessment Program (CCAP) using NOAA

AVHRR data. This program is believed to be the longest running program using satellite imagery in Canada.

3.1.3. Nova Scotia[45]
John Wightman

CCRS contributed a great deal to the activities in remote sensing in Nova Scotia. It was a true collaboration. CCRS bent over backwards to plant the seeds, provide the early fertilizer and do the early weeding that led to a healthy and vigorous field of remote sensing in Nova Scotia. It never would have happened without CCRS.[46]

As noted above, the original NSCRS was housed at COGS. The Centre's focus in the early years was on agriculture, forestry and geology working with the local communities ranging from local farmers to larger projects.

One project that had a great deal of local impact was associated with the Annapolis River Tidal Power Project. Plans called for a causeway and turbine complex that would raise the level of the river on the in-coming tide. This was a cause for concern for the local farmers about the potential for salt-water intrusion into the very valuable croplands behind the dikes along the river. The NSRS Centre arranged for a number of colour IR imagery flights by CCRS both before and after the project in the period of the late 1970s/early 1980s. The imagery demonstrated that there were no detrimental effects. This was a case of getting ahead of the potential problem by securing the evidence. The farmers were happy and the Project moved forward with the support of the local community. The NSRS Centre also arranged for weekly colour IR photography flights during the growing season for 3 years through the flying club at the Greenwood Air Force Base. This imagery showed crop development throughout the Annapolis Valley and how it was affected by drainage and possible damage from salt-water intrusion.

One project in the late 1970s looked at the St. George's Batholith in southern New Brunswick where tin and tungsten were being prospected for. The problem of doing geology in this part of the world is tree cover. John Wightman looked for stressed hardwoods and early senescence and did this with Landsat. This approach was similar to that done by John MacMannon (Angus) Moore of the Royal School of Mines in London with whom John worked on tin in Cornwall where he used air photos for fracture analysis. Faulting and fractures or their absence were indicative of tin deposits associated with intrusives. Six or eight targets in NB were identified from Landsat images with the assistance of Tom Alföldi and every one showed intrusion-related mineralization upon field investigation.

3.1.4. The Ontario Centre for Remote Sensing
Bob Ryerson

The Ontario Centre for Remote Sensing (OCRS) is important to discuss and understand in the CCRS context. While it certainly owed CCRS some credit for its establishment, it operated in a far different manner related to industry than did CCRS. In effect, for most of the first two decades of its existence, it competed with industry and thereby helped retard the development of a service industry compared to the situation in both Alberta and Quebec.

The proposal that led to the eventual creation of the Ontario Centre for Remote Sensing (OCRS) was written by a group of academics from the University of Guelph and University of Waterloo. (Collins *et al*, 1972) The 44 page report was submitted to the respective university administrations who were in turn asked to submit it to the Government of Ontario. The importance accorded CCRS can be seen by it being

[45] The details on the activities in Nova Scotia came from an interview conducted by Bob Ryerson with John Wightman on April 9, 2017. John, as Principal at the College of Geographic Sciences (COGS) and the Nova Scotia representative on CACRS, has a unique perspective on the development of Remote Sensing in Canada from Tiros 1 through RADARSAT. John subsequently reviewed the material provided.

[46] Note from Ryerson, the interviewer: CCRS also benefited from the cooperation of Nova Scotia to test sensors, carry out projects with national importance and, of course, COGS was and is a wonderful success story.

described on the first page of the proposal. Reference to CCRS and how various parts of it would relate to the Ontario Centre are sprinkled throughout the document. Interestingly, the proposal called for an organization similar to that of CCRS. The proposal suggested that industry would play a role in carrying out more routine tasks. As it happened this aspect did not come into being for some time: the relationship of OCRS with industry was a lingering problem into the late 1980s and early 1990s.

The proposal outlined the importance of the technology, how the centre should be organized, where it might be located (near the two universities!), number of staff, facilities required, and the role of the universities in its research, development and training. It called for a total of approximately 30 staff with a budget of $1.25M for equipment and $1.26M for the building. Given salaries at the time the staff costs would have been on the order of $250-300K.[47] The total requested budget was on the order of $2.8M – or $16.4M in 2017 dollars. The fact that even a scaled down OCRS was in operation by 1973 was a credit to the persuasive powers of a group of academics, Morley and the quiet but persistent work of Victor Zsilinszky, [48] the founding Director of OCRS. OCRS was located within the Ontario Ministry of Natural Resources (OMNR) in downtown Toronto, and many years later moved to Peterborough Ontario when much of OMNR moved.

Zsilinszky was paraphrased by Hamilton (1978, p.10) as having said “the Ontario Centre functions as a research group on applications. It has a staff of more than 30 and equipment with a replacement value of approximately three quarters of a million dollars. It is conducting a physiographic survey of the James Bay lowlands, it is providing data to the Forest Fire Control Services, it is using Landsat imagery and low altitude photographs to evaluate forest regeneration and it is involved in many other projects. It operates, in part, on a cost-recovery basis, i.e. the funds for its major projects of interest to other provincial departments must be justified by the department concerned before becoming available to the Centre. The Centre gets involved mainly in projects using satellite imagery or in innovative applications of airborne imagery.”

The objectives of the Ontario Centre for Remote Sensing were “to provide a highly specialized service for the collection, processing, interpretation, and development of applications, of remote sensing data, as provided by the airborne program of the Ontario Forest Resources Inventory, by the Centre's own supplementary aerial photographic capability, and by the federal government and the US earth-resources satellite programs. The Centre's purpose is to investigate and implement the practical usefulness of remote sensing data to resource and environmental management and land use planning in the Province of Ontario. This objective is to be achieved primarily through undertaking projects by which to satisfy existing information requirements of managers and developers, through the development of new remote sensing methodologies.” (Zsilinszky quoted in Hamilton, 1978) There were seven sub-objectives:

1. To set priorities on all requests within the province for federally supplied remote sensing data;
2. To provide an overview of the provincial program to ensure that duplication does not occur;
3. To provide advice to government agencies on the effectiveness and suitability of remote sensing applications presently in use while developing and publicizing new applications;
4. To provide as required, specialized equipment as well as specialized interpretation services beyond the existing capabilities of ministries;
5. To evaluate and modify remote sensing hardware to be used in the development of new data gathering and interpretation techniques;
6. To conduct research and training programs in remote sensing data processing and interpretation systems and to maintain liaison with other agencies in Ontario with similar interests; and
7. To maintain a central remote sensing image library.

[47] A year later CCRS hired scientists at $12,500 per year, while the top salaries for CCRS managers was in the vicinity of $20,000.
[48] http://www.oars.on.ca/honorary/zsilinszky.php

“The total budget for at OCRS for fiscal year 1977-78 was $940,000. This included $80,000 for capital equipment. Of this, some $360,000 was "recovered" through projects done for various provincial government departments. Both of these figures include $200,000 for completion of a special project on surficial geology mapping of Northern Ontario; thus the "steady state" budget would be considered as $740,000 for salaries and operating costs.” (Hamilton, 1978, p. C2)

“At the peak of the summer season a total of 31 including seasonal and contract employees have been on staff. The "permanent" staff includes:

- one thermography specialist
- one geotechnical engineer
- one environmental specialist
- two land use capability specialists
- one research officer, engineering
- one research officer, forestry
- four technologists and technicians
- three supervisors
- two secretaries
- three supervisors (one geomorphologist;
- two foresters)
- one director (forester)

Contract and seasonal staff may include foresters, geomorphologists, technicians, draftsmen and summer students.” (Hamilton, 1978, p. C2)

By 1978 OCRS had a digital image analysis system, but the focus was still largely on tools to use photographic imagery as described in the CCRS publication by Alföldi and Ryerson (1973, 1976) OCRS equipment had a total value of $722,000 in 1978 $. See the following Table.

Ontario Centre for Remote Sensing Equipment – 1978[49]

This list of equipment used by OCRS is given here in that it is similar to what CCRS had access to in the early years (1974-75). At CCRS access to sensors and aircraft was through the airborne sensing unit while most of the CCRS equipment used for interpreting or viewing imagery was housed in the Applications Division. Since CCRS was focused on R&D it did not have multiple copies of some equipment and with the Image 100 (See Section 6.8.2.2) CCRS’s image analysis capabilities were superior to what OCRS had at the time.

- 1 ISI-150 Image Analyzer ($100,000)
- 2 Zoom Transferscopes ($10,000)
- 2 Zoom Stereoscopes ($24,000)
- 25 Mirror Stereoscopes ($25,000)
- 8 Light tables ($5,000)
- 1 Electronic planimeter ($4,000)
- 1 Densitometer ($3,000)
- 2 Refrigerators ($2,000)
- 2 Freezers ($2,000)
- 2 Vinten camera systems ($9,000)
- 5 Aerial camera mounts ($5,000)
- 1 Aerial exposure meter ($4,000)
- Minicomputer ($110,000)
- *2 Tape recorders ($3,000)
- *1 Audio visual system ($12,000)
- *1 Stereo projector system ($6,000)
- 2 AGA Thermovision 750 ($80,000)
- 4 Prob-eye thermo systems ($32,000)
- 2 Vehicles ($13,000}
- 2 Enlargers ($22,000)
- 1 Black & white printer ($10,000}
- 1 Aztec D aircraft (on lease - value $55,000)
- 1 Norpak RGP 3050 Digital Image Analysis System with PDP 11/34
- 1 Wild A-9 Stereo-Plotter with digitizer ($80,000)
- 1 Foliage penetrating Radar Altimeter ($30,000)
- 4 Nikkormat cameras & accessories ($5,000)
- 6 Nikon motorized camera systems ($25,000)
- 5 Hasselblad camera systems & magazines ($30,000)
- 1 Muirhead weather satellite imagery receiver ($16,000)

[49] Source: Hamilton, 1978. p C3

Through the 1980s the staff levels at the OCRS remained relatively constant at about thirty employees, as shown in a staff photo circa 1988. The key scientists were Dr. Simsek Pala, Dr. Vern Singhroy, and Andrew Jano.

Over the years a growing number of complaints were made that OCRS was competing with industry and, in effect, limiting investment by industry in the field. One comment made by a prospective investor was "why would I invest in buying a Dipix system when OCRS is using my tax dollars to pay for subsidized offices, subsidized staff and subsidized equipment to compete with me?"[50] In the mid-late 1980s Dr. Leo Sayn-Wittgenstein who was then President of Dendron Resource Surveys (and later became DG of CCRS) is credited with convincing the Government of Ontario to reduce OCRS's role in cost recovery projects. Shortly after this change in policy Geomatics International, located in Burlington Ontario, saw dramatic growth, which some credited to this change in government policy. At the same time Dr. Pala left OCRS to start his own successful mapping company. A small group still exists at the facility in Peterborough under the leadership of Frank Kenney.

3.1.5. Alberta Center for Remote Sensing[51]
Bob Ryerson

The Alberta Center for Remote Sensing developed under the Leadership of Cal D Bricker, a veteran of World War 2. The objective or role of the Alberta Remote Sensing Centre was as "an autonomous remote sensing center within the Canadian remote sensing program…to administer, coordinate and develop remote sensing in Alberta. It has four major activities:[52]

1. It assists all provincial users in the acquisition, application and analysis of remotely sensed data for the survey and management of Alberta's natural resources;
2. The Center's facilities are available free of charge to Albertans – provincial government, federal government, educational institutions, private industry and interested private citizens;
3. The Center deals with all aspects of remote sensing except conventional aerial photography. This includes both Landsat and airborne multiband applications. The interpretation facilities are, of course, available to users of aerial photography; and
4. The Center does not carry out research projects, but assists those who do. The staff are not "experts" in the multidisciplinary fields and uses of remote sensing. But, as they work closely with so many remote sensing agencies and persons throughout North America they can come up with most answers or make referrals to those with the answers. This centralization and coordination concept has proven advantageous." (Bricker cited in Hamilton, 1978)

The Alberta Center saw its role as a supporting organization with fewer staff, less equipment, and far lower budgets than Ontario. In that respect it was closer to the size of the Manitoba Centre, albeit with a clear policy of non-competition with industry. The 1978 operating budget was $136,000 for a total of four staff – three technical and one support staff. It began with the standard types of equipment then being used with the photographic products from ERTS/Landsat since digital data were not routinely available until the mid-1970s. The major pieces of equipment used are similar to what was used in both CCRS and OCRS, but at the outset without digital analysis capability. A list of the equipment, along with descriptions provided by ACRS, is given in the following table. The descriptions are believed to be useful to describe the equipment that CCRS had early on.

[50] The investor made these comments in the presence of the Editor. He never did buy the system and in the 1990s became an executive in a company in western Canada.
[51] Cal Bricker, the founding Director of the Alberta Center for Remote Sensing was adamant that the US spelling of Center be used and this is how the word is spelled in all materials provided from ACRS sources.
[52] Today there are remote sensing activities in several agencies of the Government of Alberta but there no longer appears to be a specific Center for Remote Sensing.

Descriptions of Equipment Used at the Alberta Center for Remote Sensing in 1978
Microdensitometer: Spatial Data Systems Hodel 703-32. A 32 color density slicer. A transparency (preferred) or paper print is viewed by a television camera, the various grey tones and brightness levels are converted to colors and displayed on a color screen. A control panel adjusts the color display to allow any part of the grey scale to be analyzed in greater detail. A digital readout indicates the area of any color or combinations of colors as a percentage of the total picture area. The color display can at any time be instantly recorded in color by using the Center's Polaroid and 35 mm copy cameras. Users are required to supply their own 35 mm and Polaroid color film rolls if the copy cameras are used.
Multispectral Viewer: International Imaging System I^2S Mini-Addcol Multispectral Viewer - Model 6040PT. A viewer/projector/recorder/tracer multispectral additive system that displays an enlargement of the original image on an inclined screen for analysis, photographic recording and drawing image detail on tracing materials. Up to four 70 mm Landsat or airborne multiband or multi-date transparencies may be viewed, color coded, and recorded singly or in combinations as 6.7X color paper prints. The viewer has a projection magnification capability of up to 20X for viewing on a separate screen.
Interpretoscope: Zeiss/Jena Interpretoscope. A versatile 15X zoom stereoscopic analysis unit with facilities for scanning, height finding and scale correction between images. Two interpreters can simultaneously and cooperatively analyze stereo pairs or film strips in either paper or transparency form.
Transferscope: Bausch and Lomb Zoom Transferscope Model ZT4. A binocular optical transfer unit for transferring imagery data onto a map, imagery or other data base. Most combinations of smaller or larger imagery scale to data base scale can be rapidly and accurately matched by the unit's 14X zoom capability and selection of .75X, lX, 2X and 4X lenses. with a maximum image to data base ratio of 7:1.
Four Film Light Table: Richards Direct Viewing Light Table. A versatile four film model. Displays in parallel position for comparative viewing imagery simultaneously acquired in different wavebands and film types. Accommodates four rolls or individual frames in all processed forms.
High Power Stereoscope - Light Table Combination: Bausch and Lomb 240 Zoom Stereoscope and Richards MIM System #2. A direct viewing light table for simultaneously viewing film rolls or individual frames in all processed forms. An attached Bausch and Lomb spotting stereoscope provides continuous variable magnification in stereo and mono to allow small scale imagery to be analyzed at very large magnification. **Stereoscopes:** Mirror and lens stereoscopes with height finding attachments for basic analysis.
Electronic Planimeter: Numonics Graphics Calculator Nadel 253-116. An electronic planimeter for accurately measuring areas from any type of graphic display (aerial images, maps; plans or similar material) at various scales with readouts in user-required measurement units.
Landsat Imagery Viewer: A 32X enlargement viewer to assess Lnndsat imagery from ISISFICHE (microfiche) received from the Prince Albert Satellite Station a few days after each orbital pass over Canada.
Data Terminals: An on-line terminal to the Canada Centre for Remote Sensing's Technical Information Library allows requestors to expeditiously, and at no cost, obtain technical documents on remote sensing and data on Landsat scenes of Canada to users specific requirements. A video computer terminal tied into the Canada Geographic Information System (CGIS) at Environment Canada in Ottawa. The CGIS is based primarily on Canada Land Inventory (CLI) map data, and can compare and plot selected CI.I variables and values (forestry, recreation, agriculture, etc.) in a graphic map format.
Source: Appendix B, Hamilton, 1978

The Alberta Center used similar equipment to that shown above that was in use at CCRS in the 1973-74 period and includes (left to right) a colour additive viewer (Multispectral Viewer), density slicer and zoom transferscope.

It is interesting to note by way of comparison to Ontario that by this time there were at least two active and successful firms engaged in remote sensing in Alberta. These were Intera (See Section 3.3.3) and F.G. Bercha and Associates (See Section 3.3.4.5), with several more firms on the horizon – including Horizon Remote Sensing founded by Richard Gorecki. In Ontario a fledgling remote sensing industry had been established in Ottawa around CCRS, while in Southern Ontario in the area more influenced by OCRS there was almost no industry activity in remote sensing in the 1970s and early 1980s.

3.1.6. The Applications Division Relations with the Provinces
Frank Ahern

From the very beginning of the CCRS Applications Division projects were undertaken with resource managers in the provinces, primarily through the Applications Development Section. Early work on crop area estimation in New Brunswick (King *et al*, 1977; Mosher and Ryerson, 1977; Ryerson *et al*, 1979) and soil management in Prince Edward Island (Ryerson *et al*, 1979) were just the beginning.

By the early 1980s, CCRS had forged close working relationships with several provinces through its Technology Transfer program (see the following Subsection). In addition, the work of the Applications Division (AD) continued to incorporate more and more projects where provincial liaison and cooperation were an integral part of AD projects. This was a result, in large measure, by the insistence of Lee Godby, who chaired the Project Selection and Review Committee (PSRC) discussed in Section 2.3.4.3. Even the research scientists in the Methodology Section were expected to include “end users” in their projects.

The engagement of Methodology scientists with the end-user resource managers was a new development, as previously the Applications Development Section was the group expected to deal with end users, while the Methodology Scientists remained at “home” solving research problems. The advent of the mobile spectrometry lab in 1978 saw collaboration with Agriculture Canada in Ottawa in 1978 during its initial shakedown deployment and then in 1979 during a summer-long deployment to a typical large-field area near Melfort, Saskatchewan for the study of row crops. (Brown and Ahern, 1980; Brown *et al*. 1980; and Ahern *et al.*, 1980) A second summer-long deployment in 1980 to Alberta, to study rangeland, brought in the rangeland management group in the Alberta Government under S.G. “Bud” Klumph, as well as the Alberta Center for Remote Sensing. This degree of provincial involvement greatly magnified the effectiveness of our efforts. The research efforts became much better focused on actual user needs than they would have otherwise. And any subsequent transfer of successful results became much easier.

The 1979 effort in Saskatchewan demonstrated the great advantages the Thematic Mapper sensor, in development at the time, would bring to the problem of crop mapping. The 1980 effort in Alberta yielded immediate benefits by showing how Landsat MSS data could be used to classify range condition into four classes: poor, fair, good, and excellent. It also provided excellent understanding of the underlying interaction of sunlight in the various spectral bands with the grasses, forbs, and other plants that make up the range ecosystem and respond to grazing pressure in different ways. We even learned why, from the perspective of a cow, the grass IS always greener on the other side of the fence! (Thomson *et al*. 1980; Ahern *et al.*, 1981; and Thomson *et al*., 1983)

The close interaction with provincial resource management agencies continued to increase in the early 1980s, as the research and development efforts were organized under six disciplines including agriculture, forestry, hydrology, geology, ice and environment. Each of the discipline efforts were led by an experienced and capable scientist with good leadership skills: Ron Brown for agriculture, Frank Ahern for forestry, Terry Pultz for hydrology, Vern Singhroy for geology, Mike Manore for ice, and Ko Fung for Environment.

In forestry an ambitious program led by Ahern and supported by two to three research assistants explored many potential applications of optical data from several sensors. In each case, provincial forest management agencies were intimately involved in the planning, evaluation, and subsequent technology transfer of successful results.

Much of the work in British Columbia was done with the Forest Inventory Branch under the leadership of Frank Hegyi. Hegyi also worked closely with David Goodenough, Head of Methodology in Hegyi's attempt to bring down costs through the use of satellite data as described in Sayn-Wittgenstein *et al*, 1999. Goodenough left CCRS to join the Pacific Forest Research Centre, another part of Natural Resources Canada.

As explained elsewhere the beginning of the 1990s brought a major shift in emphasis from optical sensors to radar. The primary reason for that shift was anticipation of the launch of RADARSAT-1 aided by substantial funding through CSA.[53] As a commercial enterprise, RADARSAT-1 was supposed to make money through its commercial distributer RADARSAT International (RSI). As the name implies, there was emphasis on international sales, because the federal government and the provinces were entitled to large data allocations with no profit for RSI. At the same time, the remote sensing applications for forestry were becoming routine using data from the TM sensor, while research with the MEIS sensor was phased out when attempts to commercialize the technology did not succeed.

3.1.7. Technology Enhancement Program
Bob Ryerson[54]

3.1.7.1. Background and Introduction
The Technology Enhancement Program was originally a child of the Applications Development Section under the leadership of Dr. Josef Cihlar. The concept first arose in 1979 as part of a Landsat D submission under the Interdepartmental Committee on Space (ICS). In 1980 Cihlar *et al* produced a proposal for a "Remote Sensing Technology Transfer Program" that formed the basis of a stand-alone element of the ICS submission. The proposal was subsequently funded but under the name Technology Enhancement Program (TEP). In the end it was found that calling it the Technology Transfer Program was not allowed because there were restrictions on the Government of Canada transferring technology to provincial and territorial governments. The TEP's focus was on the provinces and territories – other programs of CCRS dealt with developing capacity in industry. (See Section 3.3 and especially section 3.3.2, Approaches to Technology Transfer and Building an Industry.) As is further explained in Section 3.2, transferring technology to academe was never an objective of CCRS, although CCRS did see a need for training materials that could be used in academe.

"The objective of the TEP is to improve the management of provincial and territorial natural resources through remote sensing technology. This is done by: (i) demonstrating the usefulness of remote sensing techniques as tools in resource management and (ii) establishing facilities and mechanisms which will permit resource managers to employ remote sensing in natural resource management on a continuing

[53] Author's recollection was that we got about $5M/year for 15 years.
[54] This section draws heavily on a paper by Doug Heyland (1986). Doug, an early proponent of remote sensing in the wildlife area, was the manager of the TEP and Helmut Epp (1989) was one of the scientists/advisors who worked on the program. Both subsequently were employed by the Government of Northwest Territories, a client of the TEP. Epp later represented the Government of Northwest Territories on several federal-provincial-territorial committees dealing with geographic data.

basis." (Heyland, 1986) Federal government agencies were the developers while the provincial and territorial agencies were seen as the adopters of remote sensing technology. Again, the concept was based on the premise that the value of remote sensing data is realized only through the data's use.

The program began in November 1982 with four person years and a mandate to "take technology to the user." (Heyland, 1986)

3.1.7.2. The Technology Enhancement Program Process: How It Worked

An agreement with a specific province or territory was based on a Memorandum of Understanding (MOU) between CCRS and an agency of the territory or province. In effect both CCRS and the agency would commit to "best efforts." There was no legally binding agreement on who would do what, although before an MOU was signed, a number of what appeared to be practical and workable projects were identified between CCRS and the agency.

Unlike the work done in the Applications Development Section of CCRS, research was not part of the TEP's activity. For this reason there are few publications on the TEP, especially on the latter programs in Newfoundland and Northwest Territories. This has long been one of the inherent difficulties in furthering the spread of applications: those using the technology operationally were seldom very interested in writing papers describing how it was used.

The TEP focused on conducting projects using previously proven remote sensing technology to solve specific problems of interest to the province or territory. Often these had been demonstrated with other users in the Applications Development Section or by another provincial agency in another province. The programs would typically last two years during which period CCRS would place a full-time remote sensing specialist within the province. In some cases equipment might be loaned to the host agency.

The first TEP MOUs were signed in Manitoba (1982), the Maritimes (1983), and Saskatchewan (1985). Others were later signed in Newfoundland and, by 1988, field work was being done under a TEP project to detect and classify Muskox habitat using Landsat Thematic Mapper data on Banks Island in the Northwest Territories. (Ferguson, 1991) Helmut Epp, who was the TEP employee on the ground in Saskatchewan, took on the responsibility as the CCRS specialist for the TEP in the Northwest Territories and eventually joined the government of the Northwest Territories. The TEP activity there has since morphed into a Centre for Geomatics.[55] Other's employed in the TEP in the provinces and territories included Christine Hutton, Tim Perrott, and Larry Horn.

3.1.7.3. The Technology Enhancement Program: Some Results

The TEP was assessed on whether or not there was sustained growth in the use of remote sensing after the CCRS TEP staff left. Growth was measured on the basis of follow-on projects in the province or region, acquisition of additional equipment, training courses, private sector activity and data purchases.

Manitoba was an interesting case inasmuch as it had already established the Manitoba Centre for Remote Sensing. In this case the TEP was seen to have enhanced its capabilities. (Heyland, 1986) The Manitoba Centre purchased a digital image analysis system, and a better map output device before the TEP was completed. A further measure of success was that an additional remote sensing specialist was hired by another government department. Thirty projects were undertaken by the MRSC after the TEP concluded between 1984 and 1986, including work for federal agencies and the private sector.

In the Maritimes the Maritime Resource Management Services (MRMS) purchased an image analysis system for its facility in Amherst, Nova Scotia a year before the TEP was completed. It was noted in the review by Heyland (1986) that the province of Nova Scotia was using remote sensing for geological mapping and gave MRMS a sizable contract for analysis services and was also mapping forest clear-cuts.

[55] See http://www.nwtwaterstewardship.ca/sites/default/files/NWT%20Centre%20for%20Geomatics.pdf accessed December 19, 2017.

In New Brunswick the province was also using remote sensing for forestry and geology, while New Brunswick Hydro was conducting studies using Landsat. Prince Edward Island was conducting studies on soil moisture for potatoes as well as forestry-related studies. In the private sector Trainor Surveys had contracts to map snow cover related to the St. John River flood forecast.

In Saskatchewan the program hosted by the Saskatchewan Research Council (SRC) started just a year before Heyland's 1986 review and yet one project was completed and two others were in the final report stage. In the first year some 69 people received training in digital image analysis and there were 11 specialized workshops attended by 250 people as well as two university short courses. In addition to TEP projects, the SRC had already completed several contracts and were seeking additional contracts.

In Newfoundland Heyland (1986) reported that although an MOU had not yet been signed, work to identify a portfolio of projects was well underway by the re-assigned TEP specialist who had worked with the MRMS. NORDCO, in collaboration with the Government of Newfoundland and Labrador, was reported to have already bought an image analysis system.

The next program was projected to be in Northwest Territories and this did occur.

3.1.7.4. Conclusions on the TEP

There is no doubt that the TEP resulted in increased awareness and use of remote sensing in provincial and territorial governments as it was meant to do. Capacity was built and many contracts were let to the TEP partner organizations. At the time there was some tension between the TEP and those (like this author) engaged in the development of industry. It was argued that while the TEP did indeed develop capacity in provincial agencies it also sometimes led these same provincial agencies to compete in the market with private sector companies. It was argued that this competition largely stifled private sector growth in the areas where it operated. This tension was never fully resolved before the TEP came to an end in the early 1990s.

3.2. Academe

Bob Ryerson[56]

3.2.1. Introduction

Academe and education activities in remote sensing in Canada pre-dated the formation of CCRS, as can be seen from the activities noted above by Harky Cameron, the Interuniversity Course in Integrated Aerial Survey described below, and work by Dr. John Parry at McGill, Dr. Dieter Steiner at Waterloo and others.

While education and academe certainly got a "shot in the arm" with the founding of CCRS, for a number of reasons that "shot in the arm" did not translate into a dramatic increase in funding or close R&D relationships between CCRS and academe, especially in the early years. What happened is explained in the next Subsection. The following sections briefly mention some of the first academic and research programs in academe that had at least some ties to CCRS, followed by a discussion of the increasingly important programs introduced at the college level, finishing with a section on the limited activities eventually carried out by CCRS with an academic focus.

3.2.2. University Activities in Remote Sensing and CCRS

3.2.2.1. Setting the Stage…for Limited Future Interactions with Academe

CCRS provided a certain degree of legitimacy to the upstart field, as well as data, support, and, in some cases guest lecturers. However, the early strong relationship with academe soon met a wall.

At the suggestion of Morley, Dr. Dieter Steiner of the University of Waterloo led a group of academics in developing a concept for a national remote sensing training institute. The idea was that this institute would serve as a major international training centre for the field, attracting students from around the

[56] Except where otherwise stated, this section was written by Bob Ryerson

world and, at the same time, showcase Canadian expertise. The idea was that these international students would both help support the growth of this institute with their fees, and serve as an entrée into international markets when they returned home. The RESORS library (see Section 6.2) was conceived based on some of the same principles – to put Canadian remote sensing on the world map.

The concept document suggested that the institute would be based at Waterloo and include faculty from University of Guelph, McMaster and University of Toronto. The same universities that cooperated in the inter-university course described in the next section, as well as in the concept document to found an Ontario Centre for Remote Sensing. Several of the PhD students at the time, including Ryerson and Howard Turner at Waterloo, were identified as potential junior faculty members.

What happened next is somewhat unclear. What we heard at Waterloo was that one or two provinces complained that under the British North America Act education was a provincial responsibility and CCRS had no business meddling in an area of provincial jurisdiction and thus CCRS got a proverbial slap on the constitutional wrist. While rumours suggested where the complaints came from, nothing was ever officially said and the concept was allowed to die. A great opportunity for Canada died along with the concept. Interestingly enough the Netherlands' International Training Centre did add a strong program in remote sensing to its surveying and mapping programs and became what Morley has envisioned – a key player in technology transfer, training and education of over ten thousand mapping, GIS and remote sensing specialists from both developed and (especially) developing countries. Ironically some years later CCRS hired Helmut Epp, a graduate of the ITC, to work on technology transfer activities.

This provincial reaction to the international training institute seems to have had a long-lasting impact on the relations CCRS had with academe. When the Applications Division was begun in 1973 scientists were encouraged to avoid any but necessary contact with academe: the BNA Act was given as the reason. With the exception of work with York University's Dr. Alan Carswell on lasers (which led to the creation of the successful company Optech), there was little interaction in R&D with academics across the country. While academics were occasionally welcomed as visiting scientists (e.g. Dr. Phil Howarth then of McMaster), this was more the exception than the rule. CCRS scientists were, however, often involved in teaching university courses and advising or evaluating theses. In the 1970s and early 1980s CCRS scientists were involved with teaching, thesis evaluations and/or program evaluations at a number of universities in Canada, the US, Australia, India and China including McGill, Carleton, Ottawa U, UQUAM, Sherbrooke, UNB, Calgary, Cornell, RMIT, JNTU and Peking University. In the early years the only place where academics and CCRS seemed to usefully interact on a regular basis was at CACRS.

3.2.2.2. Undergraduate Students
Tom Lukowski

There was one important area where CCRS did interact with universities and that was in hiring student employees to assist in the work of CCRS. These students, often from university cooperative education programs, provided support in various ways including assisting with fieldwork, processing of data, development of algorithms and writing computer code. While fulfilling a need at CCRS, this was also an opportunity to assist in their professional development. This employment provided practical experience in scientific and engineering work and exposure to the opportunities for such a career including positions in government laboratories. It has always been a pleasure to hear of students who have passed through CCRS and it has been gratifying to know of those who continued with careers in science and engineering. In a number of cases this has included the pursuit of higher levels of education. Some of these students have become members of the remote sensing community and have gone on to leadership roles and success in industry, government and academe.

3.2.2.3. Interuniversity Course on Integrated Aerial Surveys
Bob Ryerson

The Interuniversity Course on Integrated Aerial Surveys has been called one of Canada's first remote sensing courses and was certainly the first inter-university course in the field. It was a child of the work done on the aforementioned remote sensing training institute. It was started by a group of faculty members at four southern Ontario universities. The eclectic topics covered in the course were tightly tied to the interests of the faculty members involved. Dieter Steiner of Waterloo focused on digital image analysis and automated cartography. Stan Collins of Guelph was interested in image geometry, orthophotography and its uses while Dr. Jerry Vlcek of the University of Toronto focused on thermal imagery and forestry. Dr. Phil Howarth, then at McMaster (he later joined Waterloo) was interested in geomorphology, photogrammetry and visual image interpretation. Others also contributed, including Dr. Andrej Kesik and David Erb of Waterloo. Several of those who took the course were later hired as scientists at CCRS (Alföldi, Bruce, and Ryerson) while others made their mark in industry (Mike Kirby), academe (Howard Turner at Ohio), and US Government (John Crawford at NASA's Jet Propulsion Lab). Keith Thomson, later a scientist and Section Head at CCRS and faculty member at Laval, was a guest lecturer. The course ran for several years and ended when Steiner returned to his native Switzerland in 1975.

3.2.2.4. University Activities
Bob Ryerson

As noted above, before CCRS was operating, there were a number of faculty members across Canada doing what was then called, or would have been called, remote sensing. In the following table we list some of those along with their relationship to CCRS. The list is not intended to be exhaustive, but it does give a sense that there was some academic activity already producing the staff needed to grow CCRS applications and the use of remote sensing in Canada. The table is heavily weighed to applications, reflecting the background of the author.

Academics Involved in Remote Sensing or Related Fields Before CCRS Applications Work Began
Bob Ryerson

Faculty Member	Academic Institution	Area of Research/Connection to CCRS
Harky Cameron	Acadia	Geology using U2 imagery; colleague/friend of Morley
John Parry	McGill	Radar applications; US DoD support; on CACRS WG
Stan Collins	U of Guelph	Orthophotography technology and uses: advisor to Morley
Dieter Steiner	U of Waterloo	Digital Image analysis; advisor to Morley.
Phil Howarth	McMaster (later U of Waterloo)	Geomorphology, photogrammetry; on CACRS WG, sabbatical at CCRS, worked on COSPAR publication with CCRS
Richard Protz	U of Guelph	Soil mapping; on CACRS WG
Allan Carswell	York University	Developed laser sensors, worked with Sensor Section at CCRS
John Munday	U of Toronto	Water quality – worked with Alföldi at CCRS
Jerry Vlcek	U of Toronto	Heat sensing, video
Andrej Kesik	U of Waterloo	Geomorphology
Dave Erb	U of Waterloo	Air photo interpretation
Harold Wood	McMaster	Photo interpretation keys, agriculture.
Eugene Derenyi	UNB	Geometry of imagery

The first six individuals listed are judged to have had a significant impact on CCRS, primarily through providing advice to Morley or CCRS in the early years. Carswell developed lasers, worked closely with the CCRS Sensor Section and went on to found Optech – an early success story in Canadian remote sensing. Munday worked with Alföldi on chromaticity research. The last five had limited ties to CCRS, but taught many students who went on to leadership positions in the field.

Following the creation of CCRS there was an upsurge in academic activity in Canada in the nascent field of remote sensing. The first PhD granted in Canada with a specialization in remote sensing applications was in 1975 to Ryerson. The first Canadian to have earned a PhD in the field was the late Dr. Peter Murtha who earned his PhD at Cornell a year or two before. Murtha began his career in the Forest

Management Institute and later joined UBC where he began a long and distinguished career. Others who were active early included Dr. Eugene Derenyi of UNB, who did significant work on the geometry of imagery. The late Dr. Ferdinand Bonn came to lead a large and active remote sensing program at the University of Sherbrooke which trained many of the French speaking experts in the field. Bonn was active in CACRS and the national remote sensing program. The late Robert Gauthier of the University of Quebec at Montreal (UQUAM) was active in CACRS. A number of other Quebec academics were active, but tended not to be engaged with CCRS at the outset. That was to change as CCRS became a more comfortable workplace for Francophones. In Ontario Dr. Ellsworth LeDrew joined the University of Waterloo where he worked with Phil Howarth to create what was widely regarded as the top remote sensing academic program in English Canada. LeDrew was active in CACRS and was involved in Josef Cihlar's work in remote sensing and climate change. In 1995 LeDrew published a book on this and related work. Dr. John Miller of York University was an early pioneer in hyperspectral remote sensing and was associated with the Centre for Research in Earth and Space Science (CRESS) at York University. In western Canada Dr. Peter Crown developed a program focusing on agricultural remote sensing at the University of Alberta. Like LeDrew he published a number of papers with CCRS scientists and was active in CACRS.

The Founding of the Canadian Space Agency and l'Université de Sherbrooke
Bob Ryerson

In the early 1990s as the newly formed Canadian Space Agency (CSA) was to be located on the south shore of the St. Lawrence south of Montreal, a meeting was called by another CCRS – the Chambre de commerce de la Rive-Sud (now the Chambre de commerce et d'industrie de la Rive-Sud) to learn of the potential importance of the CSA to the region. A number of management level federal bureaucrats in the space sector from Ottawa were designated to speak to the group of some 200 people. Virtually all of the speakers were Anglophones and as I recall almost all gave the majority of their presentations in English. I decided that to do so would be insulting to a largely French audience so I elected to speak in French.

By that time the Université de Sherbrooke had developed an exceptionally strong remote sensing program – likely the strongest academic program in the country. Of course I began my presentation (in French) talking about the "two CCRS" organizations. I spoke of what "my" CCRS did, the value of remote sensing, and I then said (again, in my less than perfect French) that as a graduate of Waterloo it grieved me to say that not far from the new location of the space agency was the Université de Sherbrooke which I personally regarded as having the best university remote sensing program in Canada, if not the world. After I said this, a gentleman in the front row stood up, and with his back to me faced the rest of those present with his hands clasped over his head, looked around at the crowd and then bowed to the crowd as if he had just won the heavy weight boxing championship. The crowd cheered and I was aghast! I was very embarrassed and wondered what I had said in my "less than perfect French." It turned out it was nothing I had said…the gentleman happened to the Vice President of Advancement and External Relations of the Université de Sherbrooke and he was simply responding to my comment in a humorous and exuberant fashion. When that was explained, and my concern explained, it resulted in a lot of good-natured bantering. Once again I was made to feel welcome in Quebec by my Quebec colleagues as I have been for over fifty years - from Expo 67 to the 2017 Canadian Symposium on Remote Sensing!

A number of other well-known individuals were graduate students, both under those named above and others, went on to distinguished careers, many of which involved working to some degree with CCRS. Usually CCRS provided imagery and access to RESORS. Perhaps the best known of these is Dr. Steven Franklin who became President of Trent University. He was an early client for Landsat data when he was at Memorial University and then Calgary.

To describe how the field has grown, in 2011 Franklin stated that he had determined that his just-finishing PhD student would be the 100th PhD granted in remote sensing in Canada…an average of almost three a year since 1975. A significant number of these PhD graduates have had ties to CCRS and its scientists – and a number became scientists at CCRS, other agencies or academic institutions across Canada. These include Monique Bernier (INRS, Quebec City), Lynn Moorman (Mount Royal University), Heather McNairn (first at CCRS and then Agriculture and Agrifood Canada), and Elizabeth Simms-Lambert (Memorial University). The last three mentioned in the previous sentence all worked at CCRS as employees or contractors before earning their PhDs. Other PhDs who have made a mark include Olaf Niemann (U of Victoria), Ron Hall and Mike Wulder (both at the Canadian Forestry Service), Derek Peddle (U of Lethbridge), Paul Treitz (Queens), Dave Barber (Manitoba), Joe Piwowar (Regina), Jin-fei Wang (Western), Margaret Kalacska (McGill), and many others. Some have found their way into universities elsewhere (e.g. Peng Gong at Berkeley) or industry (Kevin Lim). To show how academe has grown, by 2017 eight PhD theses were nominated for the Canadian Remote Sensing Society's Award for best PhD thesis of the year.

While CCRS cannot claim responsibility for all of these successes, it certainly played a supporting role in the development of a strong academic base in Canada. Today virtually every university in Canada has some activity and teaching in remote sensing.

3.2.3. Colleges

3.2.3.1. Introduction

Bob Ryerson

Early on colleges became a major player in GIS and remote sensing education and training. The first one involved in any depth was the College of Geographic Sciences described in the next section. At the outset the colleges offered two streams of study. One was a two year program for graduates of high school who were seeking technical positions. The second stream, and soon the dominant one, accepted and trained students who already had degrees in a one or (more often) two year program. These post-graduate diploma programs in remote sensing and GIS tend to produce students who were older, more experienced, and ready to immediately contribute in the work environment.

To meet the need for technical staff a number of other remote sensing/GIS programs developed at the college level across Canada in the early years of CCRS. While CCRS may have helped foster the interest in such programs, with the exception of linkages to the early COGS and with its emphasis on research, CCRS had few if any ties to any of the college programs. Other than COGS the best known college programs were at Fleming College[57] (formerly Sir Sanford Fleming), Northern Alberta Institute of Technology (NAIT) in Edmonton, Southern Alberta Institute of Technology (SAIT) in Calgary, the BC Institute of Technology, and BC's Selkirk College. In recent years most colleges have come to offer some training in remote sensing and GIS.

Over the years many of the College programs have developed ties to universities allowing students to seamlessly move from the college experience to the university experience, or vice versa. Some have joint programs that allow students to pursue a post-graduate degree that is less research focused and more practical in nature.

3.2.3.2. College of Geographic Sciences (COGS)

John Wightman

COGS got its start under John Wightman who had worked under Harky Cameron at Acadia. COGS was at the early leading edge of the conversion from analogue to digital. It was likely the first college program to have a DIPIX system and the associated specialized training that was then possible with such equipment. The program got technical advice and personnel from CCRS at the outset. For example, Ernie McLaren was a great teacher of aerial photography interpretation and acquisition and he, of course, came from CCRS. Dr. Vern Singhroy was an instructor in the program and later became a valuable member of the CCRS team. Tom Alföldi of CCRS was also on site every few months and others also contributed.

[57] The author of this section served as a visiting faculty member at COGS and more recently has been an advisor to the Fleming College GIS program.

COGS developed a number of international relationships with the ITC in the Netherlands and the Asian Institute of technology in Bangkok. Students came from around the world supported by CIDA (with the assistance of Randy Trenholm). A key component of the training programs at COGS was the parallel development of the first dedicated training program in Geographic Information Systems (GIS) at the suggestion of Dr. Roger F. Tomlinson and implemented under the leadership of Dr. Bob Maher. The in-house ability for students to extract information from digital remotely sensed imagery and then incorporate that information into a natural resources management system gave the students insights and tools that greatly enhanced their future careers. COGS also housed the initial Nova Scotia Remote Sensing Centre for the province.

COGS became the beacon that others tried to emulate. More recently COGS has entered a new phase with an active research program in LiDAR, among other areas under the scientific leadership of Dr. Tim Webster. COGS graduates are found across Canada and around the world in positions that range from technical to senior executive.[58]

3.2.4. CCRS Activities in Support of Education
Bob Ryerson

3.2.4.1. Introduction
To CCRS, supporting "education" meant more than supporting academe: it also meant educating potential users. There were two types of activities by CCRS in support of education: those that were intended to support education in the broadest sense and those that were byproducts of other on-going CCRS activities. These can be separated from activities and products meant to market remote sensing – an activity that had a different intent, as is discussed in Section 6.2. Section 3.2.4.2 identifies some of the outputs of other CCRS activities that found their way into both the user and education community. Section 3.2.4.3 provides a concise summary of some of the education focused activities undertaken by CCRS.

3.2.4.2. Supporting and Educating Users: Byproducts of Other CCRS Activities
A fundamental characteristic of CCRS in the early years was that almost everything it did was done with an eye to serving multiple purposes. This was, of course, a natural byproduct of the philosophy of doing more with less – which can also be expressed as meeting multiple objectives with the same output. While delivering remote sensing products and research and development of remote sensing applications and technology were the central foci, it was realized that if the technology was not used and if benefits did not result, the program would wither and die. As a result, as mentioned previously, many of its activities had a secondary focus on the users or potential users of the technology. Here we list but a few of the "other" activities whose byproducts had an impact on users or potential users. Most are discussed elsewhere in this document.

RESORS: Access to the searchable remote sensing library data base RESORS was widely used by the Canadian academic community including faculty and graduate students. (See Section 6.3) RESORS saved time in searching for materials, and ensured that Canadian academics' work was given international exposure and that they did not miss relevant work from outside the country. Eventually RESORS added a slide collection of some 5000 35 mm slides documenting hardware, applications, sample imagery, and the like. These too were made available to those who might make use of them, including academe.

Availability of satellite imagery: Sample imagery, often with interpretations and explanatory notes, was made available for the cost of reproduction for academe, including colleges. This material was widely used by academics for teaching purposes and led to a greatly expanded pool of potential users of satellite data – the intention of the program. Safeguards were put in place to ensure that this subsidized imagery was not used for commercial purposes, a concern of industry worried about competing with academics for commercial work, and later a concern of the industry selling Landsat data.

[58] One COGS graduate and former employee of Intera has even ended up as a Member of the Legislative Assembly in Nova Scotia!

Airborne imagery and reports: Every project carried out by the CCRS Airborne Program for a user (See Section 6.5) required that a report be prepared to document what the project objectives were, what data were acquired, the results, and in general terms the benefits of doing the work. The reports also contained the flight parameters, flight maps and the means of accessing the imagery. These reports, often used by academics for teaching purposes and/or research, formed an invaluable resource housed at the airborne facility.[59] The reports detailed the uses (both successful and unsuccessful) of the airborne data ranging from high altitude photographic imagery in colour and colour IR to LiDAR, radar and thermal sensing. In many cases the airborne data were obtained over an area of interest to a government agency while imagery over the same area was obtained directly by academics to support research by faculty and graduate students. One example of this dual use of data acquired at the same time for both academe and government is from the oil sands of Alberta. Data were obtained for a graduate student (Aronoff, 1978) as well as for the Alberta Oil Sands Environmental Research Program. (Thompson *et al*, 1978) The Thompson *et al* 1978 report formed the basis for environmental studies of the area for some years into the future. The imagery acquired for Aronoff was subsequently used in class sets for senior courses in remote sensing at the University of Calgary, Carleton University and perhaps others.

Slide Sets from Application Projects: By the early-mid 1980s when J-C Henein became Director of the Applications Division, Applications Division scientists were required to prepare slide sets documenting their projects. These sets were then added to the RESORS data base and were widely used in academe and in training materials developed by the Training Section[60] headed by the late Bill Bruce.

3.2.4.3. Education Focused Activities of CCRS

Carolyn Goodfellow

3.2.4.3.1. Introduction

As noted elsewhere the relationship between CCRS and education had to be carefully managed inasmuch as education was (and still is) a provincial responsibility. This section details the wide range of education and training focused activities of CCRS that were aimed at further developing the ability of users and industry to effectively use remote sensing both at home and as part of an aggressive export strategy. At the same time CCRS can be seen in this section to be playing a role in developing the educational sector's ability to provide the many highly qualified personnel required to ensure that Canada could benefit from the research and development activities being undertaken at CCRS.

3.2.4.3.2. 1972 to 1990[61]

Canadian students were active participants in the Digital Revolution (1970s to 1990s). Soon after the launch of Landsat-1 in 1972, educators and researchers at Canadian universities, colleges and schools began to incorporate printed satellite images into their programs and seek access to the tools and knowledge necessary to use these images in digital form for both research and educational purposes. While CCRS did not provide support to purchase computer equipment, educators were able to access a wide variety of training materials from CCRS. Two key factors made these materials important for Canadian educators: (1) the examples used Canadian remote sensing imagery in applications relevant to Canadian natural resources; and (2) materials targeted for use by the Canadian public were published in both English and French.

[59] It is not clear what happened to this valuable resource after the airborne program ended in the mid-1990s.
[60] The material on what we have called the Training Section has been developed in part from memory and in part based on materials that still appear on the web that were developed by this group. Mr. Bruce passed away in 2016.
[61] This section may not be as complete as one might wish: the author left CCRS on maternity leave in 1982 when at the time she was seconded to UAMU. She returned to CCRS in 1989 and was assigned to help Les Whitney organize a UN COPUOS meeting (Committee on the Peaceful Uses of Outer Space) that was held in Ottawa. In 1990, she moved to the Technology Transfer and Training Section headed by Bill Bruce.

During this period, the CCRS Image Analysis System (CIAS) (which had evolved from the Image 100) and the equipment for using prints and transparencies were made available to all users. Even during the development stage when new or improved methods were being implemented, sessions on the CIAS were in high demand for R&D projects by users from universities, other federal agencies, provincial governments, industry and public utilities. Access to the CIAS was continued until the early 1980s when commercial image analysis systems became available. Through the mid-1970s there were only a few digital image analysis systems routinely available in Canada (five in 1981), although the number grew as the costs of computer equipment gradually decreased.

While there was no charge to use the CIAS, the researchers were required to submit a written request to use the system and were required to work with a CCRS scientific liaison who provided guidance with analysis methods for different applications. Those from outside CCRS were also required to work with an operator during the session(s). This form of technology transfer was particularly beneficial for the many first-time users. Some university researchers and graduate students made use of this resource, although distance and costs were major limitations. This early development work resulted in many published papers, unpublished technical reports and annotated slide presentations of examples of applications that CCRS gathered and made accessible through the Technical Information Service (RESORS). (Cihlar, Goodfellow and Alföldi, 1980)

During these early years the linkages with universities were primarily through their use of RESORS. However there were university faculty members who used the CIAS such as Roger Pitblado of Laurentian and at least one academic, Dr. Phil Howarth then at McMaster, who spent a sabbatical at CCRS.
By 1979, a CIAS User Guide had been completed and CCRS had given its first workshop on digital analysis of remote sensing data. Training manuals, seminars and presentations in different application areas, e.g., forestry, agriculture, marine, were developed that drew from results of CCRS applications development work. These training materials were widely used in a series of workshops organized by provincial agencies who were building local remote sensing capabilities (Edmonton, Fredericton, Regina, Winnipeg, and Victoria) and by the Technology Enhancement Program (1979 to mid-1980s). Workshop attendees included local professors who gradually integrated the knowledge and training resources into university and college courses. The resources included slides taken of the CIAS screen to illustrate analysis steps and results, exercises on paper and documentation describing methods. (Alföldi, 1978)

Through RESORS, educators were able to order copies of CCRS training materials such as annotated slide sets, technical articles and published papers, copies of posters (image maps, project results), and CCRS publications such as "Satellite Imagery Interpretation-Suggestions for Laboratory Design" (Alföldi and Ryerson, 1973, updated 1975) and "Introduction to Digital images and Digital Analysis Techniques." (Alföldi, 1978) CDs began to be used in the late 1980s. A number of education-focused publications were supported by CCRS from its beginning to 1990. Three of these are described in the text box below.

A Sample of Education Focused Support by CCRS

- ***Terminologie de la télédétection.*** Brian McGurrin, Head of the Technology Information Service at CCRS, served on the committee that produced this guide created to assist with translation at the ***4th Canadian Remote Sensing Symposium*** in May 1977 in Quebec. Published by the Ministre des terres et forêts du Quêbec, it provided the starting point for subsequent French-English remote sensing glossaries. (Ministère des Terres et Forêts, Québec, 1977)

- ***Eye in the Sky: Introduction to Remote Sensing / Terre, Mer et Satellites: Introduction à la télédétection.*** The first edition of this book was written by Dorothy Harper, a physicist and spectroscopist at Bishop's University. It was published in 1976 (176 pages). A second, significantly updated edition was published in 1983.The author wrote this introductory book (252 pages) "for the non-specialist, for the educated layman, and for the scientifically inclined high school or junior college student." It was widely used in schools and in even in universities and colleges for students studying fields such as forestry, agriculture, and geography. The author acknowledged the generous help of CCRS staff and CCRS's financial contribution to writing and travel costs associated with the second edition. (Harper, 1983 and Harper, 1984)

- ***Radar Remote Sensing: A Training Manual / Télédétection par Radar: Manuel de formation.*** This 193 page manual containing 75 35mm slides was written by Dirk Werle. It was published by Dendron Resource Surveys Inc. under contract to CCRS Applications Division. It was distributed by RADARSAT International. First published in September 1988, it was updated in December 1992. (Werle, 1992)

As was the case with other CCRS activities, education was influenced by recommendations that came out of the Canadian Advisory Committee on Remote Sensing (CACRS). The CACRS recommendation in 1975 called on CCRS to be receptive to university requests to serve on thesis committees, consulting on methodologies of applications, sponsoring R&D and assisting universities to obtain equipment. Except for the request dealing with equipment, all of these where acted on in the period covered in this document. A number of universities and colleges requested that CCRS scientists travelling in their areas contact them to arrange to give special lectures. Many CCRS scientists were invited to serve on thesis committees, to provide advice on adding remote sensing to courses, and to cooperate in academic research. Over the years a few CCRS scientists left to join academe while others established formal linkages as adjunct professors, research associates, etc.

Another recommendation was to encourage university research on problems considered relevant by CCRS. Such mechanisms could span a continuum from no special support, through "data-only" support, to contract support. CCRS precedents existed and a number of activities were undertaken.

3.2.4.3.3. 1990 to 2011 – The Importance of Geomatics Education for Global Competitiveness

In 1989, CCRS established the Training and Technology Transfer Section (TTTS). Initially it consisted of three scientists from the Applications Development Section and two contracted environmental research assistants. In the mid-1990s, the CCRS Multimedia Team was added. The Section name was changed to the Technology Transfer and Outreach Section in 2003. Bill Bruce was the Section Head from 1989 until he retired in 2005; the Section continued to exist until the Applications Division was reorganized in 2009.

The Section carried out specialized Geomatics information research and provided training products and services as part of CCRS activities such as for GlobeSAR-1 workshops in French in Morocco and Tunisia. The scientists facilitated activities and projects where educators and industry were developing education materials and services, e.g. the User Education and Training Initiative to foster the use of remote sensing, in particular RADARSAT. It should be noted that several UETI projects produced products & services that did not use RADARSAT data. It also undertook project management for several international projects, and consultancy services for CIDA, Canadian Geomatics industry and multilateral agencies. Training Workshops in the 1990s were usually part of international TT projects described below under International Technology Transfer activities.

The Multimedia Team provided design, research, editorial and publication support for scientific, technical and promotional publications and for the web. The Multimedia Team (Marguerite Trindade, Julie Allard and Heather Dickinson) played a major role in the development of the CCRS Web site, with leadership from Tom Alföldi until he retired, and then as part of TTTS until 2007.

3.2.4.3.4. Education – More S&T required for the New Curricula Across Canada[62]

Since the early 1990s federal government objectives guided CCRS's activities with the educational sector. The S&T policy released on 11 March 1996, titled ***Science and Technology for the New Century: A Federal Strategy*** was accompanied by Action Plans, which summarized the S&T action plans of many of the leading science-based departments:

> *Science and technology (S&T) play a critical role in the health and well-being of Canadians and in the country's ability to generate sustainable employment and economic growth. ... Science and Technology for the New Century recognizes that the world's advanced economies are undergoing a fundamental transformation to knowledge-based industries. Canadians must respond with policies, programs, institutions and partnerships that will maximize our economic opportunities and sustain our social fabric. (quote from Policy)*

A number of reports during the 1980s and 1990s underscored the importance of a highly educated workforce for success in the global economy. Two examples are the reports by the Canadian Chamber of Commerce (1993), ***The National Direction for Learning,*** and by the Economic Council of Canada (1992), ***A Lot to Learn***. These reports argued for greater emphasis on science, math, and engineering education to enable Canada to compete in the global economy and for greater congruence between education and employers' needs. Stronger links were being encouraged between schools and the world of work. (Prosperity Secretariat, 1991)

In ***The Common Framework of Science Learning Outcomes K to 12*** published in October 1997, the Council of Ministers of Education, Canada (CMEC) set out a vision and foundation statements for scientific literacy in Canada – the framework for the development of science curriculum across Canada. The first version of Ontario's Common Curriculum for Grades 1-9 was issued in 1993 and changes to curriculum were also occurring in other provinces. In Ontario, a new grade 11/12 geomatics technology course was to be implemented as schools became equipped to teach it. An RFP was issued by the Ministry of Education of Ontario to supply software for this course. All of this activity resulted in a sudden increase of requests to CCRS and RSI for Canadian imagery for use in education. The requirements included images for use in 1) textbooks, 2) Geomatics software (K-12 and college/university versions), 3) in-class exercises and lesson plans, 4) multimedia educational products for use in classrooms, and 5) images for individual student or class projects. In response, CCRS met with RSI and CSA to develop a strategy. TTTS compiled a list of imagery examples that were already available – on the Web as well as CDs, posters and brochures. The list included offerings useful for educators from the CCRS Web site, the National Atlas's SchoolNet Web site, the Geoconnections/GeoGratis Web site, RSI's web site and CSA's web site. Below are some of the CCRS contributions on that list – all available at no cost:

- Interactive web tutorial: ***Fundamentals of Remote Sensing***;
- Interactive web tutorial: ***Digital Images and Analysis Techniques***;
- Interactive web tutorial: ***Radar and Stereoscopy***;
- Web-based: ***Image Tour of Canada*** – annotated examples of imagery for different locations in Canada that student selected from a map of Canada;
- Web: ***Education Fun & Features*** – four examples of images of interest for younger students;
- Web-based: ***Remote Sensing Glossary*** – illustrated, bilingual;
- Web-based: ***RADARSAT in Action***: 13 applications examples with full resolution images and interpretations;
- Web page with links to university and college programs that teach remote sensing;

[62] References for this section include Brassard, 1996; O'Sullivan, 1999; Canadian Chamber of Commerce, 1993; Economic Council of Canada, 1992; Prosperity Secretariat, 1991; Canada Council of Ministers of Education, 1997; Ministry of Education of Ontario, 2000)

- CD-ROM – ***Geoscope : An interactive Global Change Encyclopedia,*** produced for the International Space Year (ISY) in 1992 – Global coverage of more than 40 parameters from various satellite remote sensing satellites and ancillary map documents. Also illustrations, with higher resolution satellite data, of localized phenomena linked to global environmental change, e.g. El Nino, deforestation, desertification;
- CD-ROM – **RADARSAT Monitors Natural Disasters: The Red River Flood of 1997 / Le suivi des désastres naturels par RADARSAT: l'inondation de la rivière Rouge, 1997** (CCRS/CSA/RSI) - CD-ROM introduced the RADARSAT system and demonstrated its value and operational capabilities in the area of disaster management. To increase the educational and training potential of this CD-ROM, two full resolution RADARSAT images were included: a pre-flood image dated June 16, 1996 and an image taken during the flood, dated May 1, 1997. These images can be viewed using the Proview software included on this CD-ROM;
- CD-ROM – ***Pipeline Navigator*** – a review of different remote sensing images for detection of vegetation change caused by oil pipelines;
- CD-ROM – ***Inondation au Saguenay 1996 Saguenay Flood***, Vues sous l'angle de la télédétection (CCRS and Ministères des ressources naturelles du Québec) – An overview of the post-flood situation was captured using remote sensing imagery. The CD contains a data base of more than 2000 aerial and soil photographs, satellite images and some animated movies collected by CCRS and collaborators – both source data and interpreted data. The goal was to make the database publicly available as soon as possible;
- Poster – ***Canada from Space***; RADARSAT mosaic (CCRS/CSA);
- Poster – ***North American Vegetation Index Map*** (CCRS/EROS); and
- Posters – Image maps, e.g. Ottawa, Peterborough, Sherbrooke (Canada Centre for Mapping & CCRS).

Throughout the 1990s, the demand from educators and schools for remote sensing images at low or no-cost for use in the education sector continued to grow. The following two initiatives helped to address this demand:

1. **RADARSAT-1 Data for Research Use Program – CSA/RSI**
   In early 2000, the CSA and RSI initiated the RADARSAT-1 Data for Research Use Program. Universities both in Canada and abroad could propose research projects that, if approved, could receive up to five lower-cost RADARSAT-1 images. (Canadian Space Agency, 2001)

2. **User Education and Education Initiative (UETI)**
   The User Education and Education Initiative (UETI) was one of four new Earth Observation applications programs included in Canada's Long Term Space Plan (LTSP2) approved in 1994. The program was designed to foster the use of remote sensing, and in particular RADARSAT. Between 1995 and 2000, UETI co-invested with Canadian industry in more than 40 projects. Some of the projects developed training products and services that the companies used as components of market development strategies for target markets, e.g., Central America, Malaysia, FAO and for specific application areas, e.g. coastal zone management, natural hazards, environmental monitoring. However, in some of the projects, Canadian companies partnered with Canadian educators to generate deliverables for use in schools, colleges and universities.

   Bill Bruce, head of the Training and Technology Transfer Section at CCRS, was the program manager. TTTS scientists were assigned as scientific authorities for many of the projects, facilitating the transfer of CCRS knowledge and expertise in development of training products and services. (Canadian Space Agency, 1998, 1999 and 2000)

Some UETI Deliverables Produced by Canadian Companies for Use in the Educational Sector[63]

- INTERMAP***: RADARSAT-1 Lesson Plans /*** **RADARSAT en class.** The Plans aimed to introduce students and teachers to remote sensing and to Canada's first earth observation satellite, RADARSAT. Three sets of lesson plans were developed to target different age groups: elementary, junior and senior secondary. The lesson plans contained activities, exercises, information, and RADARSAT images that could be used digitally or in hard copy. It was distributed on CD-ROM.
- INTERMAP: ***Geomatics Education Forum held in Montreal, QC, on October 17, 1998.*** The Forum brought together geomatics educators to address the issues associated with available remote sensing and geomatics resources, the role of industry and others to map future educational needs, centralizing information on the web, and test educator in-service training courses. Seven Canadian companies gave presentations, each demonstrating how they were willing to support educational initiatives. Representatives of organizations involved in curriculum development also participated, e.g., Canadian Council for Geographic Educators, Société de professeurs de géographie du Québec, Ontario Association for Geographic and Environmental Education.
- INTERMAP, Image Centre ***: Geomatics Education Resources Web Site/Site Internet des resources éducationnelles en géomatique***. Web site which was designed to help teachers find materials, information and data that will help them prepare geomatics lessons and curriculum. The final section provided an overview of career opportunities in geomatics and related fields in Canada.
- EOA Scientific: ***The EarthStation Library.*** Educational earth science courseware in interactive multimedia CD-ROMs using a satellite remote sensing perspective. Each volume contained 3 levels of difficulty covering: Grades 6-9; Grades 10-12; and Post-Secondary.
- Geomatics International: ***RADARSAT Distance Learning Program (RDLP).*** A popular and freely distributed CD-ROM. It covered basic imaging radar theory and RADARSAT application examples in an easy-to-use format suitable for educators, researchers, and Earth and environmental science professionals.
- Groupe Perspective D'Avenir: ***ISAC – de l'image Satellite à la carte.*** A practical guide (using Canadian examples) for interpreting and integrating remotely sensed data into cartographic applications. Distributed on CD-ROM.
- Data Quest: ***SAR.101.*** This CD-ROM contained detailed annotation for more than 100 SAR images with their related ground and aerial photographs, literature references and SAR system descriptions, a glossary of radar terminology and ProView software for interactive display and image enhancement. The data sets included airborne and spaceborne SAR systems over a variety of geographical settings around the world. The CD-ROM software, data conversion, image scanning, and system integration were completed by DataQuest Inc. "SAR.101" content was produced by AERDE Environmental Research, under the Canadian Radar Data Development Program (RDDP).
- IQ Media: ***Queen Charlotte Islands Mariner.*** Tour the Queen Charlotte Islands through in-depth investigation of the terrain, real-time flight simulations and explore the rich historical content. Distributed on CD-ROM.
- IQ Media in partnership with Canadian Geographic: ***Canadian Geographic Explorer / Canadian Geographic Explorateur: An Interactive Journey Around Canada.*** Created together with a host of leading Canadian partners, this CD-ROM has been rated outstanding for its rich content, and design. You'll find beautiful photos and articles from Canadian Geographic Magazine, video clips from the NFB, and a host of space imagery from the Canada Space Agency...introduced by the astronauts themselves.

[63] The company name is listed and then a description is given. The descriptions are from Claude Brun del Re, an Ottawa teacher, copies of the CD-ROMs, and from RADARSAT Annual Reports.

- Noetix Research: ***Image Insight.*** A software extension for use with Arcview that allowed students to create thematic maps from Earth Observation data. Five lesson packages were included on the CD-ROM.

3.2.4.3.5. University Geomatics Research Program - GEOIDE

In 1998 the Government of Canada's Network of Centres of Excellence funded, through a competitive process, a proposal from a team of geomatics researchers at Université Laval, the University of Calgary and the University of New Brunswick. The GEOIDE Network or "Géomatique pour les interventions et decisions éclairées/ GEOmatics for Informed Decisions" was a fourteen-year experiment in conducting collaborative research, linking Geomatics researchers with partners in various disciplines, from mathematics, engineering, natural sciences to social sciences and health.

NRCan contributed financially to the first phase – a mix of in-kind and cash, and became a GEOIDE partner. Dr. Keith Thomson, then Director of le Centre de recherche en géomatique, Université Laval was selected to be the first Scientific Director of GEOIDE; earlier in his career, he had been the Head of CCRS's Applications Development Section. CCRS managers served on the Board of Directors for 11 of its 14 years (Les Whitney 1999-2001), Dianne Richardson (2003-2006), Stuart Salter (2007-2010) and Doug Bancroft (2010) and from 1999-2006 two scientists were members of the Research Management Committee to review project proposals and project reporting. (Phil Teillet, 1999-2001), Dianne Richardson (2001-2006)

GEOIDE funded scholarships for university students, cooperative programmes, a Student Network, workshops, and a Market Development Fund. Opportunities were provided for developing leadership skills and building important interdisciplinary networks. Over the period from 1989 to 2012, GEOIDE funded 121 projects, with a total investment of $79.3 million (CAD$). In these projects, 395 research scholars and 1437 students from Canada participated. Links were established with researchers from 146 institutions around the world. In addition, 174 industrial affiliates and 95 governmental entities at all levels were engaged. Collaboration with the user sector helped to point the way for them to invest in promising innovations.

A generation of highly qualified graduates with experience in networking and collaborative interdisciplinary projects took positions across the geomatics community – about a third moved directly to jobs in industry, while a number of them continued to provide leadership in the academic sector, including 18 who were hired to tenure-track positions in universities across Canada. Several multi-million dollar companies came out of GEOIDE research, including ones involved in the scientific areas dealt with by CCRS. (Chrisman and Wachowicz, 2012)

3.2.4.3.6. Glossary

The Glossary was a resource developed by CCRS that was widely used by educators and professionals in Canada and globally. Remote sensing was a new technology in the seventies and new technical words appeared quickly. The first glossaries developed by CCRS were "living documents" with scientists, editors, RESORS staff and translators adding to them as new terms were published. They quickly became vital resources for technical translation and for training materials.

A bilingual remote sensing glossary was one of the first tools developed by CCRS. Over more than 20 years, Tom Alföldi, Christine Langham, and Kathleen Naluzny led CCRS efforts to publish it on the WWW. The glossary provided explanations of technical terms, some with illustrations and examples of use in a particular contest, and links to related words. It was internationally[64] recognized as a reliable and accurate resource for the field of remote sensing, and widely used for a variety of purposes in education,

[64] The American Society for Photogrammetry and Remote Sensing published a glossary that used much of the CCRS material.

technology transfer and business development. One of the longest definitions was for the word "range" because it had several meanings and translations depending on the context.

The remote sensing glossary died when the Multimedia Team left CCRS. Some CCRS educational materials were transitioned and can still be found on the NRCan web site – at https://www.nrcan.gc.ca/node/9503. Unfortunately, the full technical glossary was a database application that would have required significant expertise and effort to transition, so only a few basic terms are on the web site.

3.2.4.3.7. Educational Components of GlobeSAR-1 and GlobeSAR-2

The major objective of GlobeSAR-1 was to prepare potential users to apply RADARSAT data to solve local monitoring and mapping problems. The first step in that preparation was the delivery of workshops in each of the countries involved. The workshops covered the basics of radar remote sensing and the finer details of using data for a variety of applications based on the experience already gained in Canada by CCRS and its partners. In addition to the basic principles of radar data and its application other useful information was covered. One especially important aspect was on how to collect appropriate field data for use with radar data. The material on field data collection prepared for GlobeSAR was eventually used in the third edition of the ***Manual of Remote Sensing: Principles and Applications of Imaging Radar*** to show how one should do field work for radar data. (Henderson and Lewis, 1998, pp 803-807) The material was provided in English in Asia, the Middle East and East Africa. The material was provided in French in Tunisia and Morocco.[65] To conclude the program several symposia were held in the host countries and regions involved to share the knowledge gained. The resulting proceedings were widely used as educational materials.

In the early part of the GlobeSAR-2 Program**,** as in GlobeSAR-1, the focus was on the demonstration of applications of RADARSAT for use in priority areas of natural resource management, as identified by participating countries. The process of implementing the demonstration projects enabled investigators in each country both to gain and to create knowledge about applications of RADARSAT data relevant to their region. GlobeSAR-2 investigators presented results from their applications projects at the final GlobeSAR-2 symposium in Buenos Aires Argentina in May 1999, successfully ending this portion of the GlobeSAR-2 Program.

Strong interest from the university community in South America was evident during the selection process of the applications projects. In response to this interest, the GlobeSAR-2 Program was extended to include a component targeted to universities. This program consisted of two main elements: North-South Linkages and the ***Educational Resources for Radar Remote Sensing*** CD-ROM.

The GlobeSAR-2 North-South University Linkages component created opportunities for educators and researchers from participating countries to establish and developed joint research and educational linkages with their counterparts in Canadian universities. More than 20 exchange projects were established involving 13 universities in 7 Latin American countries and faculty from 12 Canadian Universities. These collaborative projects were typically one year investigations that addressed research challenges relevant to documented needs in Latin America and took advantage of experience and expertise of Canadian university researchers.

The CD-ROM ***GlobeSAR-2 Educational Resources for Radar Remote Sensing*** contained a comprehensive and unique set of radar remote sensing training materials created for use by universities in Latin America and Canada. The resource materials were divided into four main sections: basic, intermediate, advanced, and applications. The product was multilingual - Spanish, Portuguese, French and English. (Canada Centre for Remote Sensing, 2001)

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[65] Prévost, C. 2019) Communication personnelle. Christian Prévost et Linda Cyr ont travaillé sur le transfert technologique en imagerie Radar, Programme GlobeSAR, Maroc et Tunisie (1992-1995)

The CD-ROM incorporated training slides developed by scientists at the Canada Centre for Remote Sensing for international technical cooperation programs, including GlobeSAR-1, GlobeSAR-2 and ProRadar. Significant contributions were also made by radar specialists from different disciplines and by scientists and user agencies in many countries, particularly in South and Central America.

These two components of GlobeSAR-2 University Program have helped ensure a lasting impact and sustainable capacity in the use of SAR imagery, through curriculum resources and linkages among GlobeSAR-2 partners.

3.2.4.3.8. Examples of Outreach Activities

A variety of ad hoc outreach activities were undertaken in response to requests that came mostly from outside CCRS.

- University work term / summer employment opportunities;
- Geomatics Professional Development Program;
- Practicums for local students in university and secondary school Geomatics courses;
- NRCAN Science and Tech Day, GIS Day events, Take your Kids to Work Day, organized tours of CCRS facilities (university/college level);
- Internships; and
- Interviews re careers in geomatics by students, by educators and by companies developing materials for use by educators;

Another area that saw CCRS engaged in training was in provision of on-the-job experience, e.g., the Geomatics Professional Development Program set up by the Canadian Centre for Training in Geomatics. This program was a two-year apprenticeship program for recently graduated university professionals, and for professionals and senior technicians within the Sector. Different divisions throughout the Sector hosted the trainees for six-month placements. Of the seven placements that CCRS hosted, five were in TTTS: Tim Coulas, Van Varve, Corina Vester, Sharon Sauvé and Joely Wilson. (Geomatics Canada, 1994, page 10)

CCRS also provided internships for recent graduates to get experience. Over the years Thierry Toutin had several interns working with him – primarily international interns who came with their own funding from China, US, and France as well as graduate students from Germany, Italy and Belarus.

3.2.4.4. Conclusion

As noted in the introduction to this section and elsewhere in this document, the relationship between CCRS and education had to be carefully managed inasmuch as education was (and still is) a provincial responsibility. Even so, this section demonstrates that CCRS managed to effectively work over many years with educators, industry and other governments at home and abroad in education and training and do so while addressing some of the most complex scientific topics in remote sensing.

3.3. Industry and Technology Transfer

3.3.1. Introduction

Bob Ryerson

CCRS was well known and highly regarded for the way in which industry was involved in its programs – both by providing technology and services to CCRS and by commercializing technologies and applications developed within CCRS.

CCRS was considered so effective in its development of industry that it was studied to gain insights into how science could lead to commercial success. The following text box provides a summary of a 1997 study that included participation of staff from the Treasury Board, Department of Finance, and the Office of the Auditor General.

CCRS Impact[66]
Les Whitney

CCRS has always collaborated with industry to develop and exploit EO technology. As the industry matures it now looks to CCRS to shift emphasis from technology to the development of those applications which will sustain and grow the industry's share of world markets.

In 1997 CCRS conducted the first major impact assessment of Government S&T, with participation of Treasury Board, Finance, and Auditor General staff. The impact model and methodology established continues to be the recommended practice in NRCan and has been applied in subsequent CCRS and CSA impact studies. This assessment covered 31 projects selected at random, representing 20% of CCRS funding. Industry estimated revenue of $70 million attributed to participation in these projects and anticipated a further $425 million by 2002, largely concentrated in export markets. The companies credited CCRS with helping them develop markets by enabling earlier market entry, creating new products which opened new markets and creating new employment with significant impact on the companies' knowledge base and its ability to expand into new areas. Unsuccessful commercialization was linked to poor marketing strategy or technologies too far ahead of market acceptance.

The 1997 study also attempted to evaluate the end-users' savings associated with the use of remote sensing and concluded that "the value in terms of savings to Canada for domestic and Canadian aid-related work is of the same magnitude as commercial sales." A notable achievement was the transition to use of satellite data by the Canadian Ice Service, enabling it to save some 35 positions during Program Review while extending the navigation season in the North.

The 1997 study concluded that the projects would contribute some $170 million in incremental sales to the remote sensing industry, with spin-off of over $100 million in other sectors. Impact assessment continues as an annual exercise, but not as comprehensive in scope. One study in 2002 confirmed projections of CEONet benefits and the sales history of MDA and CREO, a spin-off benefit in the printing industry, support the other main sales projections. The remaining 80% of CCRS project and overhead activities would not have proportionate impact but it is reasonable to attribute a conservative equal share for remote sensing sales and user savings.

Industry sales projections in 1997 were for a rise to $400 million by 2000, later reevaluated to $350 million with the full $400million realized by 2004. Since remote sensing is integral to the GIS, mapping and consulting sectors as well, a higher market revenue share projection would be reasonable and supportive of the impact assessments' conclusions. A conservative attribution of 10% (17% for the sample R&D projects in the 1997 study) would give CCRS an ongoing commercial economic return of 2.0 on the CCRS A-Base average of $20.0 million. This compares well with CSA preliminary assessments of 2.8 to 6.57 economic return on EO industry support programs such as the RADARSAT User Development Program, largely managed by CCRS.

Collaboration

The first and largest impact of CCRS/industry collaboration came from ground station development with MDA,[67] beginning in the 1970s. MDA acknowledged that its growth as the world's leading supplier of remote sensing receiving and processing systems ($400 million by 1997 and doubled now) is founded on these joint activities. Collaboration on the Canadian Earth Observation Network (CEONet) has since led to exceptional technical and commercial success, forming a principal component of the Canadian Geospatial Data Infrastructure and a key element of MDA's design for the British National Land and Information System , valued at $200 million/year.

[66] This document was prepared in March 2004 by Les Whitney at the request of Bob Ryerson then Director General of CCRS. Many of the companies named here are further profiled elsewhere in this section.

[67] MDA is now known as Maxar.

Partnership

Based on early CCRS research into the physics of laser measurement and the engineering of a scanning laser system, and in partnership with the Canadian Hydrographic Service (CHS), an aerial hydrography project was established in the 1970's. Optech Inc conducted the design study for CCRS' prototype laser bathymeter, CHS developed the navigation and data processing systems, and a long series of successful bathymetric surveys begun on CCRS' aircraft took place in Canadian lakes and the North through the 80s and into the 90s. The second prototype, developed by Optech, established the company as the world leader in the technology. Commercial success lagged for ten years, until aircraft positioning problems were resolved, incorporating significant intellectual property of CCRS scientists. As a direct result of its interaction with CCRS, Optech Inc had sold 19 terrain mapping systems at $1 million each, and had sold or was building nine laser bathymeters for $3 to $4 million each by 2002.

Technology Transfer

CCRS and PCI have developed a strategic relationship balancing CCRS intellectual property development with PCI's market awareness of public good and commercial clients' needs. CCRS encouraged PCI to adopt an aggressive data format and transferred state-of-the-art algorithms, assisting PCI to become the world leader in Image Analysis Systems, with products independent of hardware and software operating systems. CCRS' leads in radar analysis, geometric correction of satellite imagery and, more recently, with hyperspectral data analysis have played a key role in PCI's market dominance. This success validates CCRS research efforts and gives CCRS scientists incentive to continue research with short term potential for technology transfer. PCI, with annual sales over $20 million, credits CCRS with providing the endorsement and applications expertise support for much of its ability to market its products internationally.

The numbers cited above were impressive at that time, but pale in comparison to today. Today the annual sales of just MDA (now Maxar) are over $2 billion.

Some of this success came from taking advantage of government programs – such as the Unsolicited Proposal Program of the Science Branch of the Department of Supply and Services[68] or CCRS's early interest in incubators. Others came from the way in which CCRS leadership envisioned the role of industry. Various approaches used to develop industry are outlined in Section 3.3.2 with further details on marketing in Section 6.2.

Section 3.3.3 provides a very detailed example of one such technology transfer and industry engagement that benefited CCRS, the company, and Canada. While there were many successes, some of them outlined in detail in Sections 3.3.3 and 3.3.4, there were others that were less successful, as shown in 3.3.5.

3.3.2. Approaches to Technology Transfer and Building an Industry
Bob Ryerson

3.3.2.1. Introduction

As noted above in Section 2.1.4, industry was regarded as a key component of the national remote sensing program, even before the establishment of CCRS. As explained previously, one of the early and continuing objectives of CCRS was the development of a healthy industry. The approaches to meeting this objective provide one of the valuable lessons learned by CCRS, lessons that have been applied with varying success in a number of other countries including Australia, China, Thailand, and Malaysia.

As explained in some detail in Section 2.2 and especially in Section 2.2.6.3.6, the development of a viable industry was a central focus of both the CCRS leadership (Morley, 1991) and CACRS recommendations over a number of years. The way in which CCRS responded to these recommendations and how it took advantage of a variety of government programs to help in the development of a viable industry is the focus of this section. The reader should note that this is meant to be a summary of methods to engage and develop industry, rather than an itemization of specific contracts or activities. As a result of this approach

[68] The UP Program of DSS under the leadership of the late Dr. Peter Meyboom was one of the most successful programs ever to fund and develop government-industry partnerships to foster innovation while providing a showcase client in government of industry's capabilities.

not all of the companies with which CCRS was involved, nor all of those that were successful (or failed), are necessarily mentioned.[69]

As mentioned previously there were four general recommendations on activities and policies to support the development of industry. These are discussed in the next three Subsections. The fourth Subsection deals with how CCRS responded to more specific CACRS recommendations dealing with industry. The final section describes some of the programs that CCRS used to meet its goals with reference to industry.

3.3.2.3. Industry Representation on CACRS Working Groups

This recommendation saw a steady increase in the number of industry representatives in CACRS working groups. Eventually a separate day at the annual CACRS meetings was devoted to the concerns of industry. As noted in Section 2.2.6.3.6, by 1984 26 % of all WG members were from Canada's remote sensing industry – an industry that did not exist ten years before.

3.3.2.4. CCRS Should Not Compete With Industry

This recommendation was relatively easy and painless for CCRS to implement in most areas. Unlike the provincial centres in Ontario and Manitoba for example, CCRS was unable to charge for its image analysis services and retain the funds. All funds it received went into the General Revenue Fund of the Government of Canada. Indeed, the growing market for digital Landsat imagery caused a great deal of trouble for CCRS. Over a period of five years sales by CCRS increased by 400%, while its budget to produce the data remained the same. Every sale of data ended up costing CCRS. Eventually sale of satellite data were turned over to industry to eliminate the drain on CCRS resources. When the private sector began preparing to offer digital image analysis services, CCRS restricted what had long been free or nearly free access to the Image 100 only to bona fide researchers. Operational users were referred to private sector service suppliers, several of which began to offer services in the Ottawa area.

3.3.2.5. CCRS Response to Specific Recommendations Directly Supporting Industry

A number of more specific recommendations that were aimed at supporting industry were responded to by CCRS in a generally positive way. Each recommendation is given followed by the action or response. The most important response to the CACRS focus on industry was the development of a comprehensive international marketing plan discussed in the 1984 CACRS meeting and implemented over the following years.

Foster the development of low cost image analysis systems including PC-based software for image analysis: To provide support and serve as a demonstration site CCRS purchased software from some of the early suppliers such as PCI Geomatics and smaller suppliers such as Eidetic Digital Imaging.

Support Canadian industry involvement in foreign satellite programs: CCRS supported a number of suppliers through serving as a demonstration site for data reception, data production, data analysis, and data storage. Companies ranging from MDA to PCI, CREO and others benefited. An indirect activity was early CCRS leadership in the establishment of the Committee on Earth Observation or CEOS: CCRS was one of the founding members.

Contract out routine production and distribution of ERTS imagery: At the beginning production and distribution of data was contracted out, but with poor results. Eventually CCRS took over the marketing, production and distribution of data following complaints about quality control that were made at CACRS (See 1975 CACRS Report, page 7.) The marketing and distribution of satellite data was eventually turned over to RADARSAT International.

[69] The mention or lack of mention of any company is not to be construed as either an endorsement or a criticism of any specific company by the authors or editors of this document.

Support industry with adequate funds to produce an advanced imaging radar sensor: This was done and eventually the C/X SARS on the CV-580 and the two RADARSATs and the RADARSAT Constellation Mission were the result.

Provide technical assistance to the service industry: This recommendation could not be directly acted upon by CCRS inasmuch as it did not want to compete with industry or pick sides in a competition between companies. CCRS did agree to provide advice and support on an equal basis to all Canadian companies. It also provided significant help to the service industry in terms of demonstration projects within both the Airborne Program and Applications Development. For several years in the late 1970s an applications scientist was assigned to the airborne activity to provide advice to users. (Both Josef Cihlar and Bob Ryerson served in this capacity.)

Provide a directory of RS-related facilities available in industry, government and universities: A directory of industry capabilities and university courses was developed and maintained by the User Assistance and Marketing Unit. The activity led to the ability to clearly track the significant growth of the industry, which was done for the years 1987 to 1994. (Sayn-Wittgenstein *et al*, 1999, p. 447) A more comprehensive list of educational capabilities was later developed on contract by Roger Stacey.

Produce a brochure or movie to inform potential international buyers, especially in developing countries, of the services available from Canadian private industry: A brochure was produced (see Section 6.2.) as were videos.

Inform CIDA of Canadian (government and industry) expertise in remote sensing and land evaluation and rangeland applications: CIDA and IDRC were both engaged in the international marketing initiative discussed in the Section 6.2. Both later came to play a major role in GlobeSAR, described in Section 3.3.3.9.

3.3.2.6. Government Programs Accessed by CCRS to Meet its Mandate

One of the strengths of CCRS was in the awareness senior staff and management had of funding programs across government. To some of us it seemed that programs would barely be announced and someone at CCRS would be targeting the programs for funding. Especially adept at this were Leon Bronstein (a manager in the data Acquisition Division and who later served as Deputy Director General), J-C. Henein (Chief of Program Planning and later the Director of the Applications Division), and Les Whitney (Head of Planning). Another aspect of the same capability was the ability to have ideas in place on how to quickly spend any budget amount that happened along – especially at fiscal year-end. Over time a number of scientists and other managers became more adept at locating funds as A-Base budgets shrank. While partnerships were important to CCRS from the beginning, they became even more important as budgets decreased in the mid-1990s and beyond.

We have already mentioned the Winter Works Program used by the provinces in the early 1970s to hire staff at nascent provincial remote sensing centres. This early use of a government program to help remote sensing develop was but the first of many programs used by those forward-thinking individuals working with this new and innovative technology.

The first major program with funds attached to it that CCRS used was Unsolicited Proposal or "UP" Program of the Science Branch of the Department of Supply and Services. It proved to be the single largest source of funds other than the on-going A-Budget for CCRS activities in the late 1970s into the early 1980s. And CCRS was, by all accounts, the primary beneficiary in all of the federal government – to the point that there were questions asked about how CCRS managed to obtain substantial budgets for its programs without having to make the normal submissions to Treasury Board. The UP concept was quite simple: companies would submit a proposal to the Science Branch with an indication of who they thought might support the idea in Government. Ideas were, it seems, communicated to a number of companies who then submitted proposals. Among other purchases the fund was used to pay for the portable satellite receiving station and other hardware and systems. As noted in Section 3.3.3.3 by Mike Kirby, MDA acquired a contract to develop a digital SAR processor for the processing of SEASAT imagery. In the same section Kirby also notes that the UP Fund supported a proposal from Intera to help organize and conduct SAR data acquisition and processing studies for the Canadian user community. These studies and systems resulted in spinoff benefits to the CV-580 facility and later to Intera's airborne systems, as well as laying the ground work for the future RADARSAT mission.

At the same time as the major budget cuts occurred in 1994, the CSA managed to be the only program in government to see a significant increase in funding – some $800 million.[70] Needless to say, CCRS actively sought out and obtained some of the funds targeted for earth observation. While these funds could not cushion the loss of the Airborne Program, they did allow scientists to continue with high level research. With the CSA focus on RADARSAT, more of CCRS's efforts were from that time on spent on radar applications and less attention was paid to optical data. This attention to radar data did pay off in significant new developments, as are detailed in Section 6.6.3 by Dr. McNairn and Section 6.7.2 by Drs. Livingstone, Gray and Touzi.

As issues like climate change and the environment became more important, and given its experience and reputation, CCRS also managed to establish partnerships with other government agencies, including the provinces and ones in Europe, to jointly fund activities. One notable more recent example was the focus on the oil sands that began with a workshop in 2011 under the leadership of then Director General Doug Bancroft working with the Alberta Government. (Ryerson *et al*, 2012)

What are today called Public Private Partnerships (PPP) were also used by CCRS. PPP arrangements were used within the airborne program with agreements with Innotech Aviation and Intera. (See Section 3.3.3) The arrangements in the 1970s and early 1980s that saw industry provide support staff for CCRS at less than market rates to gain early access to new applications and opportunities may also be seen as a form of PPP.

Early calls by Canadian industry and academe to engage CIDA and IDRC to bring the benefits of remote sensing to less developed countries saw a number of companies and universities engaged in programs with both organizations. Some of the individuals who made a mark in those arrangements were Arif Turkelli and Randy Trenholm of CIDA and Djilali Benmouffok and Gilles Cliche of IDRC. Companies involved included Intera, Digim/Photosur Geomat, and DIPIX. They worked primarily in Indonesia, Malaysia, and Thailand. In the mid-1980s the University of Waterloo received IDRC support to bring several Chinese students to do PhDs. One of those, Dr. Jinfei Wang, is now a well-respected professor of remote sensing at Western University, another, Dr. Peng Gong, is a Professor at UC Berkeley.

Another program that was used for many years was the Industrial Research Assistance Program (IRAP) of the National Research Council. Les Whitney was an early and continuing advocate of the program to provide advice to smaller companies. The late Dr. Ray Lowry, who was one of the early scientists hired at CCRS to work on radar and who then went on to Intera, later worked as an IRAP employee and advisor.

Trade development programs were also tapped by CCRS. A number of trade missions aimed at the Asian Market were supported by External Affairs. These are more fully described in Section 6.2.

[70] The initial justification for funding was written by Glenn MacDonnell of Industry Canada and Bob Ryerson. They participated in a cross-government exercise led by MacDonnell to justify spending on space to generate jobs and other benefits that come from the use of space. The focus in their report came to be on the benefits of space imagery. It was supported by letters from a number of company CEOs from across Canada who targeted the local Minister, Government MPs and the appropriate Ministers. Further details are noted in Sections 2.3.4.2 and 4.3 and 6.6.1

3.3.3. The Emergence of Canada's Global SAR Leadership: A CCRS Technology Transfer Success Story

Mike Kirby[71]

3.3.3.1. Introduction

Sometimes events and policies combine at a critical time to cause a sea change in the emergence of technologies and players on the world stage. This is a recounting of such a story for what started out as a small environmental consulting company from the prairies to become a world leader in Synthetic Aperture Radar (SAR) technologies and services directly as a result of the technology transfer policies of CCRS. However, the road to success for the company also had many challenges and a few setbacks, as well as some surprising circumstances, but the lasting effects of the process forever changed the face of remote sensing in Canada.

3.3.3.2. The Early Years (1974 – 1977)

In 1974 Intera Environmental Consultants Ltd. (Intera) was formed when the environmental division of a petroleum engineering company, INTERCOMP Resource Development Engineering in Houston, Texas merged with the Calgary-based environmental consulting company, ERA Sciences Ltd, with a combined staff of about a dozen people with Brian Bullock in Calgary as its president and Ron Lantz in Houston as its chairman. At the time, it was the only company in Canada that had an advanced remote sensing system (a Daedalus infrared line scanner). It was used for conducting environmental impact studies related to wildlife habitat and monitoring oil and gas production operations. That activity was headed by Diane Thompson. Other activities included air quality modelling of gasification plants over mountainous terrain and cloud seeding for hail suppression.

At this time, through the leadership of Dr. Larry Morley, CCRS instituted a policy of technology transfer to industry whereby the research activities of the Centre could be made available to industry through cooperative development programs. The Centre released an RFP for industry to participate in the Centre's airborne operations which had inherited the reconnaissance systems, including aircraft, from the Airborne Sensing Unit of DND. Intera, in conjunction with Innotech Aviation Ltd (Innotech), submitted the winning bid for the operation of the Centre's aircraft and sensor systems. Innotech, under the leadership of Ernie Gardiner, was the prime contractor with the responsibility to provide the pilots and aircraft maintenance engineers, while Intera, under the very capable leadership of Bruce Fretts, provided the sensor operators, sensor technicians and mission managers. The partnership between the companies was formalized with the creation of a new company, Intertech Remote Sensing Ltd. After a few years of operations in the heat loss and forest fire mapping business, Intertech was folded into the Intera Ottawa office operations.

As part of the mandate of the Innotech/Intera team, they were to conduct a study of Canada's remote sensing applications needs and the commercial potential. The study was led by Intera and the company delivered a final report in 1976 that summarized the emerging applications and the potential for remote sensing in Canada. Two central conclusions came from that study that had long-term implications. The first conclusion was that the dominant emerging application for Canada was the mapping of sea ice and icebergs in the country's eastern and northern regions. The interest in these areas came as a result of the effects of the 1973 oil embargo by the OPEC nations, which forced the oil industry to look for alternate oil and gas sources in the difficult offshore regions of the east and northern coasts. The second major conclusion of the study was that the most appropriate sensor technology to support these emerging Canadian needs would be Synthetic Aperture Radar or SAR systems.

At that time Canada did not possess any SAR systems and the world's knowledge base with this technology largely resided in the Environmental Research Institute of Michigan (ERIM) through its research and development activities with their airborne X-Band and L-Band system. It so happened that

[71] Mike Kirby is the former Executive Vice President of Intera Information Technologies Corporation. He holds one of the first post-graduate degrees awarded in remote sensing applications in Canada, an MA from the University of Waterloo. He has held a series of senior executive positions in industry related to remote sensing and space.

ERIM was moving to new research development topics on behalf of the Department of Defence (DoD) and had less need for the current SAR system – what they called the SAR-580. At the same time CCRS had recently acquired a Convair 580 (CV-580) aircraft through the efforts of Ralph Baker, which would be a suitable platform for the large ERIM SAR system. Under a cooperative agreement with ERIM, CCRS acquired the ERIM dual frequency SAR system and had it installed in the CV-580 aircraft.

As part of the technology transfer policies of CCRS, the Centre also opened up opportunities for the Canadian applications industry to participate in the Centre's applications research activities. Through a competitive tendering process, Intera was awarded a series of contracts between 1977 and 1994 to support the research of the Applications Division initially led by Dr. Murray Strome, with Dr. David Goodenough as the Section Head of Methodology and Dr. Keith Thomson as the Section Head of Applications Development.

Over the years between 1977 and 1994, many of today's top remote sensing researchers and managers in government, industry and academe worked for Intera at different times during this period as part of the Applications or Data Acquisition Divisions. Many are still active in the country's remote sensing sector, including (in alphabetical order): Brian Brisco, Bruce Baker, Pal Bhogal, Carl Brown, Gilles Cliche, Yves Crevier, Daniel DeLisle, Marc D'Iorio, Gunar Fedosejevs, Dean Flett, Mathias Fruwirth, Claire Gosselin, Rob Gould, Steve Gravelle, Bonnie Harris, Jeff Harris, John Hornsby, Bill Jefferies, Mike Kirby, Tim Lynham, Hugh Mackay, Mike Manore, Karim Mattar, Brian McLeod, Heather McNairn, Lynn Moorman, Kevin O'Neill, Scott Paterson, Nancy Prout, Terry Pultz, Karl Staenz, Jeff Sutton, Jeff Tracy, John Wessels, Dave Wilson, John Wolfe, and many others. The CCRS contracts provided Intera with invaluable applications and technology experience that it effectively used to help build its remote sensing business.

3.3.3.3. The SURSAT (1978 – 1980) and RADARSAT Programs (1981 +)

In parallel with the system developments, Intera followed up its user requirements study with an unsolicited proposal to the Department of Supply and Services (DSS), with the support of CCRS, to help organize and conduct SAR data acquisition and processing studies for the Canadian user community. This proposal resulted in contracts over a two and a half year period totaling $1.5M for Intera and served as its springboard into the SAR world. The activities became part of the federal government SURSAT (Surveillance Satellite) Program (1978 – 1980), directed by Dr. Roy VanKoughnett, which saw the CV-580 fly projects across the country for the national user community for applications that included geology, agriculture, forestry, land use, sea ice and icebergs, wetlands, topographic surveys and flood mapping. The results of the vast amounts of research from the SURSAT Program studies served as the forerunner to the development of the RADARSAT Program. At the time, ERIM had one more invaluable gift for Canada in the person of Dr. Keith Raney who was, and still is, the world's foremost SAR theoretician. His significant contributions to the national SAR program cannot be overstated.[72]

In addition, a few CCRS scientists were seconded to Intera for short periods to assist with certain remote sensing initiatives during the SURSAT period, including Dr. Keith Thomson, Tom Alföldi and the late Dr. Ray Lowry. Lowry eventually joined Intera full time and played a key role in leading many of the company's successful SAR development programs. Lowry's addition to the Intera team from CCRS gave the company a new and necessary depth in the understanding of SAR theory and technologies.

As part of the technology transfer policy of CCRS, the Intera/Innotech team was encouraged to seek outside commercial projects for the CV-580 SAR facility. The marketing and management of these commercial projects was led by Intera, who then subcontracted the CV-580 through Innotech's operating license. During the SURSAT Program, the major commercial interest in the SAR data came from the offshore oil and gas industry from Gulf Resources, Mobil and Exxon, but particularly from Dome Petroleum, whose research team was led by Dr. Bryan Mercer and who subsequently joined the Intera radar team with Ray Lowry and Rob Inkster.

[72] Editor's Note: Dr. Raney is the author of Chapter 5.

This was a watershed period for CCRS, Canada, Intera and Macdonald, Dettwiler & Associates (MDA) in the development of SAR technologies and applications. From the SURSAT Program two major conclusions were confirmed. The first conclusion was that Canada needed and could use a spaceborne SAR system for a wide range of applications, particularly for sea ice. Secondly, it was clear to Intera that a commercial airborne SAR business would be viable to service the oil and gas industry and topographic mapping agencies around the world.

In parallel with these developments, MDA had acquired a contract through the DSS unsolicited proposal route, along with additional support from U.S. organizations, to develop a digital SAR processor for the processing of SEASAT imagery. This was an immensely successful venture and resulted in spinoff benefits to the CV-580 facility and later to Intera's airborne systems, as well as for the future RADARSAT missions.

At the time of the SURSAT Program, the recorded CV-580 SAR data had to be optically processed using the ERIM optical bench. This was a useful approach but it had serious limitations for the generation of the SAR products, which had to be printed on film that had a dynamic range that was only about one fifth of the full dynamic range of the SAR signals. MDA's digital processor capability was subsequently directed to creating a digital recording and processing system for the CV-580. This then created a platform for the development of two additional complementary subsystems: a real time image recording and display system on board the aircraft and a real time digital downlink system. All of these developments were supported by CCRS and occurred within a short period of time and they revolutionized the SAR business. Researchers could make use of the full dynamic range of the SAR signals using image processing analysis systems and advanced calibration methods. And Intera had the basis from which to better service its emerging oil and gas clients in a way that no other company in the world was able to match.

Shortly after the success of the SURSAT Program, the RADARSAT Program Office (RPO) was established under the leadership of Dr. Ed Shaw. It continued the SAR applications and technology development activities for several years, along with defining the specifications for the RADARSAT-1 satellite, until it was amalgamated into the newly formed Canadian Space Agency in 1989.

Furthermore, the advanced research that CCRS conducted through its Data Acquisition Division, led by Leon Bronstein, and through the Applications Division led by Dr. Murray Strome, working with various user agencies from across the country, helped to confirm the most appropriate imaging approaches for a wide range of important applications. The innovative research conducted by CCRS scientists and engineers like Laurence Gray, Chuck Livingstone, Bob Hawkins, Bob O'Neil, Susan Till, Vince Thompson, Bob Neville, David Goodenough, Ray Lowry, Ron Brown, Burt Guindon, Frank Ahern, Phil Teillet, Keith Thomson, Josef Cihlar, Tom Alföldi, Bill Bruce, Bob Ryerson, Carolyn Goodfellow and several others, led the way in creating an unparalleled Earth Observation applications and systems knowledge base that quickly became noticed by other leading research organizations around the world.

3.3.3.4. European Campaigns (1981 - 1989)

As CCRS, Intera and other Canadian scientists and engineers began publishing the research results from the SURSAT Program, researchers in Europe became interested in the possibility of conducting a similar research program across Europe. A cooperative agreement was concluded between CCRS and the European Space Agency for a campaign to be flown throughout Europe with the CV-580 in the summer of 1981 to be coordinated by Intera. Several European research organizations would participate in the program including the DRA from the U.K., CNES from France, DLR in Germany, JRC and ASI from Italy, along with a number of universities.

At the same time in Canada, as a result of the SURSAT Program, preference for a C-Band SAR for the RADARSAT mission had emerged. CCRS commissioned the development of an airborne C-Band radar sensor for the CV-580 to conduct radar trials. The CAL Corporation was awarded a contract to develop this system, which was delivered to CCRS a short time before the ESA campaign to Europe was to begin. As a result, the testing of the system had to be conducted during the European flights. Fortunately, with the help of engineers from the DRA, the C-Band system was successfully commissioned in Europe. The research community then had access to the world's most advanced multi-frequency, multi-polarization, digital SAR system with X, L and C-Bands. Only two of the bands could be operated together at any one time, but this gave European scientists their first look at digital backscatter data over their own terrain.

The digital SAR data were collected with the CV-580 over a five week period in the U.K., France, Belgium, the Netherlands, Germany, Italy, Switzerland, Spain and Denmark. This first European campaign was contracted through Intera and gave the company the opportunity to conduct the coordination of the projects with researchers from across Europe. Additional CV-580 campaigns were contracted to Intera in Europe through the 80's, generating data that helped to form the foundation for the European ERS SAR missions.

3.3.3.5. STAR-1 (1981 – 1996)

One of the key results from the SURSAT Program for Intera was the confirmation that an international market could be created for high resolution SAR data from an airborne platform. At the time, ERIM engineers had just completed an advanced SAR development project for DoD in the U.S. and were looking for something new to develop. Intera approached ERIM to see if they could design and build a lightweight, digital SAR for the company. ERIM was happy to oblige and created Intera's STAR-1 (Sea ice and Terrain Assessment Radar) X-Band system using much of the knowhow that they had acquired during the DoD work. In 1983 the completed system was installed into a high performance Cessna 441 Conquest turboprop aircraft and immediately became an operational success, starting with the offshore oil and gas exploration industry in the north.

To further promote the capability, the company took the STAR-1 system on a worldwide tour that resulted in a series of large topographic mapping campaigns in Asia and South America. One of the first major mapping projects was in Indonesia in support of the Transmigration Program. As a result of this program, a company office was opened in Jakarta to help service the project and regional marketing efforts. This office eventually became the data production facility for the follow-on company, Intermap Technologies Corporation (Intermap), which is still in operation today.

As part of the servicing of the offshore exploration and shipping industry in the Arctic with the CV-580 and STAR-1, in 1986 Intera developed a special purpose SAR workstation, called STARVUE. It provided real time display and analysis of SAR imagery on the bridge of a ship for the Canadian Coast Guard and for Canarctic Shipping. This system was the prototype for a series of shipborne workstations that would be used for receiving and analyzing all future airborne and spaceborne SAR data over Canadian waters, including RADARSAT.

One of the other spinoff technology developments from the STAR-1 manufacturing process was the licensing of the future airborne systems to the MDA Corporation. At the time, Intera was not interested in manufacturing and selling SAR systems: it was interested in providing SAR data acquisition and map production services. The company provided MDA with the system design details and licensed them to sell and build SAR systems, which became the MDA IRIS airborne SAR product.

Over the 13 year history of the STAR-1 system operations, Intera conducted more than one hundred projects around the world and created terrain and surveillance products that added new dimensions to the global mapping community. During this time, the company only had one competitor, AeroService of Houston that flew a large Caravelle jet aircraft with an optical Goodyear SAR. The U.S. Geologic Survey (USGS) wanted to conduct terrain mapping surveys with the digital STAR-1 system to be contracted through the corporation's Houston company. However, AeroService launched a concerted lobby with the Texas Senator in Washington to try to prevent Intera from flying in the U.S. When the Senator discovered that Intera was contracting through its Houston company, he dropped his support of the AeroService objections. Nevertheless, AeroService persisted with a further lobby with immigration rightly claiming that the work was being done by Canadians in a U.S. registered aircraft. Intera solved the problem within a few months by buying AeroService from Goodyear and immediately retiring the Caravelle aircraft to the airplane boneyard in Phoenix, Arizona. USGS could then contract Intera without any further objections.

3.3.3.6. Japan Campaign (1983)

Japanese researchers took notice of the SURSAT and ESA campaigns with the CV-580 and were interested in collaborating with Canada and in conducting a similar airborne program in Japan. Discussions between NASDA (Japan's space agency at the time) and CCRS resulted in the approval for a campaign that was conducted in September and early October, 1983 in Japan. A contract for the campaign was signed between Intera, NASDA and Asia Air Survey to conduct the work. For over a month, the capable CV-580 flight crew that included, Bryan Healey, Alfie McDonald, Dave Gardiner, Ed Giles, Bill Bayer and Reid Whetter, successfully conducted all of its data acquisition flights out of the operations base in Sendai over many sites across Japan, including over Mt. Fuji, on behalf of hundreds of Japanese scientists and engineers. With the help of NASDA, Asia Air Survey and RESTEC in Japan, the Canadian team was able to deliver on its commitment to assist Japan in receiving its first digital SAR data over its sovereign territory and to lay the foundation for the creation of the JERS SAR spacecraft. This was the last time that the CV-580 flew its L-Band system in a foreign program. As a result of this work and other efforts, Canada forged a longstanding close relationship with Japan for collaboration that continues today.

3.3.3.7. RADARSAT International (1989)

As part of the commercialization plans for the upcoming RADARSAT satellites, a consortium of shareholders formally created RADARSAT International (RSI) in 1989 for the purpose of marketing and distributing RADARSAT data products. The original shareholders included SPAR, MDA, ComDev and Intera. Each company held equal amounts of shares and contributed $1M each to the start-up operations. However, after the first year of operation, two things became clear to Intera. First, RSI would require far more funding support over the next few years than the initial investment. Second, Intera would not see any return on its investment for several years to come based on unknown future data sales, while all of the other shareholder companies were immediately receiving related revenues based on their roles in building and operating the satellite. As a result, Intera took the decision to sell its shares back to the other shareholder companies. These shares were eventually sold to Lockheed Martin. In the meantime, Intera continued to support the RADARSAT cause through its R&D efforts as part of the CCRS applications and acquisition support contracts. In addition, some of Intera's top people joined RSI, including: John Hornsby, Bonnie Harris, Bill Jefferies and Mary van den Tillaart, contributing to its success for many years.

3.3.3.8. SAREX-92 (1992)

Sometimes things do not work out as initially planned, but eventually succeed through a circuitous route. In 1991 ESA approached Intera for a CV-580 proposal to conduct data acquisition flights in South America in a program that became known as SAREX (South American Radar EXperiment). Test sites were identified in six countries and Intera prepared the flight plans as part of its proposal to ESA. As ESA was putting together the contract, a CCRS scientist inadvertently mentioned to another company at the Canadian Symposium on Remote Sensing in Calgary that Intera was in the process of concluding a contract with ESA for a CV-580 campaign in South America. A representative of this other company contacted ESA to inform them that Intera was not the only company in Canada that could perform this work. ESA contracts people asked CCRS for written confirmation that Intera was the most experienced company to coordinate this activity so that they could go ahead with sole sourcing the contract. Unfortunately, CCRS sent a letter to ESA that did not clearly support the Intera position and as a result, ESA was forced to launch a competitive bid process.

The competitive process included Intera's flight plans for the program in the RFP and resulted in two bids from Canada. The other company underbid the work and was awarded the contract to the dismay of both Intera and the ESA program manager. The ultimate irony was that the CV-580 flight crew included three Intera employees. Nevertheless, the program was a success in that good CV-580 data were collected in April of 1992 over test sites in Venezuela, Brazil, Guyana, French Guiana, Colombia and Costa Rica. Furthermore, it set the stage for future collaboration between Canada and South America in preparation for the RADARSAT mission.

However, the impact of the setback on the board members of Intera was not so positive. A letter of complaint was sent to the Minister of NRCan about the government leak of confidential commercial information to a competitor that resulted in a big loss of revenue to the company after having spent significant time and effort, at company expense, developing the concept and plans with ESA and the South American users. The result within the company was that the government was considered not to be a reliable partner in keeping confidential information secret, even though it was understood that the leak was unintentional, and that the company would not expend further resources in promoting the use of the CV-580. The only exception would be the continuation of the GlobeSAR initiative that had already begun and with signed commercial contracts in the U.K., France and Taiwan.

3.3.3.9. GlobeSAR (1993) and GlobeSAR-2 (1997)

During a conference in Washington, D.C. in the summer of 1991, Dr. A.J. Chen of the National Central University (NCU) of Taiwan had a discussion with Ray Lowry regarding the potential use of the CV-580. After the conference, Dr. Chen visited Intera in Ottawa and was given a briefing and tour of the CV-580. He stated that Taiwan could not pay for a dedicated campaign to Taiwan but would be happy to participate in a joint campaign with other countries. A provisional contract was signed between the NCU and Intera at that time, subject to other countries sharing the mobilization and transit costs to the area.

At about the same time and unbeknownst to Intera, Dr. Bob Ryerson had developed a concept that he called AsiaSAR, which would be a program to introduce digital SAR data to a wide audience of Asian research organizations in preparation for the RADARSAT mission. Through Ryerson's contacts at the ADB, the UN in Bangkok and in China, he was able to generate much interest in the concept. Eventually, through significant additional effort in Canada under the leadership of Fred Campbell the complex SAR campaign, known as GlobeSAR, was organized.

In parallel with the CCRS activities, Intera began a concerted effort to promote the shared concept among its former CV-580 clients. RSI and the Canadian Space Agency were early endorsers of the concept as a way to promote future RADARSAT data to the world. In the meantime, Intera was able to secure commitments from the DRA in the U.K. and CNES in France. Unfortunately Japan was unable to participate at that time. Through the continuing dedicated efforts of CCRS, led by Dr. Fred Campbell and assisted by Ryerson, the international program was approved to fly the CV-580 in a number of interested countries that included financial support from CIDA and IDRC. Several CCRS scientists, supported by Intera personnel, fanned out across the Middle East, parts of Africa and Asia to set up SAR projects with local remote sensing experts. Once the participating countries and the financing support had been confirmed, Intera was tasked with organizing and coordinating the data acquisition flights, led by Bill Bayer, in conjunction with the Innotech flight crews and the CCRS country project coordinators.

Under the beautifully designed GlobeSAR logo by Marguerite Trindade of Intera, the CV-580 departed Canada in the fall of 1993. Intera conducted commercial data acquisition projects in the U.K., France and Taiwan, along with the Canadian supported GlobeSAR missions that were flown over 32 project sites in 10 countries that included: Jordan, Tunisia, Morocco, Tanzania, Kenya, Uganda, Malaysia, Thailand, Vietnam and China. It was the most ambitious and complicated SAR campaign ever conducted. Literally hundreds of researchers from these countries participated in the analysis of the data, which was the first digital SAR imagery over their territory for a wide range of applications. RADARSAT imagery was then simulated for these sites from the CV-580 data using the SARSIM package that John Wessels of Intera had previously developed under contract to CCRS. This gave researchers in many countries an opportunity to work with simulated RADARSAT imagery two years in advance of the satellite's launch and prepared them for the assimilation into their operations of actual RADARSAT data starting in 1996.

GlobeSAR Logo

Following in the successful footsteps of GlobeSAR, a second program was initiated by CCRS that became known as GlobeSAR-2. This time the program was directed towards researchers and investigators in South America and it was able to incorporate actual RADARSAT-1 imagery into the investigations. Starting in 1997 and proceeding for several years, CCRS scientists and managers cooperated with more than 80 investigators from 11 Latin American countries, including: Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Honduras, Panama, Peru, Venezuela, and Uruguay. Funding was provided by CIDA and IDRC for the program that resulted in 65 different projects for a wide range of applications. CCRS conducted 40 training workshops and seminars throughout the participating countries supported by former Intera professionals. New cooperative relationships between Canada and various Latin American organizations were established, along with many new business opportunities for Canadian companies that were opened as a result of the program.

The consequences of the GlobeSAR initiatives were massively beneficial for Canada and its industry, as well as for the many international organizations that participated in the program. Canada subsequently exported products, services and RADARSAT data worth tens of millions of dollars to these countries. Ongoing business and collaboration between researchers continue today. The GlobeSAR programs stand out as preeminent examples of exceptional national team achievements between government, industry and academia to showpiece Canada's advanced capabilities on the world stage. That effort has contributed greatly to the success of the RADARSAT missions.

3.3.3.10. STAR – 2 (1989-1995)

During the late 70's and throughout the 80's, Intera conducted many projects for the Arctic oil and gas industry, as well as for a few shipping companies using the CV-580 and STAR-1 systems. In addition, the company was contracted by Petro Canada and Melville Shipping to conduct wide area ice surveys from the East Coast through Baffin Bay, Lancaster Sound and along the Northwest Passage using the Environment Canada Atmospheric Environment Service (AES) Ice Patrol Electra aircraft. For several years Intera conducted ice and iceberg surveys using this facility that was equipped with an APS 94 SLAR,[73] infrared line scanner, cameras and a laser profilometer. The purpose of the surveys was to typify the ice conditions, including measuring the size and frequency of pressure ridges, and to classify iceberg populations in preparation for the shipping of liquid natural gas with an ice breaking tanker. Through the exemplary work by Jeff Sutton, Bill Jefferies and John Wessels, Intera pioneered the development of advanced digital analysis methods that opened the doors to new ice survey markets with the Alaska Oil and Gas industry.

During the flights over the Arctic, the AES ice experts would compile ice charts using a combination of the real time SLAR data and visual observations through bubble windows in the side of the AES Ice Patrol aircraft. In order to complete these ice charts, the ice observers had to visually monitor the ice. This was often very difficult with the poor weather conditions in the north, forcing the large aircraft to fly below the low lying clouds and fog, sometimes as low as a few hundred feet above the ice surface.

It was apparent to Intera that the ice observers could better compile their charts with the use of SAR data. Over a period of a few years, Intera attempted to demonstrate to AES the benefits of digital SAR data for ice monitoring. The work that the company was doing for the oil and gas industry, and for shipping companies, had become the operational standard for ice monitoring applications. The Ice Patrol management was interested and a proposal was sent to AES by Intera in 1986 for the creation of a wide swath, X-Band, dual sided, digital SAR facility. It was a great concept that the Canadian government liked, but it was too big to sole source.

Finally, in 1987 AES issued a competitive RFP for the system as a forerunner to RADARSAT-1, which AES intended to use for ice mapping purposes in the future. Intera's operations partner in the CV-580 work, Innotech, decided to submit a separate proposal in competition with Intera using the SAR expertise of MDA and a new Challenger jet. Innotech felt that this was too big of a concept for Intera to successfully bid. What Innotech did not know at the time was that Intera had developed a strategy to submit two proposals, one with all the bells and whistles in a Challenger aircraft and the other in a more

[73] SLAR – Side Looking Airborne Radar.

economic but compliant Gulfstream aircraft, both with MDA radars. To Innotech's great shock the second Intera bid won the day.

After Innotech's appeals had cleared, the serious negotiations with AES began. Over a period of a few months, the government had added several new specifications that they would like to include in the facility. This meant that the Gulfstream aircraft would not be appropriate and that a Challenger would indeed be necessary. However, the intended budget for the facility and its operations would be very tight. Intera approached Bombardier to see if it could negotiate a suitable lease for a Challenger 600. Bombardier was just launching its new long range Challenger 601 and proposed to Intera that it use a new one for the program. This was too rich for the budget and Intera had to look elsewhere for an alternative. To the dismay of Bombardier, Intera found a suitable Challenger 600 that was owned by an Irish businessman who wanted to divest himself of the aircraft. In the face of Bombardier's objections at the ministerial level in Ottawa, the government gave Intera the green light to proceed with the development of the CIRS (Canadian Ice Reconnaissance Service) system and the commencement of the corporation's largest contract of $60M for an advanced SAR facility that would operate for six years in the Canadian Arctic.

It was Intera's responsibility to pay for the development of the turnkey system and to provide ice reconnaissance services for the Canadian Ice Service (CIS). The company would recover its investment and pay for operations through its services with the CIS over a six year period. In order to pay for the development costs, which were estimated to be $20M, Intera decided to raise the funds on the open market. To accomplish this goal Intera needed the assistance of an experienced public company and negotiated an agreement with the Trimac Corporation to invest in Intera. In February of 1990, Intera went public on the NASDAQ and Toronto exchanges, raising net proceeds of $21M.

As part of the agreement, Trimac invested $1M in Intera and received a share of the company, while Intera took over the responsibility for the operations of Kenting Earth Sciences in Ottawa. Kenting had been losing money with a major geophysical program in Thailand, until it was rescued by Intera and successfully completed under the leadership of Bill Jefferies. At the same time the photogrammetric production facility of Kenting would prove to be a valuable asset in the future for the production of Digital Elevation Models (DEMs) with Intermap's interferometric SAR data.

After almost two years of development and with expense overruns, the CIRS facility was ready to be flight trialed and to begin operations. New aircraft certifications were obtained for the specially designed radome and for the gravel deflection kit for the Challenger jet. Internally it was known as the STAR-2 system because it represented the next generation in SAR technology and it included a dual sided, wide swath, digital SAR with downlink capability over an IRDNET network of 8 relay stations throughout the Arctic using ANIK satellite communications. This allowed the Ice Centre to receive in real time the SAR imagery in Ottawa while other simultaneous relays transmitted the imagery to Coast Guard and commercial ships in the network.

This facility represented the pinnacle of SAR development and would lay the foundation for the ice community's dependence on SAR data from RADARSAT and other SAR missions. It was the first Challenger configured entirely for surveillance purposes. This facility also represented a turning point for Intera.

Intera's STAR-2 Ice Reconnaissance System

In the fall of 1989, the CIRS system began its operations for the CIS and for the next five and a half years it would successfully operate throughout the Arctic while the RADARSAT-1 satellite was nearing completion. During this operational period, the requests by the CIS for CIRS flights were fewer than expected, and as a result, it was becoming increasingly unlikely that Intera would be able to recover its full investment in the facility. Although it had been expected that the CIRS system would fly upwards of 2,000 hours per year, the actual flight time total was much less than that amount. Furthermore, it was anticipated that the services contract would be extended as RADARSAT was being built and commissioned.

The CIRS services contract was ended in March, 1995 as RADARSAT-1 was nearing its launch date. At the time, Intera still had more than $6M in unrecovered development debt on the books with other costs, and the prospects for the system being sold to another party as a complete surveillance platform were not good. The aircraft was eventually sold separately and the radars remained unused.

Over the previous year prior to the end of the services contract, Intera had attempted to negotiate with the government a resolution to the development cost issues without success. When the contract ended, Intera took the unprecedented step of commencing legal proceedings seeking damages against the government in the amount of $8M plus interest. Eventually a settlement was agreed between the parties, but not for the full amount sought. The STAR-2 radars were transferred to Environment Canada, but were never used again. Later that year in 1995 Intera closed its doors as a legal company in Canada and in January 1996 transferred its assets and its remaining executive team to a newly formed company, Intermap Technologies Corporation, with new headquarters in Denver, Colorado.

The other divisions of Intera (petroleum consulting and waste management) were sold off to other corporations or were allowed to open separate operations. The waste management group in Texas retained the Intera name and is thriving very well today in that market under its new ownership. A small local waste management group built a good business in Ottawa and is now part of SNC-Lavalin. The petroleum group was purchased by Schlumberger and resulted in a healthy bank balance for Intermap to the tune of $70M from which to attempt to rebuild a new business.

The Intera era was over as quickly as it had begun twenty years previously, but its legacy and its impact on the SAR world would continue to today in the form of a new company, widespread SAR use by the global EO community and with the many experts that have passed through its doors as employees.

3.3.3.11. STAR 3i and Intermap (1996-Present)

The new company focused its efforts on creating the world's best Digital Elevation Model (DEM) data with its newly developed airborne interferometric SAR system, STAR 3i, using dual antenna configurations based on the STAR X-Band technology. The initial vision of the company was to create national DEM databases at the company's expense that it would own and sell under license to multiple clients, much like what government agencies do when they create map data for resale. In this process the company has generated DEM data throughout Western Europe, America, Southeast Asia, Australia and parts of the Caribbean.

Since this contribution is about CCRS and Intera, little will be said here about the history of Intermap. The company did develop one of the most advanced interferometric SAR productions facilities in the world, which it initially based in Ottawa and later moved to Indonesia in 2005. It very successfully created the DEM data from the SRTM mission in 2000, but that was its only foray into the spaceborne InSAR sphere. Since its inception in 1996, it has never made a profit and has survived largely on shareholder equity and debt financing, as well as income from data and service sales. In 2010 the company was put under new management and has attempted to reshape itself into a systems and service sales company in the Spatial Data Infrastructure (SDI) sector, where it hopes to add its DEM data products into an integrated infrastructure context and to further its mapping services.

3.3.3.12. Summary and Legacy

At its high water mark in 1991, Intera was a public corporation that employed a thousand people in four operating divisions with offices in Calgary, Ottawa, St. John's, Toronto, Houston, Austin, Denver, Jakarta, Perth and Henley-on-the-Thames, generating gross revenues of $100M. Much of its business and revenues came from the remote sensing and mapping operations.

It is estimated that Intera invested some $60M in developing and promoting its SAR and mapping capabilities over twenty years between 1975 and 1995. In that time it is estimated to have generated in excess of $250M in related revenues, a fourfold return on investment. And although the company no longer exists in its original form, its accomplishments in the SAR field were ground breaking, including:

- Creation and operation of the world's first digital airborne SAR commercial service;
- Development of the first real time, airborne, digital SAR downlink and display technology;
- Development of the first digital SAR shipborne workstations;
- Development of advanced processing and analysis software for a wide range of SAR applications as part of CCRS research initiatives;
- Development and operation of the world's first dual sided, wide swath, digital SAR ice reconnaissance system and service with real time data relay throughout the Arctic;
- Introduction and creation of SAR data services in the offshore oil and gas and shipping markets;
- Development of SAR simulation software for the pre-launch creation of satellite data products;
- Founding member of RADARSAT International;
- Management and coordination of the SURSAT CV-580 projects throughout Canada, leading to the formation of the RADARSAT concept;
- Management and coordination of the world's first multinational SAR campaigns;
- Introduction of digital SAR data to researchers in over 50 countries; and
- Contributed to the development of hundreds of highly qualified personnel, many of whom are still active in the field to Canada's benefit.

Although the company never truly embraced spaceborne SAR data and services, its activities and initiatives had involvement and implications for SAR space missions in Canada, the U.S., Europe and Japan. At one time there was even a brief internal discussion of a possible INTERASat mission. It was an ironic effect that Intera's SAR activities would help to create international momentum in the use of spaceborne SAR data, while the company almost exclusively focused on airborne SAR products and services. It was a big opportunity missed by the company.

Intera's legacy is not in the fact that it took its modest beginnings and turned it into a billion dollar enterprise, as it well could have with certain changes in direction. Its legacy is in the fact that it embraced the CCRS technology transfer policy and turned it into a viable business for twenty years that included the development of new innovations in SAR technology and applications to a plethora of new users around the world. Intera's business involved projects of various kinds in 85 countries and included introducing digital SAR data for the first time to more than 50 countries, whether it involved the CV-580 activities or the STAR-1 and 2 operations. Many of the users from these countries subsequently purchased Canada's RADARSAT data, receiving stations, image processing and analysis software, storage and archival systems, training and education services, consulting and mapping services, as well as project management assistance. Thousands of individual researchers from around the world, who would not normally have had the opportunity, benefitted from Canada's programs and cooperation in which Intera played a key part. SAR data now forms the operational standard for many ice monitoring applications, Digital Elevation Model mapping and surveillance activities directly as a result of Intera's early initiatives.

Although there are no complete summaries of the revenues from Canada's SAR business from its early beginnings in 1976 to today, it can safely be said that it totals in the many billions of dollars when including the design and building of satellites and their ground infrastructures, support technologies and services, as well as data and software sales, airborne systems, applications analysis and training services. If we are to also take into account the savings in costs accrued to the global user community through its use of SAR technologies and data as a result of their collaboration with Canada, then the benefits would be valued in the tens of billions. All of this had its genesis directly as a result of the CCRS technology transfer policies and its early visionary support of Canada's emerging remote sensing industry in companies like Intera.

3.3.4. Other Industry-focused CCRS Technology Transfer and Related Success Stories

3.3.4.1. Introduction

Bob Ryerson

CCRS had a continuing policy over a number of decades to work with industry and this section provides further detail. Section 3.3.4.2 profiles Prologic Systems, another player in the provision of support staff and contractors. Prologic got its start working with CCRS and expanded to provide support to a number of other government agencies. As is explained, it saw its role to both support clients like CCRS and to provide the initial first job to recent graduates.

Section 3.3.4.3 introduces the company Satlantic that evolved out of Dalhousie University with some ties to CCRS. The material on Satlantic shows the way in which people worked at CCRS as visiting scientists and post-docs then took their experience to industry and, in this case, internationally.

Section 3.3.4.4 describes one of the more recent of CCRS's successes – the Innovation Acceleration Centre. The last substantive Subsections detail other successes – and a notable failure.

3.3.4.2. Prologic Systems

Keith Langley

3.3.4.2.1. Introduction

From 1975 through the late 1990s Prologic Systems Limited had contracts with the Canada Centre for Remote Sensing in software engineering and research support roles in remote sensing applications development, and related informatics professional services and contracts for Government-Owned/Company-Operated Facilities Management of business units. Canada has had a lengthy and important role in the fields of remote sensing and geomatics. Prologic is proud to have been one of many contributors to these technologies. This section describes the activities of Prologic in support of the advancement of many remote sensing technologies and methodologies, and activities that process satellite, airborne, Meta-based, map-based, and GIS-based data sources. As a stakeholder in Remote Sensing/Telecommunication/Informatics, Prologic is affiliated with the Ontario Centres of Excellence (CITO-TRIO, CRESTech-ISTS), and associations OCRI, OCEDCO, and CAB*NET. Our goal has been to represent the best practices in the industry and to re-establish technology based contracts that facilitated the employment of educated youth into their first relevant employment.

3.3.4.2.2. Contributions to CCRS and Remote Sensing

Prologic contracts included the development of special purpose software for data transcription and image analysis processes for most data types with which CCRS worked (airborne, satellite, map and GIS). Data were manipulated by image analysis/transcription processes, Geo-referencing systems and derived-product production systems.

Under its R&D service contracts to CCRS Prologic has managed teams and individuals, Statement of Work (SOW) and reporting responsibilities for research support contracts, hardware maintenance, operation of unique transcription systems, and management of the branch-wide network/mail systems. Prologic worked on RADARSAT Data Development projects, the DICS Digital Image Correction System, Airborne Image Data Transcription Systems, the CIR and Fire240 Colour Imaging Systems.

Our contract personnel contributed to the development of software for radiometric correction, geo-correction, extraction of information (map and terrain), data visualization tools, mapping and data warehousing. Software developed is residing within many of CCRS processing systems, such as: LDIAS, SQUIS, DICS/GICS/MOSAICS, SOP/SOC/SAR Order Desks, GEORAD, MEIS/GEOCOR, GCE/GEOSCOPE, GCNet/CEONet, the GEOCan home page and the National Atlas.

On behalf of Geo-correction (Geocor) and the Local Environmental Applications Program (LEAP) projects we integrated CCRS processes onto different hardware processors, PC, IRIS, Indigo and Sparc, and onto different operating systems including IRIX, SunOS, Solaris. We also developed software to modify scene geometry and spatial correctness and modified Geocor to produce digital terrain height information from stereo data sets.

Not only involved in receiving technology and developing technology to be transferred, Prologic provided programmer and technical services to the Technology Enhancement Program of CCRS, using PC-based multi-media hardware and software to create materials on remote sensing technology for training and promotional products for access via Internet and World Wide Web.

Over time we integrated new data sources into Geocor, such as 2D digital video and processed remote sensing images, via CCRS GIS systems, then transcribed data onto tapes, into map based imagery, and onto CD ROM media format.

3.3.4.2.2. Applying Our Expertise More Widely

The expertise gained working with CCRS led to a number of further contracts in Canada and internationally. Using the expertise gained, we then implemented the Geocor processing software in Italy, the USA and here in Canada. Along the same lines we collaborated with industry to process data via Geocor, for Mosaic, Nova Gas, Falconbridge, the Labrador First Nations, and for government agencies to provide GIS analysis, imagery correction, ground data and maps of the proposed Voisey Bay mining site. We also used CCRS image analysis systems to produce geo-referenced imagery, before/after the Saguenay flood.

Prologic applied its expertise in converging applications that use geo-spatial technologies for data storage, data visualization and data organization. For PWGSC we did 3D modeling of proposed building sites, sun shading, real-time landscape growth visualization at their Digital Simulation Laboratory. We provided 3D Graphics Operators to gather visual information for building sites for modeling and texture mapping in SoftImage, image editing using Photoshop, rendering and animation using SoftImage and post production work using Aftereffects and Pagemaker.

For Statistics Canada we did software development on their web access/electronic shelf development for their spatial and time referenceable data warehouse and ordering process for census data. For Elections Canada we carried out a GIS data development project to automate electoral boundaries, contributing in our small way to democracy in our country. At Forestry Canada we provided programming service to develop software and to run processes, to perform radiometric adjustment, geometric correction and terrain height extraction of MEIS data for the MICFUCAM Project. Through provision of contract staff we also supported National Defence's mapping branch.

We provided scientific programmer analyst support for the Canadian Space Agency to develop and maintain science orientated packages to enable on-line extraction and analysis of sensor data via the NASA-CANOPUS network. The CANOPUS Project is Canada's contribution to the International Solar-Terrestrial Physics Program, to study the interaction of the Sun-Earth system, using remote sensing data of the upper ionosphere.

3.3.4.2.3. Conclusion

Prologic was deeply involved in helping to develop many world class products and services for CCRS. Along the way a number of Highly Qualified Personnel developed their expertise while employees of the company. That expertise has been applied for other customers of Prologic around the world, as well as contributing to the pool of HQP in the Ottawa region.

3.3.4.3. Satlantic

Howard Edel

Satlantic was formed by Dr. Marlon Lewis of the Department of Oceanography at Dalhousie University. One of the company's foci was remote sensing and in this regard the company worked closely with

Fisheries and Oceans and had ties with CCRS, DREO, and the Canadian Space Agency in several areas. One example is the work of Richard Olsen who had been a Visiting Fellow at CCRS, funded by the NSERC Canadian Government Visiting Fellowship Program beginning in the fall of 1986. While at CCRS, Richard supported the commissioning of the CV-580 airborne C-band Synthetic Aperture Radar (SAR) and worked on radar remote sensing for marine applications. He later joined Satlantic Inc. (in November 1991). Major projects which he managed at Satlantic included the development of the Ocean Monitoring Work Station and the IOSAT Transportable Ground Station, as well as several studies to improve access to satellite Earth Observation data for the marine industry and government in the Maritimes.

Richard Olsen returned to Norway in March 1998. He became program manager for the Forsvarets forskningsinstitutt's (FFI) space group, working on applications of SAR data from the Canadian RADARSAT-1 and -2 satellites, as well as ENVISAT and other European SAR satellites. The group pioneered Spaceborne AIS (Automatic Identification System) nano-satellites for maritime traffic monitoring in combination with ship detection in SAR imagery. In 2015 he became Deputy Director of FFI's Air and Space Systems Division. The FFI continues to work closely with Canadian research groups, in particular Defence R&D Canada in Ottawa and the Space Flight Laboratory at the University of Toronto.[74]

It was at Satlantic Inc. that Olsen and Dr. Bob Allen secured EOADP funding to build and demonstrate the transportable ground station which was implemented with reception and near-real-time processing and information products derived from ERS and RADARSAT-1 satellite SAR data. The resulting SENTRY ground station integrated the Ocean Workstation for near-real-time operational processing and provision of vessel detection information products for tactical support. The company IOSAT was established by Satlantic to undertake the service support and marketing of the SENTRY transportable station. A two year operational demonstration of the SENTRY system was successfully completed by DND/Navy at their Halifax facility. Unfortunately no Canadian Government department or agency undertook the purchase and operational use of the SENTRY system. IOSAT eventually sold the SENTRY system. Nova Consult contracted service support for SENTRY which provided operational ocean information products from RADARSAT-2 and Sentinal-1 in the period of 2003 to 2016 when it was decommissioned. This is an example of Canadian government initiating the development of state-of-the-art user application of SAR technology which was ahead of the identified operational requirements being identified and funded for continued operations by Canadian government (including military) missions deployed nationally and internationally.

3.3.4.4. Innovation Acceleration Centre

Bob Ryerson

The Innovation Acceleration Centre (IAC) was the brainchild of Dr. Marc D'Iorio[75] The intent was simple: it was a cooperative effort aimed at uniting government and industry in the collaboration and commercialization of research and development initiatives developed at CCRS. As stated in a press release by PCI Geomatics[76] "the IAC provides a framework for cooperation between government and industry in research and development and allows CCRS to help accelerate the development of geomatics and remote sensing products and services." To access CCRS staff and experience a company had to explain what it hoped to accomplish, what the expected market would be, and why it should be accepted.

[74] Editor's Note: Some additional material in these last two paragraphs was provided by Richard Olsen.
[75] D'Iorio was one of the Scientists identified as having the potential to become a leader – he later became Director of the Applications Division and Director General of CCRS.
[76]The material on PCI comes from https://www.pobonline.com/articles/89583-pci-geomatics-joins-the-innovation-acceleration-center

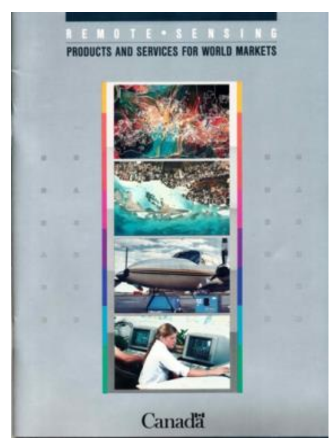
The IAC earned a high profile during its relatively short life. The potential to gain access to the IAC was announced in the autumn of 2001, with the official opening in 2002. Maurizio Bevilacqua, Secretary of State (Science, Research and Development), on behalf of the Honorable Herb Dhaliwal, Minister of Natural Resources Canada (NRCan), officially opened the Centre. Physically the IAC consisted of a large open office space on the first floor of the CCRS Headquarters at 588 Booth Street in Ottawa.

Among the nine first participants were PCI Geomatics and Alcan Aluminum. PCI sought to better understand the CCRS Imaging Spectrometer Data Analysis System to ensure proper implementation in the PCI Geomatics software environment, and the potential for the application of the technology. Lori Wickert of Alcan worked on a project to evaluate the technical capabilities of a wide range of satellite-based and airborne sensors and other remotely sensed data, including hyperspectral, as an exploration tool for bauxite deposits. Her study area was the Northern Territories of Australia.

Over a period of several years a number of industry participants worked with CCRS. In 2003, for example, AUG Signals sought to increase the capabilities and applicability of the Image Fusion Centre available at its web site. The plan was to develop a "multi-node Web-based distributed processing system for remote sensing applications through a new processing node built at Canada Centre for Remote Sensing (CCRS)." The project was to develop an "enhanced geospatial tool ready for online implementation that will be used on various data (e.g. hyperspectral, SAR)" for a wide variety of applications. The work tied together remote sensing applications in agricultural and land mapping applications to the Canadian Geospatial Data Infrastructure (CGDI). The CGDI then being developed was seen as the potential way to bring data together for analysis for precision farming, crop identification and mapping, yield estimation, productivity forecasting, land use/land cover change, estimating biomass, mapping forest degradation, etc. AUG Signals was one of the first companies to invest in the technology that is now known as cloud computing.

3.3.4.5. A Sampling of Industry Cooperation and Engagement
Bob Ryerson

The problem about mentioning individual companies is that we are bound to miss an important one. For that reason **we must state at the outset that mention of any company or failure to mention any company should not be construed as either an endorsement or criticism.**



At the start of CCRS there were no companies that professed to "do" remote sensing – no company built the technology and almost no companies used it. Over time that changed dramatically. By 1987 there were enough companies successfully engaged in the international market with world-leading products and services that External Affairs trade development profiled thirty-four companies in the full colour 48 page booklet ***Remote Sensing Products and Services for World Markets***. (External Affairs Canada, 1987) Indeed, remote sensing was seen as a way to promote Canada's credentials in the provision of high technology products and services well beyond remote sensing.

There were some companies that have become household names and others that quickly came upon the scene and, just as quickly, left. Some carried on under new ownership, lasted many years or entered new fields, while others provided a good income for their owners, but ceased operations as the owners retired. Here we have focused on a handful that seem most interesting as we examine how CCRS interacted with industry. Of the thirty four companies already exporting or judged to be export ready in 1987 six are among the ten profiled here. The reader is referred to the previous sections for a firsthand look at both Intera and Prologic.

MacDonald Dettwiler Associates (MDA) MDA (now owned by Maxar) is the company that is most closely associated with CCRS, virtually from the beginning of both entities. The importance of CCRS and Dr. Larry Morley in the growth and international success of MDA is clearly detailed in an interview of Dr. John MacDonald conducted for ***Quest*** by Barry Shanko. (Shanko, 2012)[77] MDA was incorporated on February 3rd, 1969 by John MacDonald, then an Associate Professor at UBC and Vern Dettwiler in part to provide local opportunities for the best engineering students graduating from UBC.[78] MDA began by building real-time monitoring and control systems. They got into remote sensing after bidding on and winning a contract to build a component of the receiving station for ERTS-1 (renamed Landsat 1). MDA built the same box for Bendix for a ground station in Brazil and "that was the beginning of MDA's international business."(Shanko, 2012, p. 47) From this MacDonald and Dave Sloan (who brought the original remote sensing opportunity to MDA) concluded that they could build a full ground station in a 10 x 40 foot trailer, for a cost of $2 million, vs $25 million for the stations NASA was building.[79] To better assess quality of the image data being downloaded MDA added a "quick-look" system. The first of these inexpensive systems was installed in Newfoundland. The potential sale of ground station technology was so important that a technical trade mission was planned around MDA that saw a number of companies attend the Asian Conference on Remote Sensing in Hyderabad, India in 1985. The thinking was that if India, a cautious and informed buyer, bought MDA's system, other sales would follow. That is what happened. MacDonald estimated that MDA had 85% of the satellite ground station business. Assessments by this author put the market share even higher and most of the stations MDA built were of the larger variety, costing on the order of $20 million for the full system.

MacDonald stated that "the Canada Centre for Remote Sensing (CCRS) played a key role in MDA's development as an international space company. Larry Morley, the CCRS's Director General during the 1970s, believed that government should define what it needed and then fund companies to create those products or services and the technology behind them." MacDonald said that "it was from Larry that we learned how to build a high tech company in Canada." (Shanko, 2012, p. 47) He further stated that one had to develop an export focus because the market in Canada was too small. Into the 1990s exports were four times the value of sales to the Government of Canada.

MacDonald saw Dr. Morley as unique – "a civil servant with an entrepreneurial mind….who would take a risk." The Unsolicited Proposal Program, mentioned in several other places in this document was also noted as being important to MDA. The UP program provided the funds and the all-important beta client to work out the bugs in a new system for an understanding client who shared the risk. MDA would then bring international clients to CCRS to see their systems being used. In many cases the sale of a ground station was contingent upon the client country sending staff to CCRS to learn how to operate a ground receiving station. CCRS was happy to have these international guests working with them. Life-long friendships – and business relationships – resulted.

Associated with ground station technology was the FIRE image recorder developed by Dan Gelbart then with MDA. The first system was sold to the NRSA in Hyderabad India. "Our first sale to NRSA in Hyderabad India in 1983 opened the doors at RS centres in Malaysia, China, Japan, Thailand and Australia. I think by the time the Fire became obsolete due to the internet, we sold 200 units worldwide – a mix of black and white laser and colour models. (Customers included…) DLR, JPL, Kodak, Polaroid, CIA, DIA, CCRS, ACRES, Telespazio, CNES, ESA, MACRES, NRSA, ISRO, SAC, IMO, Ecuadorian RS, German Geological Institute, Facilities Management Limited, Hughes Aircraft, ERIM, ERSDAC, JAPEX, Mitsubishi, Hitachi, Chinese Academy of Sciences, China Coal, China Oil Company, BP

[77] The balance of this section is derived from material in Shanko as well as from the authors recollection and later participation in some of the events chronicled. See http://www.spacebusiness.com/quest-topic.pdf and search for Item 19:4 under Oral Histories, Biographies and Stories.

[78] John MacDonald told the author this during a breakfast discussion in the early 2000's.

[79] The reader should keep in mind that these dollar values are expressed in 1970s dollars: $25M in 1975 would be over $110M in 2018 and $2M would be $9M.

Petroleum, Hunting Geophysics, Alaska SAR facility, EROS Data Center, USGS, Western Geophysical, etc." [80]

The next big breakthrough involving MDA was the development of a digital processing system for SAR data. The importance of that development is clear: it led directly to the two RADARSATs and the RADARSAT Constellation Mission. Further details on this breakthrough are provided in Section 7.6.

Intera/Intermap. Intera was a key and early player in both airborne remote sensing and the application of the technology. A thorough profile is provided in Section 3.3.3. The original owner of the company died in an airplane crash and the company was bought by Brian Bullock. Diane Thompson (Coleman) was one of the first employees and became an early and highly respected leader in the field. She was later joined by Mike Kirby, Rob Inkster, and Marc Wride. Diane left Intera in the mid-1990s and helped Golder Associates develop their remote sensing expertise in part through the purchase of Terrain Resources owned by Malcom Lowings.[81]

Dipix. Dipix was founded by a group of employees of a technology firm in Ottawa that was originally contracted to make modifications to the Image 100. It was led by Paul Pearl and the Chief Scientist was Steve Gourlay. They developed a hardware-based image analysis system that they called ARIES. Two of the first systems were sold to the Forest Management Institute led at the time by Dr. Leo Sayn-Wittgenstein and the Ontario Centre for Remote Sensing. As is explained in the accompanying text box, a big break occurred in 1982. At its peak Canada had as much as 50% of the world market for digital image analysis systems and Dipix had the majority of that. It eventually sold its image analysis business to PCI. Pearl and the other owners of what became Dipix Technologies then focused on machine vision systems for the on-line inspection of manufactured food products: Dipix was sold to another technology firm in 2007.

Dipix, Serendipity and the Market in China
Bob Ryerson

In September 1982 the International Society for Photogrammetry and Remote Sensing's Commission VII (Interpretation of Data) was holding its quadrennial conference in Toulouse, France. CCRS sent a sizable delegation including Paul Hession as Head of Marketing and a number of scientists including Ron Brown, Bob Hawkins and this author. For the first time in decades there was a large delegation from the Peoples Republic of China at a Commission VII meeting, including the head of remote sensing for the water resources department, one Professor Wang. The weather was hot as was the exhibit hall.

The meeting was seen as an important conference for the suppliers of image analysis equipment. The British were there with their GEMS system, as were both French and US suppliers with their respective systems. When we arrived the day before the exhibit officially opened the British, French and American suppliers were busy trying, without success, to set up their systems in a very warm exhibit hall without air conditioning. The DIPIX team was nowhere in sight. As I recall the DIPIX team, led by Vijay Dube, eventually rolled in early the next morning – literally an hour or two before the first day of the exhibits after having driven overnight in a Volkswagen van from Rome where they had been showing the system to the FAO. By this time none of the others had managed to get their systems to work. Dipix came in, unloaded the van, plugged in the system and it began to work from the get-go. None of the other system providers ever did get their systems to work properly throughout the entire week, so Dipix was the only game in town. This was the best result one could imagine for the reputation of Dipix and, by extension CCRS and Canada. Shortly after Dipix started getting orders for systems from unknown groups in China.

[80] Personal Communication from Dan Murray, June 24, 2018. Dan was a well known and trusted fixture at the Asian Conference on Remote Sensing from the mid-1980s into the mid-1990s.
[81] Editor's Note: Bob Ryerson joined Terrain Resources as a Vice President in 1996 and when the company was sold to Golder Associates in 1997 he became a consultant to Golder for a short time and founded Kim Geomatics Corporation.

Two years later when in China on a UN assignment (January 1984) I happened to meet up with Prof. Wang who showed me his very modern looking image analysis lab – the only modern looking lab of this type I saw in Beijing after two weeks visiting labs every afternoon. When I offered a positive comment he replied "This is nothing – you should see my regional labs – I have three Dipix systems in them." When I asked how that happened he replied: "Remember Toulouse. I figured that if the other suppliers could not get systems running in Toulouse how would they ever get them running in the cities where we work? So I bought Dipix systems, as did others."

When giving a lecture in Beijing as part of my UN assignment I said that "we processed a Landsat image to map potato acreage." I was certain that my interpreter Ms. Li Li said "dipix" in her translation into Mandarin. When I asked what she had said her response surprised me. She replied that "dipix" was used as a verb in Mandarin to replace the much more convoluted verb structure that meant "process an image." So many systems were purchased in China that for a time "Dipix" became a verb – as in "we dipix a Landsat image to map potato acreage."

And this all happened because a dedicated group of young engineers made a system work at a conference in France after driving all night from Rome to Toulouse.

PCI Geomatics. PCI was started in 1982 when it bought the image analysis side of OVAAC-8, a company started in the mid-1970s,[82] which hired David Stanley in 1981. The late Dr. Bob Moses, a medical doctor whose interest in medical imaging led him into investing in PCI later owned and ran the company. David Stanley was a key individual from the beginning with a number of roles including Chief Technology Officer and Board Member. Dr. Murray Strome was President and CEO in 1984 leading some of the early development that resulted in PCI becoming a force in the business. His involvement again illustrates the close linkages industry had with CCRS. PCI was based on a software rather than a hardware approach to doing analysis, building on the rapid development of processing power in small computers. With its own internal research and development activity headed by Stanley, PCI was well positioned to identify and use CCRS software and research in licensing agreements. As early as 1992 Dr. Thierry Toutin's DEM multi-sensor generation algorithms and systems (Section 6.6.8.1.) were licensed by PCI and were updated over a number of years for a series of satellites. Dr. Toutin received the prestigious Prix d'Excellence in 1999 for his collaboration with PCI – one of the longest collaborations between a Government of Canada scientist and industry.

As noted above, PCI has used the Innovation Acceleration Centre – the CCRS incubator as well as various programs operated by the Canadian Space Agency. Eventually PCI bought the image analysis business of Dipix. As of 2018 PCI has continued to successfully operate in a highly competitive international market.[83]

Optech. Optech was started in 1974 by Dr. Allan Carswell, a Professor of Physics specializing in laser systems at York University. With Carswell's expertise and "early CCRS research into the physics of laser measurement and the engineering of a scanning laser system, and in partnership with the Canadian Hydrographic Service(CHS), an aerial hydrography project was established in the 1970's. Optech Inc conducted the design study for CCRS' prototype laser bathymeter, CHS developed the navigation and data processing systems, and a long series of successful bathymetric surveys begun on CCRS' aircraft took place in Canadian lakes and the North through the 80s and into the 90s. The second prototype, developed by Optech, established the company as the world leader in the technology. Commercial success lagged for ten years until aircraft positioning problems were resolved, incorporating significant intellectual property of CCRS scientists. As a direct result of its interaction with CCRS, Optech Inc had sold 19 terrain mapping systems at $1 million each, and had sold or was building nine laser bathymeters for $3 to $4 million each by 2002." (Whitney, 2004) Optech grew to 200 employees with offices in the US and Canada and clients from literally around the world. In 2012, Teledyne Technologies bought a majority stake in the still very much alive and still successful company.

[82] OVAAC-8 and its ties to CCRS are mentioned in section 7.4.
[83] See http://www.pcigeomatics.com/about-us/about-pci

CREO. CREO was founded by Dan Gelbart (the person behind the successful MDA FIRE image recorder) and Ken Spencer in 1983. They developed a data storage system that was at the time far better than the high density tapes that were then being used at satellite receiving stations. CCRS served as the beta site for the product which was later sold to satellite receiving stations around the world. While CREO left remote sensing to focus on the printing business, Gelbart has often spoke fondly of the importance of CCRS as a beta site to get the company started. At its peak CREO was a technology success story employed 4200 people in British Columbia. It was bought by Eastman Kodak in 2005. Gelbart has continued to develop new ideas in a company he has financed with the proceeds of selling CREO, while other CREO alumni have made their mark in other areas.[84]

F.G. Bercha and Associates. F.G. Bercha and Associates was founded in 1975 by Frank Bercha, a Professional Engineer. They formed part of the basis of a remote sensing services industry in Alberta focused on the energy sector. Bercha and Associates also provided employees to CCRS on a contract basis as part of the early CCRS technology transfer activities. Bercha and Associates specialized in Arctic offshore and petroleum engineering and diversified into risk analysis and remote sensing. By 1980 they had acquired their own airborne multisensor system including side looking airborne radar (SLAR) in a Gulfstream G-1 aircraft. By 1982 they were active in South East Asia and South America and had a reputation for work on pipelines and offshore developments. The company is still active in these areas with some fifteen employees.[85] Like Intera the F.G. Bercha alumni have gone on to careers with a number of other players in the field. The late Val Shaw, a Vice-President of F.G. Bercha, has had a major award of the Canadian Remote Sensing Society posthumously named after her.

Imapro: Following its inception in 1976 Imapro Inc., a startup company in Ottawa, initiated the development of a high-resolution digital color film recording system called the Color Image Recorder (CIR). The CIR recorded full colour digital images from Landsat on 9-inch colour roll film. (See Section 7.7 for more details.) Imapro Inc. and later the Imapro Corporation have played a major international role in the business and presentation graphics, color scanner and film recorder markets.[86]

WorldSat International. The relationship with WorldSat is instructive on several levels. WorldSat International was started by west coast artist Robert Stacey. He saw the potential to sell satellite image posters to tourists and others. He also thought that the beauty in the imagery could be exploited by making the colours more like what one would expect – simply stated…blue water and green vegetation. It happened that he came up with the idea just as CCRS was beginning to publish promotional (and free) poster maps. Stacey developed a way of enhancing the imagery that no-one else seemed to be able to duplicate – including some of the best minds at CCRS. Stacey came to Ottawa to ask if he could get access to the data and pay a licensing fee, rather than pay the several thousand dollars per scene up-front. This reduction in up-front costs to replace the CCRS cost of giving away free posters while still gaining visibility for the program with the CCRS name on every poster was a "no-brainer." This licensing approach is how it was done for the first few products: after that WorldSat bought the data. The poster maps printed on art quality paper were a success from the outset – hundreds of thousands were sold with a focus on cities and tourist areas. CCRS did a small study of topographic map sales and WorldSat products several years later. That study showed a decrease in map sales over every area where WorldSat produced an image map with one exception. The one exception was a topographic map bought by the Canadian military for training purposes – large numbers of that map were still being sold after WorldSat produced a map of the same area! With the growth of the Internet WorldSat has moved on to produce high quality satellite data for airline use, globes, and other promotional materials and imagery for a range of clients including ***National Geographic*** and ***Canadian Geographic***.

[84] Some of this information came from a conversation with Dan Murray in Vancouver on February 4, 2019.
[85] See http://www.berchagroup.com/
[86] Personal communications in 2016 from Neville Davis (Canada Centre for Remote Sensing, EMR, Ottawa) and Fred Andreone (Imapro Corporation, Ottawa).

A number of other companies made major contributions to CCRS. Soon after ***Canadian Astronautics Limited (CAL)*** was formed its president, Jim Taylor, did a key study on the potential for a radar satellite – and CAL later became involved in the RADARSAT program. ***Calian*** of the Ottawa area became a supplier of staff to the satellite receiving stations, as did ***SED*** of Saskatoon for the Prince Albert Satellite Station. Many small companies started up and had ties to or contributed to the success of CCRS.[87] Among these were ***Knudsen Engineering, Dendron, Noetix, Gregory Geoscience, Prairie Agri-Photo, Horler Information***, ***Pacific Geomatics,*** and others.

Many other companies emerged as players in remote sensing in the early years but were linked to CCRS primarily since CCRS promoted them internationally. These included ***DIGIM, Lavalin, Geomatics International, Terra Surveys, Itres Research*** and others. Itres is still very active in sensor development.

3.3.4.6. Some Less Successful Industry Cooperation

As noted above, the development of an industry was one of the goals of CCRS. Over time there were examples of problems dealing with contractors and others in industry. There were contracts whose objectives were not fully met, disagreements about how CCRS worked with a contractor, and the odd dispute about how contracts were awarded. However, by and large the companies CCRS dealt with continued to perform and perform well, but for one glaring example.

ISIS.[88] Early on it was decided that the sale of data, including taking orders and fulfilling them, would be done by the private sector. In this case, of course, there were no experienced companies – no-one had ever sold satellite images before.[89] ISIS, a local family-owned company in Prince Albert Saskatchewan was given the contract. ISIS, based at the Prince Albert Satellite Station, was the subject of complaints about poor quality and slow delivery almost from the beginning. The matter came to a head at the 1975 CACRS meeting.[90] CCRS decided to take over the ordering and production. When CCRS took over the operation it was said that there was a desk drawer full of orders that had not been filled. CCRS continued to successfully produce and sell Landsat and SPOTdata until the success of the sales effort (See Section 6.2.3.) led to a second (and more successful) attempt to have the sale of data in the hands of the private sector.

Contractors or employees? A number of on-site contractors (often referred to as consultants in government) were employed by various companies to work in various parts of CCRS. While CCRS did have a technology transfer activity that brought on-site contractors into CCRS with the goal of further developing industry capability while supplying needed support, not all contractors moved into careers in industry or at CCRS. It was argued that some of these contractors were functioning as employees and they should be employees. About 2006, after working more than 20 years under contract, some of these contractors were hired as permanent employees within CCRS and elsewhere within NRCan. Other on-site contract staff either left or got permanent positions at around the same time. Some administrative staff became government employees a few years earlier.

3.4. Other Canadian Federal Agencies

Howard Edel and Bob Ryerson[91]

3.4.1. Introduction

Scientific staff at CCRS undertook collaborative projects with other Canadian federal and provincial government departments, ministries, and agencies to both demonstrate and prove remote sensing data

[87] Some were started by former post-doctoral fellows, others by contractors to CCRS or by former CCRS staff.
[88] The name is today an unfortunate choice. ISIS is believed to stand for Integrated Satellite Information Services.
[89] After the fact it was suggested that the aerial photography industry could have done the work, experienced as they were selling another type of imagery.
[90] See the 1975 CACRS Report, p. 7.
[91] With the exception of Section 3.4.2, Howard Edel wrote much of the material in this section. It was edited, added to and re-organized by Bob Ryerson

applications. The process used is further described in Section 6.6. In the early years CCRS often provided the remote sensing expertise and data while the cooperating agency provided the topical expertise. There were exceptions. Agriculture Canada, Forestry, Fisheries and Oceans, Atmospheric Environment (the weather and ice service), the Canada Centre for Inland Waters and the Canadian Wildlife Service all had some expertise in remote sensing. Some of these and others such as the Lands Directorate and Statistics Canada acquired expertise over time.

While the initial Applications Scientists were almost all hired from outside government, CCRS did bring in scientists from other federal and provincial government organizations. Dr. Keith Thomson joined CCRS from the Canada Centre for Inland Waters while Doug Heyland came from the Canadian Wildlife Service to head the Technology Enhancement Program. Dr. Vern Singhroy came from the Ontario Centre for Remote Sensing after spending time in both COGS and J.D. Mollard and Associates. Over the years a number of CCRS scientific staff left to join other agencies and universities where they contributed to the further development of remote sensing applications. There was a major exodus in the 2002-2005 timeframe when CCRS was forced to change its focus to work only on topics within the mandate of Natural Resources Canada.

Several university trained scientists completed their Post-Doctoral Fellowships (PDFs) in remote sensing and were employed in federal, provincial, territorial government agencies as well in industry and international organizations. Others joined Canadian University remote sensing programs where they are educating the next generation of university graduates in computer science and scientific applications disciplines. The text box in Section 3.6.2 describes one Post-Doctoral Fellow's experience at CCRS and the impact it had on his influential career on the world stage.

Other science departments as well as those with a more operational mandate undertook a major shift in the utilization of Earth Observation, from the interpretation of environmental parameters in individual scenes, to developing environmental models capable of crop forecasting, forest fire movement/containment, tracking ice breakup/movement, oil spill movement/spreading, flood prediction, and ocean productivity tracking. The rapid cost effective increase in computing power enabled the development of expanding predictive environmental applications of EO data sources as they international EO satellites became operational. The balance of this section is organized by the federal department or agency with which CCRS worked.

3.4.2. Agriculture Canada
Heather McNairn with Bob Ryerson

As Canada's federal ministry of agriculture, the mission of Agriculture and Agri-Food Canada (AAFC) is to "provide leadership in the growth and development of a competitive, innovative and sustainable Canadian agriculture and agri-food sector" (see www.agr.gc.ca). With 158.7 million acres of agricultural land (according to the 2016 Census of Agriculture: www.statcan.gc.ca) mapping, measuring and monitoring soils, land management activities and crop growth is a daunting task. Scientists at both AAFC and CCRS were quick to realize that space-based systems had huge potential for monitoring the state of Canadian agriculture, and in contributing to AAFC's mission.

Agriculture Canada was the first federal organization to actively participate in a CCRS Applications Division Project as described in detail Section 6.6.3.2. Later work at Agriculture Canada saw Dr. Pak Chagarlamudi lead agriculture scientists in using Landsat MSS data in soil productivity studies. Agriculture Canada crop scientists worked with Dr. Susan Till and Dr. Kian Fadaie who moved from NRCan/CCRS to Agriculture Canada (AgCan) to develop the tools to enhance information products from the advanced NOAA/MODIS sensor. Dr. Richard Fernandes at NRCan/CCRS worked with AgCan scientists in the development of tools to use the ESA launched/operated MERIS optical sensor data which provides greater spectral discrimination, sensitivity and 300 meter spatial resolution to monitor smaller fields with improved crop discrimination.

In its earliest days, as noted above, CCRS forged strong collaborations with Statistics Canada, a number of provincial organizations and AAFC scientists. They worked hand-in-glove to develop an understanding of how space technology could benefit the agriculture sector, and to create novel methods to extract valuable information on soils and crops. Other work with Agriculture Canada is described in Section 6.6. The symbiosis was remarkable as is described in Section 6.6.3.

3.4.3. Environment Canada

A major activity that has continued to today was and is associated with weather. Environment Canada updated their weather prediction models as orbiting EO satellite data became available to derive weather-related parameters. Beginning in the 1960's Environment Canada's Meteorologic and Atmospheric scientists implemented the use of the NOAA weather satellite data for enhanced Northern Hemisphere weather forecasting.

The first organization within Environment Canada to become involved in the sort of remote sensing in which CCRS was engaged was the Canada Centre for Inland Waters in Burlington, Ontario. There Drs. Bob Bukata and Keith Thomson were active in the early 1970s applying remote sensing to water quality and related features. The cooperation at that time was largely limited to CCRS providing data.

The Lands Directorate was involved in the Great Lakes Land Use Mapping Project described in Section 6.6.3.3.2. That organization later hired Jean Thie, the first head of the Applications Development Section of CCRS. Jean was the first CCRS staff member to join another government agency.

At the Meteorological Services, Dr. Val Swail, Dr. Rene Ramsier and Dr. Steven Peteherych led the use of passive micro-wave and active scatterometer sensor data for monitoring sea surface winds from an ever expanding satellite sensor suite operated by international space agencies. Ramsier in particular was very active in CACRS.

At the Emergency Science Branch, Dr. Mervin Fingas led the early studies of emerging remote sensing sensor and algorithm development to detect and monitor oil spills in marine and fresh water areas of Canada. Using a laser Fluorosensor, Dr. Fingas implemented the detection and identification of different oil types being transported through Canadian cold water/ice infested coastal zones by an increasing number of tanker vessels. Dr. Fingas established a collaborative science program funded and using both government and oil industry resources. Dr. Fingas also collaborated with Dr. Bob O'Neil NRCan/CCRS on the airborne tests of the Fluorosensor ability to detect oily bilge water in the marine environment.

Another early entrant in remote sensing in Environment was the Canadian Ice Service (CIS). The CIS has the mandate to produce tactical and strategic maps of Ice Conditions in the Canadian Arctic, Ice Infested Western Atlantic Ocean and the Canadian Great Lakes. The CIS participation in the joint Canada/USA ice monitoring studies with SAR sensors was led by Dr. John Falkingham using ERS and RADARSAT satellite data sources. The USA/ICE Service implemented a satellite ground station in Anchorage, Alaska providing ice information over the Aleutian Chain of Islands, Bering Sea, Bering Strait, Chukchi Sea and the north coast of Alaska. This collaboration with US scientists using SAR data for ice monitoring resulted in NASA providing the launch for RADARSAT-1 owned and operated by the Canadian Space Agency. John Falkingham was the Canadian delegate on the "International Ice Charting Working Group (IICWG) Secretariat" which was formed in 1999. The IICWG mandate is to promote co-operation between the world's ice centers on matters concerning sea ice and icebergs.

CIS became the Federal Government operational anchor user of RADARSAT-1 SAR data in their preparation of the Canadian Ice Charts used in safe navigation through the ice infested ocean routes used by national and international marine vessels. Early in the Canadian Government planning for the development and applications of RADARSAT-1 SAR data services CIS management agreed to replace their airborne radar ice surveillance with RADARSAT-1 SAR data.

The CIS implemented an electronic link from the Gatineau Satellite Station to acquire and process the SAR images at the CIS office in Ottawa. CIS also implemented a RADARSAT-1 Order Desk to streamline weekly orders of RADARSAT-1 SAR coverage to produce ice charts for the Canadian Coast Guard and other marine transport users. After the launch of RADARSAT-2, CIS undertook the development of the RADARSAT SAR based Integrated Satellite Tracking of Pollution (ISTOP) Program[92] to augment the Canadian Coast Guard aircraft based oil spill surveillance. CIS purchased the Ocean Work Station platform from Nova Consult, the company marketing the OWS, who also provided contract support OWS near-real-time electronic, CIS operator verified, oil spill and ice information services.

In 2004, David Jackson DFO/CCG became the Director of EC/CIS to enhance the link with DFO/CCG users of EC/CIS operational marine ice and oil spill information services using the SAR data from RADARSAT. DFO/CCG contracts EC/CIS to provide the ice and oil spill information along with the specific marine area meteorological forecasts from EC/MET branch.

At Environment Canada/CIS Dr. Roger D'Abrau led scientists in the development on contract of the ISTOP system for processing the RADARSAT-2 data from SAR into oil spill detection products in coastal ocean area of Canada. The ISTOP system was developed on the Ocean Workstation platform purchased from Satlantic. Michael Manore moved from CCRS to the EC/Canadian Ice Service to continue development of algorithms to enhance the sea ice type discrimination using the multimode SAR data from RADARSAT-2 and the ESA Sentinal-1.

3.4.4. Fisheries and Oceans (DFO)

At Fisheries and Oceans Dr. Jim Gower, a DFO/IOS senior applications scientist, was supported by Howard Edel who transferred in 1980 from NRCan/CCRS to DFO/Science in the capacity of Remote Sensing Coordinator. The regional DFO/Science Centres at the Institute of Ocean Sciences in Sidney, BC and the Bedford Institute of Oceanography in Dartmouth, Nova Scotia purchased mini-computer based Image Analysis Systems from PCI Geomatics. These systems gave the marine scientists the capability to process AVHRR and Coastal Zone Color Scanner (CZCS) image data into marine information products such as sea surface temperature to monitor ocean eddies and primary productivity. Later, all DFO regional science centres purchased the lower cost, personal computer based, image analysis systems from PCI enabling the sharing of applications software across the DFO regions.

Gower and Edel applied the Long Term Space Program funding which DFO Science obtained to demonstrate the Fluorescence Line Imaging (FLI) sensor using state-of-the-art CCD array digital imaging technology. DFO demonstrated the feasibility of acquiring and using airborne digital images to map phytoplankton primary productivity based on monitoring the solar stimulated red-edge re-emission levels in the oceans and Canadian lakes. The FLI was initially deployed on the CCRS aircraft and the digital image data transcribed from the CCRS instrumentation tape recording system onto computer compatible tape for analysis on image analysis system at DFO.

Based on the Canadian FLI design the European Space Agency (ESA), in cooperation with Canadian scientists, developed and deployed the MERIS sensor on the ENVISAT satellite which demonstrated the viability of monitoring global marine primary productivity from satellites. At the medium resolution of 300 meters, MERIS gathered images of global coastal zone and large lake productivity in greater detail than the earlier Coastal Zone Colour Scanner (CZCS) sensor previously deployed on a NASA satellite.

Also at BIO, Dr. Brenda Topliss led a scientific team developing the PCI image analysis system software analysis and applications of the NOAA/AVHRR satellite data. The data were used in the study of North Atlantic Ocean circulation patterns due to the warm Gulf Stream flowing north interacting with the cold Labrador Current flowing south. This results in many warm-core eddies and ocean frontal features which affect the Atlantic biological productivity. Her studies also included satellite oceanography monitoring regional ocean circulation patterns.

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[92] See https://www.canada.ca/en/environment-climate-change/services/ice-forecasts-observations/latest-conditions/oil-pollution-monitoring-overview/satellite-spills-overview.html

When the Canadian RADARSAT-1 was launched in 1994, a team of scientists and engineers from DFO and CCRS led the development of the Ocean Work Station (OWS) to demonstrate near real time processing of the SAR imagery into ocean information products. The OWS provides marine wind, wave and ocean front products to support safe vessel operations in the Canadian Marine Exclusive Economic Zone, and marine vessel detection for enhanced fisheries management. The OWS was developed and built by Satlantic Inc., with scientific support provided by NRCan/CCRS scientists Dr. Paris Vachon and Ms. Cathryn Bjerklund. DFO installed the OWS at the Gatineau Satellite station to acquire, process, distribute and demonstrate the near-real-time ocean information products derived from the SAR images. Satlantic Inc. of Halifax marketed the OWS to national and international clients. Dr. Bob Allen, principal at Nova Consult, later undertook the marketing and support for the OWS.

3.4.5. Forestry

Forestry has long been a major user of CCRS products and participant in CCRS projects. At various times forestry has had its own ministry or has been part of other departments – from Environment to Natural Resources – where it now sits. In the early 1970s the Forest Management Institute led by Dr. Leo Sayn-Wittgenstein featured well-known remote sensing scientists Drs. Udo Neilsen and Alan Aldred. The three were fixtures at early CACRS meetings and did much of the early research in forestry remote sensing in Canada. Dr. Peter Murtha was also employed by the FMI for a short time before he joined UBC.[93] The Petawawa National Forest Research Institute (PNFRI) was also active in forest remote sensing, notably Drs. Peter Kourtz (working on forest fires) and Don Leckie. When FMI was closed Neilsen, Aldred and Sayn-Wittgenstein formed Dendron Resource Surveys. When PNFRI closed, Leckie moved to the Pacific Forest Research Centre. As noted elsewhere, Dr. Sayn-Wittgenstein became Director General of CCRS. Eventually Dr. Frank Ahern led the CCRS work in forestry and worked closely with a number of agencies and companies. (See Section 6.6.2.) Forest fire remote sensing eventually found a home in the Great Lakes Forest Centre in Sault Ste. Marie under Mr. Tim Lynham who began his career as an operator of the CCRS Image 100.[94]

Dr. David Goodenough transferred from CCRS to the Pacific Forest Research Centre in Victoria where he became Chief Scientist. There he led the remote sensing program to provide scientific support to forest managers monitoring the effects of climate change, forest fires, etc. As it happened, when Dr. Murray Strome returned to government from PCI Geomatics, he too joined the PFRC and managed the remote sensing program.

3.4.6. Department of National Defence

While CCRS was clearly a civilian operation – which distinguished it from many other national remote sensing centres, the Department of National Defence has had a long association with CCRS. The original airborne operation, the Airborne Sensing Unit, was a military organization staffed by military pilots under Major Ernie McLaren. Over time that morphed into a government operation with the aircraft being operated on a contract as described elsewhere.

Links with DND tended to be based on personal interaction. An early member of the Geography Working Group, of CACRS Mr. Sid Witiuk at Statistics Canada, assumed a senior position at the Canadian Department of National Defence's agency Defence Research and Development Canada (DRDC). Through his tenure there were sporadic links. A major catalyst was the development of the Ocean Work Station (OWS). DRDC collaborated by providing enhancements to the Ocean Work Station user interface. DRDC purchased the OWS system and continues to develop algorithms for operational vessel surveillance and other ocean information products at both its Pacific and Atlantic facilities.

Dr. Paris Vachon moved from NRCan/CCRS to DRDC where he still leads the satellite SAR information product processing required for monitoring the Canadian coastal ocean areas of interest to enhance Canadian coastal zone security. (Dr. Chuck Livingstone and Tom Lukowski also left CCRS to join

[93] As noted previously, the late Dr. Murtha was the first Canadian to earn a PhD in remote sensing. That distinction was earned at Cornell University.

[94] An early study on forest change detection was done by Banner and Lynham (1982).

DRDC.) The OWS analysis processing has been upgraded to provide analysis of the enhanced SAR data products available from RADARSAT-2 and the future Canadian operational RADARSAT Constellation Mission and the ESA Sentinel/SAR satellite systems.

3.4.7. Statistics Canada

The involvement of Statistics Canada in remote sensing came about as a result of the work CCRS was doing on potato area estimation with the Provinces of New Brunswick and Prince Edward Island. In effect Statistics Canada (Barry Proud – responsible for crop reporting) was concerned that there may be two competing (and different) estimates for the politically sensitive potato crop area in New Brunswick – the one done by Statistics Canada and one by remote sensing. A research project to combine statistical reporting and remote sensing was approved by the then Director of Research (and later Deputy Minister) Dr. Ivan Fellegi.

An Additional Benefit of Remote Sensing **Bob Ryerson**
There are two problems faced by statistical reporting agencies who obtain information from respondents such as farmers. The first is respondent burden – the extra work faced by respondents to answer the questions being posed. Lowering respondent burden tends to lead to better cooperation. A second issue is the accuracy of what respondents tell field workers and enumerators. Typically farmers will tend to under-report, hoping that by so doing crop production would be underestimated and thus higher prices would result. The added benefit seen by Statistics Canada's Barry Proud of using remote sensing was that of improving the responses from farmers. By telling farmers that Statistics Canada was using satellites to monitor acreages he assumed that farmers would be less likely to under-report. This appeared to be the case.

The first result in 1981 saw the new remote sensing method provide a result for potato acreages in New Brunswick that was far more accurate than traditional methods when compared to the Census. That success led to Proud's suggestion that a remote sensing unit be developed. Ryerson was seconded to the Agriculture Division for eighteen months in 1982-1983 to develop that unit. Initially the staff consisted of Richard Dobbins (who remained with the unit until he retired), Robert Plourde, and a University of Guelph student Lynda Kemp (nee Magahay).[95] Jean-Louis Tambay provided the statistical expertise to the group. In 1983-84 Ron Brown's crop condition assessment work was brought into Statistics Canada and has remained part of Statistics Canada's reporting ever since.

Eventually the Unit evolved into the Remote Sensing and Geospatial Analysis Section with Gordon Reichert[96] the Senior Scientific Advisor. In 2016 a group of Statistics Canada employees received a Public Service Award of Excellence for work using remote sensing. The project was said to save money and reduce respondent burden across western Canada.

3.4.8. Canadian Wildlife Service

The Canadian Wildlife Service (CWS) was active in remote sensing in the early-mid 1970s through the efforts of Doug Heyland. His most famous work was with a special film developed by Kodak to penetrate water with the intent to identify submarines. CCRS flew some missions for Heyland in the Arctic to assess the film for identifying whales. The striking results later found their way into Manuals and texts on remote sensing, including that by Lillesand and Kiefer. Others were involved in habitat mapping, including Clay Rubec and Jean Thie working with CMS staff.

[95] Lynda eventually joined Statistics Canada after graduation and retired from Statistics Canada in 2017 as Assistant Director of the Agricultural Division.
[96] Reichert had worked on some of the early crop assessment work coming from the research of Ron Brown.

3.5. Scientific Societies

Bob Ryerson

3.5.1. Introduction

CCRS staff and the organization itself had a tremendous impact on a number of scientific and technical societies in Canada and internationally. The Canadian Remote Sensing Society (CRSS) was formed through the efforts of Dr. Morley and CCRS, and is discussed in more detail in the next Subsection. Other organizations in which CCRS staff played a role include the Canadian Institute of Geomatics (sometimes seen as a competitor to the CRSS), the American Society for Photogrammetry and Remote Sensing (ASPRS), L'Association Quebecoise de la Télédétection (AQT), Ontario Association of Remote Sensing (OARS), International Society for Photogrammetry and Remote Sensing (ISPRS), the Institute of Electrical and Electronics Engineers Geoscience and Remote Sensing Society (IEEE-GRSS), Asian Association on Remote Sensing (AARS) and the Canadian Information Processing Society (CIPS).

3.5.2. The Canadian Remote Sensing Society (CRSS)[97]

The CRSS, whose acronym is sometimes confused with CCRS, was formally created at the Second Canadian Symposium on Remote Sensing held in Guelph Ontario in April 1974. This followed earlier discussions including at the First Canadian Symposium on Remote Sensing in Ottawa, February 1972. The CRSS was begun by CCRS and was first led by Larry Morley. It is believed to have been the first national society anywhere with remote sensing in its name. The Society was started with a strong push by the CCRS leadership. Indeed some of the CCRS scientific staff, including this author, did not join at the outset given what was considered undue pressure put on them to do so by the then Chief of the Applications Division, Joe MacDowall.[98]

Over the years only four of the 22 elected leaders were employed by CCRS (Table 3.5.1), however the CRSS was supported by CCRS leadership and scientists in ways that were not always obvious. For example they were the force behindstarting the Canadian Symposium on Remote Sensing – the longest running remote sensing symposium in the world. Several CCRS personnel served as General Conference Chair of the Symposium over the year while a number of CCRS research scientists served as Editor-in-Chief of the Canadian Journal of Remote Sensing Canadian Journal of Remote Sensing (CJRS) (Ron Brown, Frank Ahern, Philippe Teillet, Vern Singhroy and Paris Vachon), while the current Editor-in-Chief, Dr. Monique Bernier (INRS), was with CCRS in the 1980s. Many more CCRS scientists have also served as Associate Editors for the CJRS.

A number of CCRS research scientists served as Editor-in-Chief of the Canadian Journal of Remote Sensing (CJRS) (Ron Brown, Frank Ahern, Philippe Teillet, Vern Singhroy and Paris Vachon). Many more CCRS scientists have also served as Associate Editors for the CJRS.

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[97] Some of the information in Section 3.5.1 as well as Table 3.5.1 was provided by Dr. Derek Peddle. Note that when the CRSS was formed in April 1974 as an independent Society, its elected leader held the title President. In May 1975 when CRSS joined with the Canadian Aeronautics and Space Institute (CASI) and became a constituent society, this title changed to National Chair. When CRSS left CASI and became an independent society again in December 2012, it returned to using the title President for its elected leader.

[98] That Division Chief, Joe MacDowall, was replaced by Dr. Murray Strome on August 9, 1974. The announcement was made by Associate Director General Lee Godby at a Division Staff meeting held in the Boardroom at 717 Belfast Road. Most of the scientists joined the CRSS shortly thereafter.

Table 3.5.1. CRSS-SCT National Chairs/Presidents Canadian Remote Sensing Society / Société canadienne de télédétection (CRSS-SCT)			
Name of Chair/President	**From**	**To**	**Employer When Chair/President and Notes**
Brigitte Leblon	2018	Present	University of New Brunswick, Fredericton
Gordon Staples	2016	2018	MDA, Richmond, BC
Anne M. Smith	2014	2016	Agriculture and Agri-Food Canada, Lethbridge
Monique Bernier	2009	2014	INRS, Quebec
Derek R. Peddle	2007	2009	University of Lethbridge
K. Olaf Niemann	2005	2007	University of Victoria
Dirk Werle	2003	2005	AERDE Environmental, Halifax
Marc D'Iorio	2001	2003	CCRS
Ellsworth F. LeDrew	1999	2001	University of Waterloo
Brian Brisco	1997	1999	Noetix, Ottawa
Steven E. Franklin	1995	1997	University of Calgary
Nancy Prout	1992	1994	Ontario Centre for Remote Sensing (OCRS)
Robert A. (Bob) Ryerson	1990	1992	CCRS
M. Diane Thompson	1988	1990	Intera, Calgary
Peter A. Murtha	1986	1987	UBC, Deceased 01/06/ 2016.
Ferdinand Bonn	1984	1985	University of Sherbrooke. Deceased 08/29/2006.
Simsek Pala	1983	1983	OCRS, Deceased 07/04/ 2011.
Jean Thie	1981	1982	Environment Canada, Ottawa/Hull
Ensley Allen (Lee) Godby	1980	1981	CCRS
Donald J. Clough	1978	1979	University of Waterloo, Deceased 02/22/1983.
Ralph W. Nicholls	1976	1977	York University, Deceased 1/28/2008.
Lawrence Whitaker (Larry) Morley	1974	1976	CCRS. Deceased 04/22/ 2013. (Age 93)

The CRSS also had a number of linkages with other international societies, some of which were fostered through CCRS. While it would seem reasonable for the CRSS to be associated with the International Society for Photogrammetry and Remote Sensing (ISPRS), and it now is, it was not always so.The Canadian member of the ISPRS was the Canadian Institute for Geomatics (CIG) and at the time only one member was allowed per country.[99] The CRSS did join the Asian Association on Remote Sensing (AARS) on behalf of Canada as an Associate Member in 1989 at the Asian Conference on Remote Sensing (ACRS) held in Kuala Lumpur. (An AARS Associate Member is an agency in a country that is not an Asian or near-Asian country.) Joining the AARS was championed by Diane Thompson and Ryerson who were on the CRSS Executive at the time.[100] This step was seen as a means to broaden the impact of the CRSS internationally and help Canadian industry. Over the years Canadian companies often dominated the exhibit hall at the Asian Conference on Remote Sensing which was run by the AARS. As of 2018 the CRSS was still a member of the AARS.

3.5.3. The Canadian Institute of Geomatics (CIG)

The Canadian Institute of Geomatics claims to be "the Canadian Not-for-Profit association that represents the interests of all groups in the geomatics community."[101] The leadership of the CRSS would likely disagree, as would many of those associated with the GoGeomatics activity. As noted above, the CIG was, until very recently, also the Canadian member of the International Society of Photogrammetry and Remote Sensing (ISPRS). At the time that the Canadian Remote Sensing Society was formed, the forerunner to the CIG (the Canadian Institute of Surveying and Mapping), maintained that it would represent remote sensing as a part of its activities. To this author it is not clear why a separate organization such as the CRSS was deemed necessary, although several reasons have been posed – most

[99] When Geomatics Canada, CCRS's parent organization, spearheaded the push to land Commission VII of the ISPRS several senior people from CCRS (including Ryerson) had to join the CIG.

[100] At the time Thompson, a Vice-President of Intera, was Chair of the Canadian Remote Sensing Society, while Ryerson was Vice-Chair.

[101] Source https://www.cig-acsg.ca/ Accessed October 6, 2018.

dealing with differences of opinion between the leaders of the CIG and the remote sensing community at the time. There was also some debate about how well the traditionally focused land survey community would accept the "up-start" remote sensing community. It is worth noting that two prominent members of the remote sensing community, Drs. Leo Sayn-Wittgenstein and Al Gregory were the elected Presidents of the organization in 1976 and 1981 respectively. That being said, for some years there was competition between the two groups. That competition seems to have evolved into more of a spirit of working together as witnessed by the bid for Commission VII of the ISPRS in 1988 and more recently the bid for the ISPRS Congress fronted by Dr. Monique Bernier of the CRSS and Dr. Rodolphe Devillers of the CIG. . In 2019, for the first time, the 40th Canadian Symposium on Remote Sensing and a CIG event (Geomatics Atlantic) were co-located (at Fredericton NB).

3.5.4. Other Canadian Societies
CCRS staff contributed to several other societies in Canada including the Canadian Information Processing Society and the Canadian Association of Geographers. A number of international societies were also beneficiaries of CCRS expertise: these are covered in more detail in the following Section.

3.5.5. International Scientific Societies[102]
3.5.5.1. International Society of Photogrammetry and Remote Sensing ISPRS
The first major international conference at which CCRS scientists had a major presence was the 1974 ***Symposium on Remote Sensing and Image Interpretation*** held in Banff. This was a mid-term symposium sponsored by ***Commission VII of the International Society of Photogrammetry***. This is the same conference series that CCRS staff attended in numbers in Toulouse in 1982. (See Text box on Dipix in Section 3.3.4.5) By 1988 then Assistant Deputy Minister of Geomatics Canada, Hugh O'Donnell, and senior management at CCRS (including DG Leo Sayn-Wittgenstein) decided that it would be in Canada's interests to seek the leadership of Commission VII. O'Donnell led the team of Canadians that attended the ISPRS Congress in Kyoto, Japan to seek the Commission VII for the next four years. The team in Kyoto included O'Donnell, Frank Hegyi of the BC Forest Service who was being proposed as President of the Commission, Jean Game and several others. A major exhibit on Canadian capabilities was put together and staffed by Game of the User Assistance and Marketing Section. The bid was successful and as part of the agreement CCRS provided the Secretariat under Ryerson. A successful Mid-term Commission Conference was held in 1990 in Victoria. It was one of the first remote sensing meetings in Canada to have a focus and a number of papers on climate change. A book bringing those papers together was eventually published. (LeDrew *et al*, 1995) Over the years CCRS staff members have been involved in and have led a number of other ISPRS Commissions.

3.5.5.2. American Society for Photogrammetry and Remote Sensing (ASPRS)
CCRS involvement with the then American Society for Photogrammetry (ASP) began in late 1974 when CCRS was asked to identify someone to help Dr. Al Stevens organize a North American Conference on Land Use Mapping as part of the 1975 ASP fall meeting in Phoenix Arizona. Ryerson was identified and thus began a long relationship. Ryerson was later invited by Stevens to join the ASP Engineering Applications Committee in the ASP's Remote Sensing Division with such American notables as Stevens, and Drs. Tom Lillesand, Ralph Kiefer, Warren Philipson and Siamak Khorram. In 1982 Ryerson was elected to serve as the head of the 3000 member Remote Sensing Applications Division of the ASP and serve on the Board of the ASP. During his time on the Board the ASP became the ASPRS. The links so established to the ASPRS provided greater visibility for the work of CCRS and the growing industry in Canada. With his visibility in the ASPRS Ryerson was invited to be an author and chapter editor of two chapters of the ASPRS's Second Edition of the ***Manual of Remote Sensing*** which showcased a significant amount of Canadian work. This carried on as he became Editor in Chief of the Third Edition of the ***Manual of Remote Sensing*** when even more Canadian work was featured. In the late 1990s and again in 2007 the ASPRS and the CRSS joined together to have a joint conference in Ottawa. Over time

102 The detail provided here varies from one organization to the next based primarily on the author's personal experience and the limited information available for events and activities that took place as long as 45 years ago.

the ASPRS was seen to be much less important than the IEEE and the major involvement with the ASPRS was simply in publishing papers in their Journal.

3.5.5.3. Geoscience and Remote Sensing Society (IEEE)

"IGARSS (International Geoscience and Remote Sensing Symposium) is the flagship conference of the Geoscience and Remote Sensing Society (GRSS)."[103] The GRSS is a constituent professional and learned society of the IEEE. CCRS and Canada's involvement in this group originally came through Dr. Keith Raney. From this developed what is now a long-standing Memorandum of Understanding for cooperation and collaboration between IEEE GRSS and CRSS. The most notable product of this linkage has been the hosting in Canada of a number of IEEE GRSS IGARSS conferences in 1989, 2002, and 2014, now the largest remote sensing conference internationally (CSRS also held its 2006 conference with IGARSS in Denver USA).

The first IGARSS conference held in Canada was ***IGARSS '89***, which was held with the ***12th Canadian Symposium on Remote Sensing*** in Vancouver. The General Conference Chairm was Dr. John MacDonald of MDA. Keith Raney was Vice-Chair for the IEEE/GRSS, while Dr. Peter Murtha of UBC was Vice Chair for the CRSS. Other participants on the organizing committee with a CCRS connection were Drs. Josef Cihlar and Dave Goodenough. Former CCRS Post-Doctoral fellow Dr. Geoff Tomlins was in charge of the publication – five volumes totaling over 3000 pages! Over the years Goodenough came to be a leader of the IEEE/GRS-S, including representing the organization at the ACRS/AARS in Taiwan in 2011. Another IGARSS meeting conference took place in Toronto in 2002 with the 24th Canadian Symposium on Remote Sensing. IGARSS and CSRS General Chair Ellsworth LeDrew was also heavily involved with IEEE GRSS and collaborated with CCRS scientists. In 2014 the IGARSS and 35th Canadian Symposium on Remote Sensing were co-located in Quebec Québec City.[104] Former CCRS scientists mentioned elsewhere in this document, Dr. Monique Bernier and Tom Lukowski, played major roles on the 2014 organizing committee.

3.5.5.4. Asian Association on Remote Sensing (AARS)

The AARS, which holds the Asian Conference on Remote Sensing, was started to provide a local and low cost opportunity for Asian remote sensing scientists to get together closer to home. The first conference was held in Bangkok in 1980. Others have been held at various locations across Asia on an annual basis every autumn. The first CCRS engagement was to lead a technical trade mission to the 1985 symposium in Hyderabad, India. As noted above, Canada (with CCRS involvement) became a member in 1989 at the conference in Kuala Lumpur. At that meeting the UN held a side meeting on commercialization of remote sensing in the Asia Pacific Region – Canada provided both government and industry participants. In 2000 the AARS published the "***ACRS Memorial Book***" to commemorate the 20th ACRS. Only two people from outside the Asia/Near-Asia region were asked to contribute to the book – Ryerson was one of those.

3.6. International Relationships

3.6.1. Introduction

Bob Ryerson

CCRS became known internationally starting with the initial relationships with the US described in Section 2 and then moving into RESORS and the involvement of visiting scientists and outreach programs and marketing of the Canadian brand. Marketing the Canadian brand began in earnest with the dedicated CACRS meeting in 1985. One of the strengths of CCRS, and a major differentiator from many other government agencies, was that CCRS was always looking outwards. The reasons for doing so were quite selfish in some respects. CCRS wanted to avoid the expense of needlessly duplicating other's research (leading to RESORS, see Section 6.3) and it wanted to help Canada's industry export. To help

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[103] Source: http://www.grss-ieee.org/conferences/ Accessed October 10, 2018.

[104] An IGARRS meeting also took place in Vancouver in 2011. That meeting was really a Japanese-led IGARSS moved to Canada because of the after effects of the tsunami. The other three IGARSS were organized by teams led by Canadians.

industry export CCRS served as a beta or demonstration site for Canada's industry selling to international clients, and its staff helped identify opportunities and led technical trade missions around the world as well as lending other forms of support.[105] The thinking was that a successful industry would be supportive of the program. This proved to be the case for some twenty-five of the first forty years.

CCRS had a policy in the early years to "spend approximately 3% of its available manpower on foreign aid and United Nations participation." (CACRS 1975, p. 8) In 1975 CCRS planned to assign "a full-time scientist to coordinate information and planning on remote sensing undertaken in the international field." [106] (CACRS 1975, p.9)

Through Larry Morley's early international contacts, RESORS, and the reputation of CCRS scientists, CCRS earned a strong international reputation by the mid-1970s. It has been said that the truest form of flattery is imitation. If this is so, the Canadian Remote Sensing Program should be very flattered indeed. Scores of remote sensing specialists and managers from around the world came to learn from CCRS. At various times CCRS hosted scientists from Australia, Kenya, Nigeria, Thailand, China, India, France, Germany, Japan, Brazil, Norway, Peru, and New Zealand, among others. And CCRS staff spent anywhere from a month to a year on assignments in the US, Norway, France, Germany, Thailand, and China, as well as giving guest lectures and making presentations literally around the world. The concept of a national remote sensing centre and the associated advisory structure was replicated with some success in a number of other countries, including Peru, Brazil, Malaysia, Thailand, the Philippines, Indonesia and Iran, among others.

The hallmark of CCRS's international activities was a commitment that these activities had to benefit our international partners as well as Canada. The benefits to our partners were highly varied – from training and mentoring staff, to the provision of advice, and technology to meet our partners' needs. In some cases the technology was purchased by the partner and in others it was provided as part of development assistance. While Canadian industry clearly benefited in terms of exports, CCRS benefited through the richness of ideas and experience brought by those from other countries and cultures.

The remainder of this section describes how CCRS provided international leadership through sharing its knowledge and expertise (in Section 3.6.2) while general contributions to a variety of international organizations in the field are outlined in Section 3.6.3. A much more detailed description is given in Section 3.6.4 of two major activities, SAREX-92 and ProRADAR to provide the reader with more depth on the type and quality of work CCRS was involved in internationally. Another major (and award-winning) international activity led by CCRS and also related to RADARSAT – GlobeSAR, was covered in some detail in Section 3.3.3.9.

3.6.2. Leadership Through Sharing of Knowledge and Expertise Internationally

Tom Lukowski and Bob Ryerson

For many years, CCRS was fortunate to host post-doctoral fellows and visiting scientists from around the world. With support from their home organizations as well as from the Government of Canada (such as the Visiting Fellowships in Canadian Government Laboratories Program or with CIDA aid funding) scientists, often in the early part of their careers joined CCRS in its activities. For example, the Data Acquisition Division welcomed visitors from countries which included India, Japan, Sweden, Germany, Norway, and Holland. Scientists visited the Applications Division from New Zealand, Nigeria, Kenya, Australia, India, Thailand, and Poland. While they contributed in a major way to the work at CCRS, the experiences of these visitors at CCRS proved to have a significant impact on many of their careers as is well documented in the following text box.

[105] On at least one occasion CCRS lent a staff member with appropriate expertise to a company that needed a quick emergency replacement for a staff member who was no longer available.
[106] As it happened, this ended up being a shared responsibility between several individuals – and most scientists and managers forged international contacts.

CCRS – Beginning A Life-Changing Career[107]

Dr. Adigun Ade Abiodun

Getting to know Remote Sensing

Most of this document addresses the leading role of the Canada Centre for Remote Sensing (CCRS) in the development and growth of science and technology in Canada, and how it has had an imprint on Canada and the world. This article is a reflection of my time as a foreign visiting research scientist at CCRS, and the impact of that opportunity and related experience on my career and the world I have interacted with thereafter.

My preparation for my unforeseen journey to CCRS, in December 1974, actually began after the launch of LandSat-1 and the plan to launch LandSat-2 by the United States in July 1972. That was when the University of Ife (UNIFE), since renamed Obafemi Awolowo University (OAU), brought to light, for Nigerians, the promise of Earth observation from space. I was then a Senior Lecturer in its Faculty of Technology. The university's Vice-Chancellor, at that time, Prof. Hezekiah Oluwasanmi, subsequently set-up a 9-man committee, of which I was a member, to develop a national proposal for the acquisition of Nigeria's Earth resources data by Landsat satellites. In early 1973, the year Nigeria joined the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS), the proposal was forwarded to the Nigerian government for on-ward transmission to the United States' National Aeronautics and Space Administration (NASA).

Nigeria was not the only country that made such a request to NASA; other countries also responded to Landsat's Data Interpretation and Utilisation Campaigns that were organized by NASA and the United States Geological Survey (USGS). Concerned with how these countries were going to analyze, interpret and apply the data sets they were requesting from NASA and the National Centre for Space Studies of France (CNES), the United Nations (UN) came to the rescue. Through its Space Applications Programme (an activity of the United Nations Outer Space Affairs Division (OSAD)), the UN, in cooperation with CNES, organized its first Summer School on Remote Sensing in Tarbes, France, in 1973.

The participants at the Summer School (I was one of them) were from interested countries, particularly the developing ones. An excerpt from my farewell poem that I read-out at the closing lunch of the Summer School, on September 20, 1973, gave an overview of the participants:

"Latin America came, so did North America;
Europeans were largest in squadron.
Africans, Asians were marked present;
So did Arabs and Jews from oil land of Middle East
All, ready for Télédétection Education
Under Alouges and Laverlochere of France's CNES
And America's Landgrebe……."

CCRS, here I come!

I left Tarbes on September 21, 1973, very energized and hungry for more knowledge of remote sensing and its application in water resources. Hence, I routed my return trip to Nigeria through UNESCO's Office of Hydrology, in Paris, and was warmly received by Mr. F. H. Verhoog (a Norwegian), in the organization's Division of Water Sciences. My plain request to him was: "I am looking for more research and educational opportunities in remote sensing." At the end of our very productive meeting, he gave me two envelopes and bade me 'good luck, goodbye.' Each of the two envelopes contained the application form for a post-doctoral fellowship (PDF) award in Canada and in the United States, respectively. By that time, I already spent ten years studying and working in the United States (in Seattle, Washington), and already had pleasant visits to Canada (Vancouver, BC, in 1965, Butchart Garden, Victoria Island, in the summer of 1967, and a cross-Canada train-ride from Vancouver to Montreal in 1971). Thus, I wanted to return to Canada for my PDF programme.

In December 1973, I mailed my completed PDF application form, along with all of the supporting documents, to the

[107] Editor's Note: Dr. Abiodun, who volunteered to contribute this tribute to CCRS, was one of a number of Post-Doctoral Fellows and visiting scientists at CCRS who went on to illustrious careers in the public, private and academic sectors world-wide.

National Research Council of Canada (NRCC), in Ottawa. On April 20, 1974, my graduate assistant (Dr. Sanjo Bamgboye, the Executive Director of the National Water Resources Institute of Nigeria)) went to the academic staff mailroom and brought my mail to me, in my office, including a thick, brown envelope, and said, aloud: ‘Sir, you have mail from Ca….’ I rushed at him, grabbed the envelope from his hand, flipped it into the air as one would throw a frisbee, and lifted myself off-the ground, with my hands fully stretched, in its pursuit. I clasped my hands on the envelope as it was descending, and went down on my knees with a prayer to GOD:

‘Lord, I know this envelope is from Ottawa. Thank you for granting my prayers, thank you for making it happen. You are the only one that can stop me from going. But I know you will not stop me. Thank you, I really mean it, Thank you!!!’

I was not disappointed. The contents of the brown envelope were music to my ears and they confirmed that my PDF would be tenable at CCRS; all the necessary details were enclosed. My graduate assistant and I joyfully danced and laughed thereafter. But as I had anticipated, my own departmental head became my primary roadblock. While I was expected to arrive at CCRS, Ottawa, in September 1974, Dr. Larry Morley, the then Director-General of CCRS granted my request for a delayed arrival time of 3 months to iron-out my headaches in Nigeria. Eventually, I left my university for CCRS, on leave-without pay, and I arrived at 717 Belfast Road, my CCRS home, in mid-December, 1974, for a one year research undertaking in remote sensing.

Finally at CCRS

On my arrival at CCRS, I was posted to its Applications Division Office. Dr. Murray Strome, the then Chief of the Division, warmly received me, and latter introduced me to my immediate boss-to-be, Dr. Keith P. B. Thomson, the Head of the Applications Development Section. I stayed at CCRS, not for one year as indicated in my contract, but until the end of January 1976. And as of today, February 1, 2019, my memory of CCRS remains fresh and warm.

CCRS afforded me immense opportunities that enabled me to pursue my mission of study and research in remote sensing. These included the Limnology Study of Southern Indian Lake for the Fresh Water Institute (Environment Canada, Winnipeg), under the watchful eyes of Keith Thomson, as well as the financial support I received from the Management Committee of CCRS for my study of Lake Kainji in Nigeria. Murray Strome and his staff offered me essential assistance and much encouragement throughout my stay with them. Dr. Dave Goodenough. Head, Methodology Section, and his staff, as well as Florian Guertin of the Data Processing Division, contributed to the success of the above studies, through my ready access to the IMAGE-100 system, in the processing and analysis of my research data. The system operators provided much assistance when I needed it and were very cooperative and understanding.

The output of these efforts included my reports (i) to the Fresh Water Institute, titled: Application of Landsat Data in the Limnology Study of Southern Indian Lake, and (ii) to the Nigerian Government, titled: Remote Sensing Technology in the Development of Nigeria, (iii) two publications in the Journal of Remote Sensing of Environment, respectively titled: Satellite Survey of Particulate Distribution Patterns in Lake Kainji (1976), and Movement of Water Columns in Lake Kainji (1978); and (iv) a paper, titled: The Applications of Landsat Multispectral Radiance Data to Environmental Impact Studies on Large Lakes, co-authored by Keith Thomson, M. Kirby, H. Ayles, R. Heckey and myself, and published in the Proceedings of the International Association of Meteorological and Atmospheric Physics Symposium held in 1976, in Garmisch-Partenkirchen, West Germany. I will never forget the day we, three scientists with PhD degrees, went on a field trip to the Southern Indian Lake, Manitoba, and in desperation, had to flag-down a resident of a fishing community along the shore of the lake for help. Our outboard motor engine gave up on us and left us stranded in the middle of the lake at a time when very stormy weather, loaded with golf-ball-size hail stones, was approaching in our direction. The fisherman took a smell of the fuel in the full tank of our outboard motor engine, gave us one unspeakable ‘I am sorry for you look,’ shook his head and proceeded to empty, refuel and restart our failed engine; it roared at his command. According to him, we had fed the engine with the wrong fuel. He also bade us farewell with a 6-pack of beer just before we started our race-for-cover to our cabin.

In mid-February, 1975, my work at CCRS had a brief interruption when Canada realized what the impact could be, in international relations, of the Satellite Data Interpretation and Utilisation Campaigns being conducted, globally by both the USA and France. Thus, Canada’s International Development Research Centre (IDRC) came calling on CCRS management with its request to retain my services as a consultant for up to twenty-four (24) days during the first-half of 1975. The assignment called for my going to Sierra-Leone, Ghana and Nigeria to undertake a survey and submit an associated report on ‘The level of knowledge and interest in, and the need for the application of remote sensing technology in the development of these countries.’ I undertook the mission between April 27 and

May 14, 1975. On June 30, 1975 I submitted , my mission report titled: The Applications of Remote Sensing Technology in the Development of West Africa – A Preliminary Survey to the Director of IDRC.

On my return to my teaching post at UNIFE in February 1976, I sent letters of appreciation to Dr. A. W. Tickner, Secretary, Postdoctoral Fellowship Committee of NRCC, and to Dr. L. W. Morley, the Director-General of CCRS and his staff, including, Messrs. Lee Godby, Deputy Director-General; Murray Strome, Keith P. B. Thomson, Dave Goodenough, the multi-talented and very humorous Tom Alföldi, Applications Development Scientist; Brian McGurrin, Chief Librarian; Richard Juneau, The Tape Librarian and a few others.

Through the kindness and friendship of Messrs. Lee Godby, Bob Ryerson, Tom Alföldi, Brian McGurrin and Grant Dixon, Ms. Connie Johnson and several other CCRS staff, I got to know Ottawa, its people and its environment better. I also learned and experienced the joy of tapping maple tree for its sap and producing maple syrup from Mr. Godby's maple tree farm. The Ottawa Little Theatre was my entertainment centre-of-choice, while the various museums in the Ottawa-Rideau region enriched my knowledge of Canada's culture and history.

I saw and experienced CCRS as a unique research organization, not only in the array of capable talents that gave it such a global respectability in the field of geo-spatial science and engineering, but also in the quality of its managers and the spirit of comradery that was apparent throughout the organization. Today, I am reminded of the welcoming character of CCRS' managers and I tried to replicate some of it later in my career at the United Nations (UN). My stay in Ottawa between December 1974 and January 1976 was a very rewarding and pleasant experience that influenced my career, for the better, thereafter.

Life after CCRS

By the time I returned to Nigeria in mid-February 1976, my report on Remote Sensing Technology in the Development of Nigeria, which I had delivered to the Nigerian High Commissioner, in Ottawa, was already on the desk of the Head of the International Organization Department of Nigeria's Ministry of Foreign Affairs, in Lagos. At that time, the Ministry was debating the composition of Nigeria's delegation to the 13th Session of the Scientific and Technical (S&T) Sub-Committee of COPUOS that was held in Geneva, Switzerland, March 22 - April 9, 1976. I soon received an invitation from my government to serve as the senior adviser to the Nigerian delegation to the meeting. That was the first use of my CCRS-imparted remote sensing knowledge, albeit, not in a classroom setting or project planning/development assignment as I had envisaged, but at an international political-cum-scientific meeting on the then current and future global space activities. Important topics in the meeting's agenda included: (i) Exchange of Views on National Programmes related to Outer Space Matters, (ii) Questions relating to Remote Sensing of the Earth by Satellites, and (iii) Consideration and Review of the United Nations Programme on Space Applications. At the request of the head of the Nigerian delegation, I prepared and presented formal papers on the last two items above and answered the questions raised by the delegates, thereafter.

Following my presentation on item (ii), Prof. Lubos Perek (Czechoslovakian), the then Chief of OSAD, since renamed United Nations Office for Outer Space Affairs (OOSA), invited me to join him for lunch – a luncheon that marked the beginning of a critical life-changing career for me and my subsequent secondment, by Nigeria, to work at OSAD as a Remote Sensing Specialist, for two years, effective July 24, 1977. In mid-1978, and at the request of the United Nations, Nigeria released me from my two year secondment. I subsequently became a permanent staff member of the organization in the Space Applications Section of OSAD, and had to learn more about outer space beyond remote sensing. On November 3, 1981, I was appointed the United Nations Expert on Space Applications and Chief of the Space Applications Section, with the responsibility to develop indigenous capacity and capability in space science and technology in the developing countries. By the time I retired from the services of the UN on September 30, 1999, I had led the UN efforts in establishing UN-Affiliated Regional Centres for Space Science and Technology Education in India, Brazil/Mexico, Morocco and Nigeria.

After my retirement, I served, from March 2000 – May 2003, as the Senior Special Assistant (to the President of Nigeria) on Space Science and Technology. Other engagements that benefited from my PDF days at CCRS included my service as a member of the College of Commissioners of the United Nations Monitoring, Verification and Inspection Commission on Iraq (UNMOVIC), (2000-2007), my service as Chairman of the United Nations Committee on the Peaceful Uses of Outer Space (June 2004 – June 2006), and the writing and publication, in May, 2017, of my book: Nigeria's Space Journey – Understanding its Past, Reshaping its Future (http://www.amazon.ca/dp/0998332100).

Since I left Ottawa for UNIFE at the end of January 1976, I have continued to interact with CCRS and a number of the talented men and women that gave the organization its distinguished name and cherished legacy. Murray Strome (delegate of Canada) and I (delegate of Nigeria) met at the 1976 Session of S&T of COPUOS, and later at

UNISPACE-82, in Vienna, Austria in 1982 – he, a delegate of Canada, while I served as a member of the UN Conference Secretariat. Tom Alföldi readily gave me a needed helping hand, and cheerfully imparted his rich knowledge and experience, as educator/speaker, at a number of the UN activities I organized, such as in Ibadan, Nigeria, in 1979, Nairobi, Kenya, in 1984, Jakarta, Indonesia, in 1985, and Addis Ababa, Ethiopia, in 1987. Dr. Vern Singhroy was with me in Lagos, in September 1992, at Nigeria's Celebration of the International Space Year. Dr. Bob Ryerson and I re-united in Ottawa, in 1982, at COSPAR'S XXIVth Meeting, and in Vienna, Austria, in 1999, at UNISPACE-III.

Looking back, CCRS has had a profound influence on my career for which I am indeed grateful. The yearly Christmas and New Year messages from my CCRS family continue to remind me of my inter-connectedness with CCRS, an organization that those of us in its orbit - from Canada and the wider world – will always cherish.

As noted in the introduction to this section, while there were many visitors to CCRS, CCRS scientists spent significant periods (very often up to a year) in laboratories around the world in countries such as Denmark, Norway, Japan, China, Thailand, Malaysia, and others, as well as on loan to other government departments and industry in Canada. They contributed significantly to the programs in those countries, other departments and industry while further developing their own knowledge and expertise. In both hosting visitors and being visitors, the interactions between CCRS staff and those from other organizations around the world proved to be very useful in the development of contacts and the sharing of knowledge and information between CCRS and organizations in other countries. Over the years these contacts proved helpful to Canada and its remote sensing industry.

CCRS employees acted as resources to scientists, engineers and students, not just in Canada, but world-wide. With its sensors and software CCRS provided data for research and development activities. Its applications expertise was communicated through seminars, publications, RESORS and, eventually, through the Internet. As well, it was the source of ready (and eager) assistance with knowledge on the sensors, planning and execution of data acquisition and fieldwork, data processing, and analysis. Students and university faculty, industry and other government departments were helped in this way both in Canada and internationally. CCRS scientists provided lectures and workshops to users of remote sensing data in several ways. They served as visiting lecturers and thesis advisors at educational institutions. They also made presentations to remote sensing organizations, user communities, and routinely answered questions and concerns of practitioners in the field of remote sensing.

CCRS scientists have a long history of publishing peer-reviewed manuscripts in virtually all of the major English and French journals in the field. They have also contributed as reviewers for these same journals. CCRS scientists have also served as associate editors and led in the preparation of special issues on various remote sensing topics of interest for international journals including IEEE GRSS, the ISPRS, ASPRS and GeoCarto International.

Another aspect of leadership was the active participation as noted above in a variety of international scientific organizations in which a number of CCRS staff members have served in executive positions. CCRS was also a founding member and an active participant in the international Committee on Earth Observation Satellites including its Calibration / Validation activities. Through the years CCRS employees have been ever-present in the organization and preparation of conferences and symposia both nationally and internationally of organizations such as the IEEE GRSS, ASPRS, ISPRS and ACRS. CCRS was one of the leaders in the activities that led to the creation of the Group on Earth Observations (widely known as GEO) that came out of the EO Summit called by US President Bush in 2002. Many staff have served on various conference committees and in senior positions of conference organization. Furthermore, CCRS staff routinely served on conference technical committees and provided peer review of conference submissions.

3.6.3. A Further Sampling of International Activities
Bob Ryerson

3.6.3.1. Introduction
It is impossible to give a full and complete description of all of the international activities of CCRS and its staff. Many have been profiled in other sections that deal with the beginning of CCRS, industry, applications development, technology transfer and marketing. In virtually every endeavor of CCRS one can see a link to the world outside Canada. Of course that is as it should be for a leading world-class organization: even in the Internet age you do not become (and stay) a world leader by staying at home.

The remaining Subsections here introduce some of the more important and visible international activities of CCRS as seen by this author and colleague Frank Ahern who wrote Section 3.6.4 on SAREX-92 and ProRADAR. Carolyn Goodfellow has prepared Section 3.6.3.7 that explains the activities of the Technology Transfer and Training Section. It should be noted that the activities are not given in a chronological fashion, but rather they are organized thematically. Needless to say, they also reflect the knowledge and biases of the authors.

3.6.3.2. Support for RADARSAT
Several important international programs in support of RADARSAT were supported by the Canadian International Development Agency, the Canadian Space Agency, and the International Development Research Centre, as well as by CCRS and the international partners who provided local expertise, field work, and field expenses. The three programs mentioned here are, without doubt, the largest and most expensive international activities ever undertaken by CCRS. The total estimated cost (primarily to the Government of Canada) for the three was over $11 million at the time – far more in today's dollars.[108] Of course, the amount does not seem so large when one considers the investment made in RADARSAT-1, said to be $620 million excluding the launch.

SAREX-92 and ProRADAR discussed in detail in Section 3.6.4 and GlobeSAR 1 and 2 discussed in Section 3.3.3.9, were international programs that supported the marketing and public awareness efforts leading up to RADARSAT. At the same time a number of significant papers and collection of papers were written for a variety of publications. (Ryerson, 1995; Campbell *et al*, 1995) In addition a number of symposia and workshops were held in Asia and Latin America with many hundreds participating. The GlobeSAR program won a Government of Canada Group Merit Award in 1995 that named participants from CCRS, CIDA, IDRC, CSA, Intera, and Innotech Aviation. The fact that the industry partners received Government of Canada awards for their efforts was quite unique, something that the late Dr. Fred Campbell spent a lot of effort to achieve for our industry partners. Over 30 of the award recipients were present for the award ceremony held in the Larry Morley Boardroom at CCRS. Ten countries were involved in GlobeSAR-1 in Asia, the Middle East and Africa. As noted below in Section 3.6.4 and from evaluation documents (Quiroga and Ryerson, 2000), there were an additional eleven countries that participated in the Latin American projects.

3.6.3.3. UN
3.6.3.3.1. Introduction
CCRS was involved early on in a number of UN organizations and that activity continued. The first link saw an early CCRS employee, Ralph Chipman, leave CCRS to join the UN in New York.

3.6.3.3.2. UN Committee on Peaceful Uses of Outer Space
The United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) was established in 1959 (shortly after the launch of Sputnik) as an ad hoc committee. Canada has been a member from the beginning. Over time several sub-committees evolved in which CCRS played a role, primarily through Les Whitney. It is worth noting that a former (and early) CCRS post-doctoral fellow, Dr. Ade Abiodun, became the senior official in remote sensing in COPUOS. An important Canadian-driven workshop took

[108] As noted below, the European Space Agency supported SAREX-92 with $1.2M.

place in Vienna in 1999 involved Whitney, Abiodun, Dr. Changchui He[109] of UNESCAP, this author (then a consultant), Wade Larson of the CSA, Mac Evans (then President) of the CSA, and others from several other countries. The resolution put forward by the workshop was later adopted by the UN General Assembly. That resolution stated:

"It was agreed that, whereas maps and geospatial data derived from a combination of Earth observation information and other data were as much a part of a nation's infrastructure as the transportation network, the health-care system, telecommunications and education, the creation of a national geospatial infrastructure should be accorded the same level of support as the other elements of national infrastructure."(Unispace, 1999)

This resolution has been used by remote sensing organizations and others in many nations to justify support for remote sensing and geospatial programs.

3.6.3.3.3. Support to UN Programs

CCRS recognized the importance to its industry of showing Canadian expertise. At the same time, the UN was supporting remote sensing activities in developing countries. For that reason CCRS ensured that it was aware of opportunities as they arose. In late 1983 the UN was advertising for someone to be a consultant on land use mapping, including providing lectures on the latest approaches. Ryerson went to China for the month of January, 1984 where he lent further support to DIPIX. It was during this trip that Ryerson first came in contact with a number of Chinese leaders in remote sensing, including Dr. Changchui He, leading to a lifelong professional relationship and personal friendship.

Ryerson later served in other consulting roles while a CCRS employee to the UN-ESCAP (UN-Economic and Social Commission for Asia and the Pacific) after Dr. He took over the remote sensing and GIS activity of that agency.

CCRS support did not end with Les Whitney, Ryerson and others serving in consulting and advisory roles. When a position for a senior remote sensing and GIS person came open at the UN-ESCAP office, CCRS Director General Leo Sayn-Wittgenstein intervened on behalf of the Canadian candidate, Claire Gosselin. She was appointed and served in that important role based in Bangkok for five years where she worked for Dr. He.[110] Other Canadians were placed at the UN-FAO and World Bank in senior roles with the encouragement of CCRS and External Affairs.

3.6.3.4. Multilateral

3.6.3.4.1. CEOS

CEOS is a long-standing and remains one of the key multilateral organizations involved in remote sensing or Earth observation. CCRS was a key player among the half dozen agencies that came together to form CEOS.

"CEOS was established in September, 1984 in response to a recommendation from a Panel of Experts on Remote Sensing from Space and set up under the aegis of the G7 Economic Summit of Industrial Nations Working Group on Growth, Technology, and Employment. This Panel recognized the multidisciplinary nature of space-based Earth observations and the value of coordinating international Earth observation efforts to benefit society. The original function of CEOS was to coordinate and harmonize Earth

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[109] Dr. He, a Chinese national, will be mentioned elsewhere.

[110] Following his MSc at the ITC in the Netherlands and before joining the UN, Dr. He was the senior remote sensing person at the State Science and Technology Commission of China (SSTCC) The SSTCC (i.e. Dr. He) controlled the remote sensing budget for the country and was instrumental in securing UN support for visiting scientists. Dr. He completed his PhD at Peking University at the same time that he went on to increasingly more important positions in the UN, including Head of the RS/GIS activity at UN-ESCAP, then head of the larger RS/GIS activity in the FAO in Rome, Regional Representative of the FAO in Asia, and then Deputy Director General of the FAO. Dr. He played a key role in convincing the Government of China to support GlobeSAR. He is currently a Senior Advisor to the Minister of Agriculutre in Beijing.

observations to make it easier for the user community to access and use data. CEOS initially focused on interoperability, common data formats, the inter-calibration of instruments, and common validation and inter-comparison of products." [111]

With the focus on users, interoperability, validation and formats it is easy to see the impact of CCRS on the focus of CEOS. For some time Terry Fisher of CCRS led a working group on data. Others from CCRS contributed to other working groups. Today within CEOS there are 60 Agencies operating 156 satellites. There are 32 Members and 28 Associate Agencies: Members operate satellites. Since CCRS does not have its own satellite it became an Associate Agency while the CSA is the Member for Canada.

3.6.3.4.2. GEO

The now important Group on Earth Observation (GEO) was formed following the Earth Observation Summit called by President Bush on July 31, 2003. "GEO is an intergovernmental partnership that improves the availability, access and use of Earth observations for a sustainable planet. GEO promotes open, coordinated and sustained data sharing and infrastructure for better research, policy making, decisions and action across many disciplines. The GEO community focuses on three global priority engagement areas: the United Nations 2030 Agenda for Sustainable Development, the Paris Agreement, and the Sendai Framework for Disaster Risk Reduction."[112]

The focus of the summit was on areas covered by NOAA inasmuch as the driver behind the Summit was the head of NOAA, Conrad Lautenbacher Jr. a retired Navy Vice Admiral. With NOAA being the focus, that meant that NOAA's contact in Canada, the Atmospheric Environment Service of Environment Canada was seen as the lead agency in Canada. While involved, neither the space agency nor CCRS led the discussion. Having said that, the Canadian delegation to the Summit was led by CSA President Marc Garneau and included Assistant Deputy Minister Dr. Irwin Itzkovitch and Associate ADM Dr. Susan Till of the Earth Sciences Sector of Natural Resources Canada as well as Director General of CCRS Bob Ryerson and Doug Bancroft then a Director at Environment Canada and later DG of CCRS.

An especially delicate situation concerned the wording surrounding the commercial sale of satellite image data – something that both Canada and France wanted included in the agreement that came out of the Summit. Susan Till, a former scientist, Section Head and Director at CCRS, led the discussion that saw Canada- and France-friendly wording emerge in the founding principles that allowed for commercial sale of satellite data by members. (Others argued for free dissemination of most EO data.) Ryerson and Bancroft contributed to the dialogue. What many consider to be the founding meeting of GEO took place in Ottawa in 2004 and was hosted by Environment Canada Minister Stéphane Dion. By this time CCRS was beginning to lose its influence in the international arena. (See Section 4.7)

3.6.3.4.3. The European Space Agency (ESA) –A Special Case

As noted in more detail in Section 7.9 and elaborated upon related to RADARSAT in Chapter 5, CCRS had strong ties to ESA almost from the beginning. CCRS began this special relationship with ESA in 1977 through what has become the Canada-European Space Agency Cooperation Agreement.[113] In effect Canada contributes funding and can participate in ESA programs.[114] Over the years this cooperation has been of benefit to industry and governments on both sides.

A number of European and Canadian scientists (including those from CCRS) participated in secondments and joint projects on a variety of topics. Topping the list of CCRS contributions was access to the CCRS

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[111] Source: http://ceos.org/about-ceos/overview/ Accessed September 30, 2018.
[112] Source: http://earthobservations.org/index2.php Accessed September 30, 2018.
[113] As with CEOS and other space-related agreements, it was fitting that the Canadian Space Agency took over responsibility for what CCRS had started. CCRS remained active in various working groups and technical committees.
[114] For further details see the Canadian Space Agency web site: http://www.asc-csa.gc.ca/eng/funding-programs/canada-esa/about-cooperation-agreement.asp Accessed Oct. 2, 2018.

CV-580 aircraft which, in effect, served as the test system for ESA's radar satellite programs. (See Section 6.7.2)

3.6.3.4.4. COSPAR

COSPAR was established by the International Council for Science (ICSU) in 1958. "Its objectives shall be to promote on an international level scientific research in space, with emphasis on the exchange of results, information and opinions, and to provide a forum, open to all scientists, for the discussion of problems that may affect scientific space research. This shall be achieved through the organization of scientific assemblies, publications or any other means. COSPAR shall report to ICSU on its activities and provide scientific advice on matters concerning scientific space research to the UN and other organizations as required.[115]

CCRS's Lee Godby was active in COSPAR and hosted a COSPAR conference on remote sensing in 1982. At his request a special report was produced by the Geography Working Group of CACRS to mark the first decade of Landsat and to showcase the experience gained in Canada. The report titled "***Landsat for Monitoring the Changing Geography of Canada***" (Thompson *et al*, 1982) was important for several reasons. First it showcased for the world the wide range of excellent work done by Canada's remote sensing community. Second, it provided pedagogical material for universities across the country, coming as it did with an associated set of slides available in RESORS. Third, it was the first major collection in remote sensing in Canada to be published in both official languages. Lastly, much of the work profiled found its way into the engineering applications chapter of the second edition of the ***Manual of Remote Sensing***, further bolstering the reputation of Canada in general and CCRS more specifically.

3.6.3.4.5. GOFC-GOLD – Global Observation of Forest Cover and Land Dynamics

CCRS and Canada were early participants in GOFC-GOLD "a coordinated international effort working to provide ongoing space-based and in-situ observations of the land surface for the sustainable management of terrestrial resources and to obtain an accurate, reliable, quantitative understanding of the terrestrial carbon budget."[116] The activity began in 1997. CCRS played an important role at the outset, with Ahern serving as executive director from 1997 to 2000, followed by Tim Perrott. Ahern also served as the senior co-editor of a book on the proceedings of a workshop/conference on monitoring fire from satellite. (Ahern *et al*, 2001) CCRS hosted major meetings related to GOFC-GOLD and CCRS Director General Ed Shaw was actively involved. Looking back from today the work was prescient. In the introduction Ahern *et al* (2001) made the following statement: "Increasing conflagrations of forests and other lands throughout the world during the 1980s and 1990s have made fires in forest and other vegetation emerge as an important global concern. Both the number and severity of wildfires (accidental fires) and the application of fire for land-use change, seem to have increased dramatically compared to previous decades of the twentieth century. The adverse consequences of extensive wildfires across national boundaries have global impacts."

3.6.3.5. International Standards Activities

3.6.3.5.1. Introduction

As noted in more detail below in Section 7.2, CCRS was an early player in international standards related to remote sensing. The rational was simple: if CCRS standards were adopted internationally it would recognize our expertise and help our industry, as it would if CCRS played a major role in setting standards. What follows are short notes on three of the standards-related organizations in which the author knows CCRS played a role.

[115] Source: https://cosparhq.cnes.fr/about/charter Accessed October 18, 2018

[116] Source: https://start.org/programs/gofc-gold/ Accessed February 6, 2019.

3.6.3.5.2. Open Geospatial Consortium (OGC)

The Open Geospatial Consortium (OGC) was founded in 1994 as "an international not for profit organization committed to making quality open standards for the global geospatial community. These standards are made through a consensus process and are freely available for anyone to use to improve sharing of the world's geospatial data."[117] There are currently over 525 member organizations from government, industry, NGOs, and academe. The importance of the OGC cannot be overstated when one is discussing standards and the geospatial/remote sensing sector. Even some of the corporate players who were seeking to impose their proprietary standards have joined the OGC - several as Principal Members.

CCRS's GeoAccess Division was an early player in the OGC as was PCI Geomatics,[118] discussed in Section 3.3.4.5. The GeoConnections Program, which grew out of the GeoAccess Division of CCRS, became a major player and is still listed as one of just six Strategic Members of the OGC. It is instructive to note that the OGC has only given out two lifetime awards – one of those was to Terry Fisher employed by CCRS and GeoConnections. There are at present seven emeritus Board Members – one of those is Jeff Labonte who came out of the GeoAccess Division of CCRS to eventually become the Director of the GeoConnections Program and, for a time, Director General of the Mapping Branch – at the time a sister branch to CCRS.

3.6.3.5.3. ISO

When international standards are discussed the International Organization for Standardization, or ISO, is usually a player. Geographic Information/Geomatics standards are discussed under ISO/TC 211 which was created in 1994. Over 80 standards have been developed.[119] In the early 2000's Dr. Kian Fadaie was involved on behalf of CCRS. Her role was to link the technical expertise within CCRS to the ISO standards creation.

3.6.3.5.4. ASTM International

Another organization involved in setting standards is ASTM International.[120] In 2003 Vern Singhroy of CCRS was co-editor of a book titled "***Spatial Methods for Solution of Environmental and Hydrologic Problems—Science, Policy, and Standardization***." This book provided a "how-to" set of procedures to make use of spatial data in the subject areas listed.

3.6.3.6. Bilateral Arrangements Involving CCRS

The range and number of bilateral arrangements involving CCRS and other countries (i.e. with individual countries – not multilateral arrangements like GlobeSAR or SAREX) came about for many reasons – some strategic and some more serendipitous. Some were the result of CCRS leadership seeing the value of a relationship – as was the case of arrangements made with the US. Some arrangements came about when Canadian industry was seeking help to close a sale – such as allowing scientists and engineers from another country to work at CCRS for training as was the case for Thailand. In some cases CCRS was approached because of its reputation in data reception, applications development, or some other capability – as was the case for France and the SPOT satellite. In still other cases there were ties between a CCRS scientist and someone in the other country – or ties that grew out of a multilateral activity – such as China following GlobeSAR and early UN work. While the list of bilateral relationships here is neither complete nor fully representative, it gives some insight into how such relationships formed and their value to CCRS, Canada and the partner. One of the byproducts of the relationships has been the establishment of life-long friendships between CCRS employees and scientists and engineers from around the world. These friendships have in themselves led to further successes and relationships, including ones of a

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[117] Source: http://www.opengeospatial.org/ Accessed October 6, 2018.

[118] The level of support by PCI and GeoConnections is well expressed in the "In Memoriam" for Dr. Bob Moses, President and CEO of PCI. His is but one of three such Memorial recognitions on the OGC web site. http://www.opengeospatial.org/ogc/awards/honors

[119] See https://www.iso.org/committee/54904.html Accessed October 9, 2018.

[120] See https://www.astm.org/DIGITAL_LIBRARY/STP/SOURCE_PAGES/STP1420.htm Accessed October 9, 2018

business nature. What follows is a very limited sample of bilateral arrangements in which CCRS was involved.

United States. As can be seen in Section 2.1 the many faceted relationship with the US actually began before CCRS was created. Indeed, the relationship with the US played a key role in the development of the remote sensing program in Canada. The range of relationships with the US has been so wide over so long a period that any attempt to enumerate the activities will come up far short. Here we present only a snap-shot of some of the activities and their results.

From the mid-1970s to mid-1980s CCRS and various agencies in the US were working together on data formats, data sharing, and the like with the results plain to see in MDA sales, activities in the OGC, and other successes. Many instances can be cited of CCRS and US scientists co-authoring papers and sharing results throughout the entire period being studied here. Scientists from CCRS spent sabbaticals at US facilities. CCRS staff lectured at a number of major US universities and a number of prominent US scientists visited CCRS. The radar program at CCRS and RADARSAT itself can be attributed to the close cooperation that saw CCRS acquire the ERIM aircraft and hire Dr. Keith Raney, as is detailed by Dr. Raney in Chapter 5. While the sharing of results and working together to solve technical problems were characteristics of the bilateral relationship, there were at times tensions – such as when CCRS learned of the crop failure from a US scientist before US authorities were briefed or when companies close to CCRS (such as DIPIX, MDA and Intera) were seen to have been given too much help by the Government of Canada.[121] While GEO was very much a multi-lateral activity, its original development certainly drew heavily on the close bilateral relationships that existed between, especially, the USGS and Geomatics Canada in the 2002-2004 timeframe.

France. Early on France drew heavily on RESORS – then the largest data base of literature published in French in remote sensing. Over time there were some exchanges, but the relationship with France became much more important with the arrival on the scene of the SPOT satellites. Following negotiations with the owners of SPOT, Canada ended up as the major reception centre for North America. Historic ties to the US were seen by some as an impediment to the broader use of SPOT data in Canada as well as greater ties to the growing French remote sensing program. Ridha Touzi, an award-winning scientist at CCRS and a co-author of this document, earned his PhD in France and relationships established at that time have continued.

Thailand. Thailand was an early buyer of Canadian satellite reception technology. As part of the deal a number of Thai scientists and engineers came to Canada to work with CCRS staff. One of the most interesting programs, for a Thai earth observation satellite, was conceived within CCRS in the mid-1990s. At one point Canada's SPAR Aerospace was the first choice to build the first Thai remote sensing satellite. A series of unfortunate decisions by Spar led to cancellation of the agreement by the Thai Government. While this program did not make it past the conception stage, friendships established over the years led to a number of further joint projects such as GlobeSAR and contracts with Canadian industry over the next thirty years.

Peru: As memory has it Peru received development assistance from Canada and Peru was one of the countries to have bought Dipix equipment. It was reported at the time by the late Bill Bruce who worked with the Peruvians that he was at the airport in Lima when the Dipix system was delivered. Much to his horror, the crate that the system was in was dropped as it was being removed from the aircraft – leading to a big dent in one corner. However, the system, when delivered, did work. The head of the Peruvian remote sensing program, Fritz Dubois, eventually immigrated to Canada and set up a consulting business.[122]

[121] Issues over trade seem to be repeating themselves as this is being written in September of 2018.
[122] Fritz Dubois was not alone. The head of the Columbian remote sensing program who worked on GlobeSAR also immigrated to Canada.

China. China provides an interesting example of how personal contacts (such as the UN contracts by Ryerson, GlobeSAR led by Fred Campbell, the 1982 ISPRS Commission VII meeting in Toulouse, etc.) and technology demonstrations along with good luck led to close friendships and commercial success. The relations that began in the early 1980s are still bearing fruit in cooperation between CCRS and China.

3.6.3.7. International Technology Transfer and Training Activities – 1990 to early 2000s
Carolyn Goodfellow

Continuing on from an earlier focus on developing a Canadian industry, one of the government's main objectives in the 1990s was to improve the Canadian industry's competitive situation in international markets. Geomatics Canada, in cooperation with other government departments, undertook various activities to assist the Canadian Geomatics industry in exploring and securing new export markets for their products and services. As noted elsewhere, CCRS staff participated in trade fairs, missions, sent delegations to other countries, hosted delegations from them, and carried out training and technology transfer projects in cooperation with industry.[123]

In the early 1990s, the Training and Technology Transfer Section (TTTS) created a brochure titled "Resource Mapping for a Developing World" to encourage the further use of remote sensing and related digital mapping technologies such as Geographic Information Systems in international development. The brochure provided examples of international development projects done by seventeen Canadian companies. TTTS added examples from CCRS experience and research. The brochure also described how, under the terms of a Memorandum of Understanding (MOU) with CCRS, CIDA was able to draw on the technical expertise from Geomatics Canada (SMRS) to issue calls to private industry and other Canadian government agencies for resource mapping projects. Copies were distributed by the Canadian government and companies at various international events, during trade missions and visits to developing countries and when visitors from developing countries came to Canada.

Under the MOU with CIDA, CIDA could request technical assessments of Geomatics proposals that had been submitted to them, e.g., technical feasibility, capability of proponents, known similar projects of similar nature, etc. An inventory of CIDA projects was carried out to better understand where and what Geomatics components were included in the projects that they were funding.

At the ISPRS conference in Washington in 1992, Bruce and Ryerson presented a technology transfer model defining key factors which lead to a successful transfer of technology. The model was based on their direct experience in and observation of the processes of development and implementation of remote sensing technology and applications across Canada and in a wide variety of settings internationally. Key factors which lead to successful technology transfer were identified for each of the three phases of a project. The authors also described the importance in technology transfer projects of addressing resistance to change and development of a risk management strategy. Throughout the 1990s, TTTS used this model as a guide for technology transfer projects and its sister guide "A Workshop Planning Guide for Geomatics" for training workshops.

In 1987, Geomatics Canada signed an MOU with the Geomatics Industry Association of Canada (GIAC), agreeing to work closely with them to help further develop the competitiveness of the industry. In 1993, Treasury Board approved a Revolving Fund for Geomatics Canada. The Revolving Fund was a mechanism for certain cost-recovery activities. This mechanism allowed the Sector to react quickly and positively, on behalf of industry, to opportunities that suddenly developed in international markets. In 1994 Geomatics Canada developed, in consultation with industry, a set of guidelines for Geomatics Canada (GC) cooperation with the Canadian private sector in international ventures. Part of the guideline stated that Geomatics Canada was prepared to partner with, but not compete against, industry.

[123] Geomatics Canada, Annual Review 1993-94, p. 9

Canada's technical assistance program for Russia and other countries of the former Soviet Union was announced in July 1991 to provide practical, hands-on support in the transition to democracy and a market economy. It allowed these countries to draw on Canadian skills and expertise in areas such as agriculture, energy, management, science and technology. The Prime Minister announced increased funding for the program in June 1992 when Boris Yeltsin visited Canada and again prior the G-7 meeting in Vancouver. The level of funding in April 1993 reached $150 million over five years.[124]

Dr. Leo Sayn-Wittgenstein, DG of CCRS from 1987 to 1995 was a key advocate for Geomatics Canada's development of cooperation with Russia and Eastern Europe and was instrumental in defining a strategy for working with Geomatics industry to improve its competitiveness in that region. He chaired the SMRSS Task Force on Russia and Eastern Europe. In many of these countries, government-to-government dealings were preferred and Canadian companies benefited from the assistance and cooperation provided.

With Dr. Sayn-Wittgenstein's encouragement, TTTS began to initiate technology transfer projects in the region. We started with already established contacts in the regions such as delegates from Russia and other former Soviet Union regions then part of the former Soviet Surveys and Mapping Agency (GUKB), who had visited Canada to sign an MOU for future cooperation with SMRSS in 1991.

During the 1990s, Bill Bruce and Carolyn Goodfellow initiated four projects with counterpart organizations using the Bruce-Ryerson technology transfer model. Senior managers were invited to Canada to learn how Canadian Geomatics was used operationally and then supported to define requirements and design a technology transfer project appropriate for their countries. In each project, they learned how to select a Canadian company through a competitive process to implement the project plan. Experts from within Geomatics Canada and from other departments participated in initial visits, writing the RFP and overseeing project implementation. The Bureau of Assistance for Central and Eastern Europe (BACEE) in Foreign Affairs and International Development Canada (later in CIDA) funded four projects developed by Geomatics Canada and one in which Geomatics Canada was contracted to support DMR Inc. of Montreal.[125]

By actively participating in these pilot projects, Canadian industry opened doors for future opportunities and increased awareness in those countries of Canadian capabilities and mechanisms for government and industry cooperation. When problems arose, CCRS worked in collaboration with the company and the Russian partners to find solutions.

The Revolving Fund mechanism was used for technology transfer projects to developing countries which received funding from BACEE and CIDA, but also for international contracts (e.g. Malaysia and Qatar). Some of the international training and technology transfer activities that made use of the Revolving Fund mechanism during the 1990s are outlined in the following text box.

Czech and Slovak Republics
#1 Project to Research and Document Forest Decline and Environmental Degradation in the Czech Republic **Partners:** Forest Management Institute, Ministry of Agriculture/ Skoklasa Technology, Czech Company

[124] See: Office of the Prime Minister, Press Release: Canada Urges Greater Assistance to Russia, April 2, 1993 and Office of the Prime Minister, Press Release: Canada Increases Assistance to Russia and Other Countries of the Former Soviet Union, June 19, 1992.

[125] Geomatics Canada, Annual Review 1993-94, p. 3 & 10; O'Donnell, 1994 and several internal memos and notes on agreements, including one authored by Leo Sayn-Wittgenstein documenting the decision by the Task Force on Russia and Eastern Europe, SMRS Objectives and Strategy in Dealing with Russia and History of Development of SMRS Cooperation with Russia, Feb. 25, 1994.

#2 Project to Establish a Remote Sensing Capability in the Slovak Centre for Aerospace Environmental Monitoring **Partners:** Slovak Centre for Aerospace Environmental Monitoring, Slovak Commission of Environment /Ministry of Agriculture / Ministry of Forestry and Water Management / Slovak Academy of Sciences
#3 Remote Sensing / GIS Technologies in Czechoslovak Universities – Infrastructure, Education, Research and Demonstration **Partners:** Czech Technical University, Prague / Masaryk University, Brno
Canadian Partners for the three pilot projects: Bureau of Assistance for Central and Eastern Europe (BACEE), Foreign Affairs and International Trade Canada / Training and Technology Transfer Section (TTTS), CCRS / Geomatics International Inc.
Chernobyl GIS Project – Belarus and Ukraine
To assist the Ukrainian government improve their decision-making processes to better deal with the after-effects of the Chernobyl nuclear disaster. To provide two GIS systems – one in Minsk and one in Kiev. To provide training and support for creation of GIS databases with hydrography, relief, populated places, boundaries, transportation, radiology, made-made objects and vegetation. To develop some GIS applications using the database, e.g. definition and calculation of compensation to people affected by the accident. **Partners:** Belorussian Cartographic and Geodetic Enterprise / Belorussian Main Administration of Hydrometerorology / Ukrainian Ministry of Chernobyl / Main Administration of Geodesy, Cartography and Cadastre / Institute of Geography, Ukrainian Academy of Sciences / Intelligence Systems GEO in Kiev **Canadian partners:** BACEE, GIS Division (GeoAccess Division, CCRS) / Photosur Géomat Inc. / Intélec Géomatique Inc / CANATOM (Palko *et al*,1995 and Geomatics Canada, 1997))
Ryazan Digital Mapping Project
Phase I – Project Design and Planning To provide the City of Ryazan with a digital database which draws on Canadian large-scale mapping and cadastral technologies. This project was split into phases and activities to better manage the risks involved. **Partner:** Federal Service of Geodesy and Cartography (ROSCARTOGRAPHIA) **Canadian partners:** BACEE and TTTS with participation of other divisions of Geomatics Canada (Morris and Scott, 1994; and Geomatics Canada,1994))
Phase II Ryazan Project – Data Collection Technology transfer to perform ground control and airborne photo surveys using GPS technology which at that time was relatively unknown in Russia. **Partners:** Moscow Topographic and Geodetic Enterprise, Federal Service of Geodesy and Cartography / State Research Institute of Civil Aviation **Canadian Partners:** Geodetic Division, Geomatics Canada / GEOsurv Inc. (Geomatics Canada, 1996, p. 12)
Phase II activity - Cadastral Demonstration To demonstrate the capability of the RESULTS GIS system used by Legal Surveys Division for building a cadastre for the City of St. Petersburg. Training was provided for Russian technicians to use the system to create a cadastral plan and records for a small part of St. Petersburg using computer equipment and Canadian software that was loaned to Aerogeodezyia for 8 months. Partner: State Geodetic Enterprise for the City of St. Petersburg (Aerogeodezyia) Canadian Partner: Legal Surveys Division, Geomatics Canada (Geomatics Canada,1996)
Phase III - Ryazan Digital Mapping Project and Use of Maps in a Cadastral Application Technology transfer to produce a digital 1:2000 scale topographic data bank for the City of Ryazan, based on technologies for large-scale mapping now used in Canada. To test, in cooperation with Ryazan municipal officials, the digital maps in a cadastral application. To provide documentation and training to Russian partners and managers, so that they can ensure that project results are sustainable and used them as a foundation for future initiatives.

Partners: Four divisions of ROSCARTOGRAPHIA: Moscow Topographic and Geodetic Enterprise/ Moscow Aerogeodetic Enterprise / Russian Scientific Production Geoinformation Centre / Central Research Institute of Geodesy
Three offices of the Ryazan Regional and Municipal Administration: Mayor's Office / Ryazan Municipal Land Department / Ryazanskaya Oblast Committee for Land Resources and Land Management
State Committee for Land Resources and Land Use Management (ROSCOMZEM)
Canadian partners: BACEE, Centre for Topographic Information, Geomatics Canada / Linnet Geomatics International / Intermap Technologies / SHL Systemhouse / GEOsurv Inc / Cytec

Polish Agricultural Remote Sensing Project

#1 - To produce reliable predictions of cereal crop productivity during the growing season. The Polish crop condition assessment program was to be modelled on the system in use in Canada, and
#2 - For monitoring and modeling the performance of the post-production sector of Polish agriculture (identification of grain markets with maximum profitability at different times of the year)
Partners: Remote Sensing and Spatial Information Centre (OPOLIS), Polish Institute of Geodesy and Cartography / Dept. Of Agricultural & Environmental Statistics, Central Statistical Office /
Analysis & Information Office, Ministry of Agriculture and Food Economy / State Committee for Scientific Research / NeoKart GIS, in Warsaw
Canadian partners: Trade Cooperation Program with Poland, Canadian International Development Agency / TTTS and Applications Development Section, CCRS / TTTS and Applications Development Section, CCRS / Agriculture Division, Statistics Canada / Intermap Technologies / PCI Geomatics Group (Geomatics Canada,1996 and Geomatics Canada, 1997, p. 17)

Image Maps of Qatar

Production of one image map covering the whole of Qatar at 1:200,000 scale and four image maps at 1:100,000 from satellite imagery and data from Qatar's topographic database.
Client: Government of Qatar.
Canadian contractor: CCRS (Geomatics Canada ,1994 and Geomatics Canada,1996, p. 14)

Malaysian Remote Sensing Centre – Consultancy Services

Assistance to MACRES to prepare requirements and specifications for a satellite remote sensing ground station and recommendations for the station site. Also to prepare plans for training operational staff and for technology transfer.
Client: Malaysian Remote Sensing Centre (MACRES)
Canadian contractor: CCRS, managed by Major Projects Office (Geomatics Canada,1996, p. 17)

These projects were important, not just for the transfer of the technology and training provided, but also for the insight gained by the international partners in how government and industry work together in Canada and by the knowledge and contacts gained by Canadian industry in these countries.

As of 1999, TTTS Staff had been involved in project management and project execution activities in more than 25 countries in Africa, Asia, Latin America and Europe.

3.6.4. SAREX-92 and ProRADAR
Frank Ahern

3.6.4.1. Background and Context
The projects which eventually became SAREX-92 and ProRADAR were first conceived in 1989 by Dr. Keith Raney, a pioneer in Canada's radar remote sensing program. This was a time of deep concern about the environment by the Canadian public and many others around the world. The destruction of tropical rainforests was considered one of the foremost global environmental problems; an issue well known by most Canadians because of the journalistic activism of Dr. David Suzuki, and brought into stark human reality by the murder of Chico Mendes in the Brazilian state of Acre.

There was also optimism about the role technological advances might play in protecting the environment. Canada's RADARSAT was under development, with a launch expected in 1994. RADARSAT was intended primarily to be used for ice reconnaissance, with applications in various important but secondary applications in natural resource management disciplines such as agriculture, forestry, geology, and hydrology. In 1989 Raney began to promote the use of RADARSAT for tropical rainforest monitoring as part of his EverGreen Plan, and the Canada Centre for Remote Sensing responded positively through the Tropical Forest Initiative.

In 1991 $1.2 M funding was secured from the European Space Agency for the South America Radar Experiment (SAREX-92) to fly the CCRS Convair 580 radar aircraft and obtain C-band radar data over test areas in six countries: Brazil, Colombia, Venezuela, Costa Rica, Guyana, and French Guiana. In 1993 CIDA engaged CCRS for just under $1 M to carry out an ambitious program of research, user development, and training.[126] Most of the CIDA money was spent in cooperation with Brazil, because of the strength of Brazil in the important areas of research and development, education, and training.

3.6.4.2. Objectives
The overall objective for CCRS was to obtain a quantum-jump in our knowledge of the strengths and weakness of airborne and satellite SAR in tropical environments, and to prepare for and promote the use of RADARSAT-1 data by tropical countries.

Since external funding was required, our objectives also had to support particular objectives of the others involved: the European Space Agency, CIDA and RADARSAT International.

The ESA objectives for SAREX-92 were primarily related to the basic and applied science of SAR. The ESA satellite ERS-1 was already operational, and European researchers focused heavily on comparisons between airborne data acquired during the SAREX-92 mission to Latin America and ERS-1 data. At CCRS, by comparison, we were more interested in simulating RADARSAT-1 data than exploring ERS-1 data. While ERS-1 had VV polarization because it was designed with emphasis on the water in the oceans, RADARSAT-1 had HH polarization because it was designed with emphasis on sea ice. This difference in polarization, combined with shallower incidence angles, turned out to be a major factor in the superiority of RADARSAT-1 over ERS-1 for applications in tropical environments.

The CIDA objectives were related to its international development mission. Since these were very much in line with the CCRS strengths, developed over two decades of research, development, and technology transfer, CIDA was confident in CCRS's ability to meet the objectives agreed to by both organizations.

3.6.4.3. Partners
Our funding partners were the European Space Agency under the SAREX-92 program during 1992-93, and the Canadian International Development Agency from 1994 to 1997. In 1998 and 1999, an extension

[126] Dr. Fred Campbell, who came to CCRS from the office of the ADM of Geomatics Canada, had a remarkable capability to secure external funding. His efforts were critical for the SAREX-92, ProRADAR, and the GlobeSAR programs.

of ProRADAR was directed at environmental NGOs, which resulted in the transfer of technology to large and small NGOs in Brazil.

Through SAREX-92 we developed partnerships with Costa Rica in Central America and Brazil, Peru, Venezuela, Colombia, and Bolivia in South America. Our contact with ESA for SAREX-92 was Dr. Evert Attema of the European Space Research and Technology Centre in Noordwijk, The Netherlands. Our primary contract with CIDA was Mr. Michael Brownell.

In the majority of countries our primary point of contact was a mid-level manager in an environment-related ministry. INPE, the Instituto Nacional de Pesquisas Espaciais, or National Institute for Space Research, in Brazil, rapidly emerged as our strongest and most reliable partner. INPE, and five of its research scientists, played a major role in ProRADAR and its success. Despite the economic and political issues that confronted Brazil from the 1960s to the 1990s, INPE remained a robust organization that produced leading-edge research and development, not just in remote sensing, but also in astrophysics, meteorology and satellite development. INPE also had a unique role in education: numerous enthusiastic graduate students, including a significant number of women, livened up the INPE campus and contributed immensely to their senior scientists' research.

Primary Points of Contact for Costa Rica and ProRADAR

Country	Name of Institution	Contact Person
Brazil	Instituto Nacional de Pesquisas Espaciais (INPE)	Thelma Krug (Director) Maycira Costa[127] Hermann Kux Evlyn Novo Waldir Paradella Yosio Shimabukuro
Bolivia	Asociación Boliviana de Teledetección para el Medio Ambiente (ABTEMA)	Sophie Moreau
Colombia	Instituto Geográfico Augistin Codazzi (IGAC)	Miriam Ardila Torres
Costa Rica	Instituto Geográfico Nacional (IGN)	Carlos Elizondo
Peru	Comisión Nacional de Investigación y Desarrollo Espacial (CONIDA)	Ricardo Coloma
Venezuela	Ministerio del Ambiente y los Recursos Naturales Renovables (MARNR)	Alicia Moreau Dominguez, Ramiro Salcedo
Canada	RADARSAT International (RSI)	Pamela Welgan

In passing it is worth noting that Canada's decision not to pursue the development of satellite launch vehicles has proven to be a wise decision in contrast with Brazil's costly attempts to develop a space launcher.

Another important partner in ProRADAR was RADARSAT International (RSI), the private sector company established to market RADARSAT-1 data around the world. Ms. Pamela Welgan led the RSI marketing effort in Latin America. She provided enthusiastic and effective liaison with CCRS, greatly facilitating the ability of RSI to put the developments that flowed out of SAREX-92 and then ProRADAR to best use for RSI objectives, without trying to influence our activities and reports.

3.6.4.4. Project Execution

SAREX-92 and ProRADAR were important CCRS activities from September 1992 to May, 2000. They were led by Dr. Frank Ahern, ably assisted by Mr. Ron Pietsch at CCRS. Other CCRS employees provided support as particular issues and needs arose.

[127] Dr. Costa is now a Professor of Geography and Remote Sensing at the Unviersity of Victoria.

3.6.4.5. SAREX-92

Although the overall SAREX-92 project explored the utility of ERS-1 satellite radar data as well as airborne SAR, the primary interest for CCRS and its partners was multi-polarization SAR data obtained with the CCRS SAR-580 radar aircraft discussed in more detail in Section 7.8. The airborne data were acquired in a single mission of the CCRS Convair-580 aircraft from 1 - 27 April 1992. Test areas were established in Costa Rica, Venezuela, Guyana, French Guiana, Colombia, and Brazil. CCRS was not involved in the experiments in Colombia, Guyana, and French Guiana. In preparation for the mission, CCRS made formal contacts with Costa Rica through Carlos Elizondo of Instituto Geographico Nacional, with Alicia Moreau of MARNR in Venezuela, and Dr. Marcio Barbosa, Director General of INPE in Brazil. In Costa Rica and Venezuela Mr. Elizondo and Dr. Moreau organized several in-country studies and test areas. The preparations in Brazil were considerably more complicated. Because of an unfortunate incident following an American SAR overflight many years before, it was necessary to obtain permission from the Brazilian Air Force and the President of the Republic to overfly Brazilian air space and obtain imagery for five test areas. The GlobeSAR programs in South America and Asia helped develop a better understanding of how to get approvals to fly remote sensing missions in countries that had no history of open skies. (See GlobeSAR discussion in 3.3.3.9.) An INPE scientist was chosen by INPE to be the Principal Investigator for each test area, and each scientist was invited to Canada to work at CCRS for six months.

A preparatory mission by Drs. Ahern and Raney in November 1991 provided essential information to finalize the test areas and flight lines in Costa Rica, Venezuela, and Brazil. That mission also provided an additional opportunity to consult with the local scientists, and was central to obtaining excellent airborne data for SAREX '92 the following April.

After the SAR-580 data were acquired in April, the experimental analysis was carried out by the investigators. Dr. Hermann Kux of INPE spent seven months in Canada from October 1992 to April 1993, and all of the Brazilian investigators presented their results at the 7th Brazilian Remote Sensing Symposium. Results from the work in Costa Rica and Venezuela were presented at various national and international venues. An important component of the work was the simulation of RADARSAT-1 data through computer manipulation of the SAREX airborne data.

3.6.4.6. Professional Exchanges

One of the most important and successful features of ProRADAR was a series of exchanges of professional researchers between CCRS and INPE. This served to maximize the exposure of each researcher to the environment and learning opportunities offered by the host institution. INPE assigned four research scientists as the principal scientific contacts with CCRS: Dr. Hermann Kux, Dr. Evlyn Novo, Dr. Waldir Paradella, and Dr. Yosio Shimabukuro. Each of these scientists was already engaged in applied research in the Amazon region, and each expressed a keen interest in incorporating radar data into the suite of data for their problems of interest. All but Dr. Novo spent four to seven months working at CCRS. Each scientist was responsible for developing a portion of the original proposal to CIDA which led to ProRADAR. These scientists were designated as the INPE Principal Investigators (PIs) for ProRADAR. In addition, Dr. Ahern spent six months working with these and other scientists at INPE. That exchange began with a CIDA-sponsored two-week immersion course in Portuguese, enabling Dr. Ahern to interact and contribute far more effectively in Brazil.

3.6.4.7. Preparation for RADARSAT

The understanding of the use of C-band radar data in tropical rainforest environments was greatly increased through the experience gained using the airborne data acquired through the SAREX campaign, including simulations of RADARSAT-1 data. But early experience with actual RADARSAT data was a necessary next step for ProRADAR.

One of the essential components of ProRADAR was training in radar remote sensing, presented in Portuguese, for potential users of RADARSAT-1 data. In April 1993 the first specialist workshop was held in Rio Branco in the western state of Acre. Over the course of ProRADAR, nine more workshops were held, and seven training manuals were produced. This material led to the production of SAR 101, a radar training manual on CD-ROM, in the four languages of the Western Hemisphere: English, French, Spanish, and Portuguese.

A briefing to senior Brazilian government officials about the RADARSAT program was held in Brasília in May, 1995. This event was organized by the Canadian Embassy, with technical support provided by ProRADAR partners CCRS, INPE, and RSI. This event greatly increased the awareness of RADARSAT within the Government of Brazil.

3.6.4.8. Initial RADARSAT Investigation

RADARSAT-1 was successfully launched in November, 1995, and was soon providing radar images that exceeded design specifications for nearly all image quality parameters.

Five INPE Principal Investigators gained access to RADARSAT-1 data by means of submissions to a competitive program run by the Canadian Space Agency. The INPE investigators developed their project proposals, and subsequently carried out field data campaigns, and processed their RADARSAT data quickly and efficiently using the facilities supplied under ProRADAR. Ahern was an active participant and mentor in all of these activities. All of this was made possible through the professional relationship and trust which had been built through SAREX and the earlier stages of ProRADAR. Without exception, the INPE investigations were completed quickly and efficiently, enabling the ProRADAR team to remain in the forefront of knowledge of RADARSAT capabilities in tropical rainforest environments.

3.6.4.9. Amazon Basin Project

In June 1996 ProRADAR entered a new phase, to extend radar knowledge to a number of new institutions in Brazil, and in Brazil's neighbours which share the Amazon Basin: Venezuela, Colombia, Peru, and Bolivia. This phase was called the Amazon Basin Project.

In February, 1996 invitations were sent to individuals and organizations which had a mandate for environmental monitoring or natural resource management in the Amazon Basin. The invitations requested short proposals (3 to 5 pages) to be brought to an Amazon Nations' workshop for further development. Each proposal was to include a practical application of RADARSAT-1 data, a study area, and an investigation plan.

The Amazon Nations Workshop was hosted by INPE in São José dos Campos from June 24 to 28, 1996. The program consisted of one day of presentations on radar theory, one day of presentations on radar applications, two days in which each of the participants presented his or her project proposal, and one day in which the project proposals were refined and improved through mutual discussions. The workshop was conducted in an eclectic mixture of Portuguese, English, and Spanish.

A modest allocation of RADARSAT data (nominally 2 scenes per project) was acquired for each project, and provided in enlarged hard copy photographic form, because the participants generally did not have the equipment or skills to carry out digital image analysis.

CCRS and INPE provided professional and technical support for the project teams during the course of their investigations. Frank Ahern visited each of the teams in February and March, 1997 to help with any outstanding issues and help them prepare for their presentations at the Geomatics in the Era of RADARSAT symposium (GER-97).

All of the project teams carried out scientifically sound evaluations of their RADARSAT scenes, and all of them produced quality reports for GER-97, which were subsequently collected and produced as a bound volume which provided valuable additional training material. Short reports from each project were collected into a book "RADARSAT for Amazonia: Results of ProRADAR Investigations" that was distributed throughout South America and to libraries and leading academic institutions around the world.

This initial experience with RADARSAT data could not be expected to be sufficient to make the nations outside of Brazil into operational users of RADARSAT data. Through the planned follow-up through the GlobeSAR-2 project, however, the most promising users and applications were able to move much further along the path towards operational use of the data.

3.6.4.10. NGO Pilot Projects

A final phase of ProRADAR focused specifically on NGOs. This phase was carried out in a manner similar to the Amazon Basin Project. Dr. Roberto Cavalcanti at the University of Brasília provided the primary leadership. This final phase was initiated with an Atlantic Forest Workshop held August 3 – 6, 1998 in Belo Horizonte and hosted by Conservation International. This workshop was followed by a Cerrado, Pantanal, and Amazonia Workshop held October 7 – 9, 1998 in Brasília, hosted by the University of Brasília. By this phase of ProRADAR digital image analysis software for radar could be run on inexpensive PCs, and the software itself was much less expensive than in 1994 when ProRADAR began. It was possible to develop a modest but effective image analysis laboratory at the University of Brasília using a very small outlay of ProRADAR funds which were used to purchase Canadian (PCI) software to run on hardware supplied by the University of Brasília.

As in the Amazon Basin Project, participants were invited to select a project of interest to their organizations. The projects were then developed in more detail after the participants received basic training in radar. Six projects were carried out in this phase, including two from the Atlantic Rain Forest region, two from Amazonia, one from the Cerrado, and one from the Pantanal. Participants received two to three RADARSAT scenes each. Unlike the Amazon Basin Project activity, the data were processed digitally. This required supplementary training in digital image analysis which was provided by the University of Brasília. As in previous phases, professional and technical advice was available from CCRS and INPE, but the strong capabilities resident at the University of Brasília greatly decreased the involvement needed from CCRS and INPE. A new feature of the NGO Pilot Projects phase of ProRADAR was the creation of a Conservation Technology Network, made possible through advances in Internet technology.

The NGO Pilot Project investigations were completed in 1999, and the participants were brought together in Brasília on December 17 and 18 for a final workshop to present their results.

3.6.4.11. Outcomes

SAREX-92 and ProRADAR constituted a long, sustained (8 year) effort to build a strong foundation of knowledge about radar remote sensing in tropical environments, to test that knowledge in practical applications, and to disseminate knowledge of radar imaging and its uses to a broad user community. Given the near total absence of knowledge and experience with radar in the tropics when the effort began, the results were impressive. These projects were successful in:

- Developing a cadre of strong radar applications research scientists, particularly in Brazil, but also in Venezuela, Bolivia, Colombia, and Peru;
- Learning about the uses and limitations of RADARSAT-1 data in a variety of tropical environments over a wide geographical area;
- Disseminating the new knowledge through 36 scientific publications, seven training manuals, and 15 training workshops; and
- Greatly enhancing the use and sales of RADARSAT-1 data in Latin America.

According to a third-party evaluation contracted by CIDA (Quiroga and Ryerson, 2000), "ProRADAR has exceeded its planned results. Remote sensing has been fully integrated into the activities of a number of groups and players in Amazonia."

3.6.5. Conclusion

Simply stated, the range and depth of the international relationships of CCRS highlighted in Section 3.6 can in large measure explain the impact CCRS had world-wide. That impact was enhanced through a strategic focus on matters that were important to the international partners with whom CCRS worked. At the same time CCRS ensured that those involved in the projects never lost sight of what was important to Canadian industry and other governments and government agencies within Canada with which CCRS worked. Virtually every international activity of CCRS had multiple objectives. Outcomes ranged from improved science and research in support of the issues important to Canadians, on to helping bring a nascent industry to a position of world-wide prominence and, in some cases, dominance.

4. Mergers, Acquisitions, and Closures

Bob Ryerson

4.1. Introduction

Over time what CCRS was responsible for and how it was funded changed substantially. In its formative years CCRS was much like a start-up in the private sector: additional units were added as the organization grew. The last of the additions in this phase was the Applications Division in 1973. Following on with the private sector analogy CCRS saw adjustments to how it was organized with changes that could be characterized as mergers (joining with other organizations), acquisitions (taking over other organizations), and closures (closing units for financial or other reasons).

This section details what have been judged to be some of the more important of these changes over the years.

4.2. GeoAccess Division

The creation of GeoAccess Division was one of the successes of CCRS. The birth of the idea is described in the following text box in the words of Dr. Bob O'Neil, the founding Director. The Division received a number of major awards and was recognized for contributing to a better understanding of Canada by Canadians. Further details are given in Section 6.10.

The Creation of the GeoAccess Division **Bob O'Neil**
There were some opportunities after Program Review II but the key element in the logical justification for GeoAccess Division might label me as nefarious, even diabolical. I had noticed through many years on PSRC that it was easier to promote development projects that had, as one clear objective, something explicit/concrete that CCRS could develop, deliver, keep or operate and claim as a success as other people/agencies used/exploited/benefitted from it. In my opinion, we had been attempting to hand-off projects too early to clients who had a very narrow view of the diversity of the application/benefits. I proposed GeoAccess Division to Ed Shaw as we walked up Booth Street for lunch one sunny day. There were a number of pieces in CCRS (Major Projects Office or MPO) and the Long term Space Plan (LTSP) (which was not only RADARSAT) that I could see as part of the Canadian GeoSpatial Data Infrastructure (CGDI). In addition, I wanted an operational component that could demonstrate a coherent perspective on how the CGDI might operate and the benefits. For this, I needed the Atlas of Canada and GIS Division both of which had been orphaned in Program Review. I don't think we made it to the restaurant before Ed was on side – saying something like "Go ahead, and if this is not a success in five years nobody will ever hear of you and your band of merry men again". The success of GeoAccess Division was a problem for the Earth Science Sector Program Office, Communications Branch, and maybe even the Deputy Minister. We developed a web presence larger and more diverse than the entire rest of the Department! We also had very productive partnerships with other agencies and a remarkable international reputation. As CCRS had experienced in an earlier era, we were an admirable model, one that has been imitated around the world.
Source: E-mail from Bob O'Neil, December 19, 2017

4.3. CSA Budget Increase of 1994

The following text box provides the context for the CSA Budget increase as well as the demise of the CCRS Airborne and Sensor Development programs discussed in the next Subsection. Quite simply the Government of Canada's budget was in dire straits and budgets had to be cut. Significant cuts were announced in the budget of 1994.

How Canada Tamed Its Budget Crisis[1]
Here are highlights of what led to the Liberal government slaying the deficit with the backing of a conservative opposition party. October 1992 - Standard & Poor’s cuts its rating on Canada’s foreign-denominated government debt to AA-plus from AAA on concern about the current account deficit, a growing government debt load and uncertainty about the political situation in French-speaking Quebec, home to a popular separatist party. February 1994 - The newly elected Liberal government brings down what it considers to be a tough budget, aiming to lower the deficit-to-GDP ratio to 3 percent by 1996. It nonetheless still has spending rising slightly, and immediate public and market reaction is it did not go nearly far enough. June 1994 - Moody’s Investors Service lowers its rating on Canada’s foreign currency debt to Aa1 from Aaa, citing the government’s large and growing public debt. January 1995 - A biting editorial in the Wall Street Journal headlined “Bankrupt Canada” calls Canada “an honorary member of the Third World,” lumping it in with Mexico and suggesting the International Monetary Fund might have to come to its aid. The commentary is headline news in Canada. February 1995 - Liberal Finance Minister Paul Martin introduces a deficit-cutting budget in which deep spending cuts outweigh tax increases by seven to one. “Not to act now to put our fiscal house in order would be to abandon the purposes for which ... this government stands - competence, compassion, reform and hope,” he says. In a display of unity that’s rare outside wartime, the right-wing opposition Reform Party backs the spending cuts.
[1]Extracted from ***Reuters Business Reporting*** by Allison Martell and Randall Palmer. Source: https://www.reuters.com/article/us-crisis-timeline/timeline-how-canada-tamed-its-budget-crisis-idUSTRE7AK0FF20111121 Accessed October 11, 2018.

Leading up to the 1994 Budget Glen MacDonnell of Industry Canada and Ryerson of CCRS prepared a concept document for a space plan based on a series of interdepartmental meetings and the study of current directions of both research and industry development in Canada and abroad. Justifications were prepared for a range of activities. During this process a CCRS scientist told Ryerson that he was too busy to provide any details of the value of his work. The response from Ryerson was “well, you will have a lot of time once your program is no longer funded.” The program was eventually cut and the next time that scientist was asked for information it was provided within a day! One Director in another department, responsible for the International Space Station, told Ryerson and MacDonnell that “I don’t need to prepare any justifications – I already have a budget.” He no longer participated in the discussions. Others around the table soon had his budget carved up and distributed among the rest of the players – with the bulk earmarked for earth observation/remote sensing. The result can be seen in the quote in the next paragraph. At the same time we encouraged industry people with whom we were in contact to explain to their local MPs, Ministers and regional Ministers the importance of the space sector and remote sensing in the creation of high technology jobs and exports. Industry players did this with a rather unexpected result, as is explained below.

Minister Martin stated in his speech: “We will develop a new long-term space plan that is both affordable and which offers the best possibility of commercialization and the creation of jobs. We will concentrate on areas of Canadian advantage, such as satellite technology.” He then went on to say: “Second, we have decided to negotiate an orderly withdrawal from current commitments to the International Space Station program.” The new budget (most of it for earth observation) was on the order of $1 billion as reported in the budget. In reality it came out to be some $800 million – or $80 million per year. It should be kept in mind that RADARSAT was to be launched in 1995. In the end, following an intervention by President

Clinton, the Space Station budget was not cut as much as was planned and some of the funding for the International Space Station was returned.

The impact of the new space money on CCRS was not to be fully understood until the Budget of 1995 arrived a year later.

4.4. Cancellation of the Airborne and Sensor Development Programs

While substantial cuts were announced in 1994 and there was virtually no “new” money (except for space), even greater cuts were announced in the Budget of 1995. Those cuts in 1995 for Natural Resources Canada were 40%.[128]

An all-staff meeting was called at the Ottawa Technical High School auditorium on Budget day by a shaken and emotional Geomatics Canada’s Assistant Deputy Minister Hugh O’Donnell. He announced that there would be a 40% reduction in budget and that the number of Executive positions (Director and Director General) would drop from about 30 to 11. Furthermore, any staff member over the age of 50 with ten years’ service in the Public Service could retire without penalty and receive a buy-out of up to a year’s pay for doing so. As a Section Chief with aspirations of becoming a Director, this author decided to volunteer to retire and was the first to reach ADM O’Donnell at the front of the lecture hall to do so.

CCRS management[129] decided to cut the most expensive activities that could not be supported by the infusion of funds made available from the space program. Of course the space earth observation program was focused on RADARSAT to be launched in 1995. That was the final death knell for the optical sensor program and much of the airborne program. (See the Text box in Section 6.5.3 for commentary on the earlier reduction of the LiDAR sensing work.) The CV-580 and its radar sensors were transferred to Environment Canada. With the exception of a very few people (almost all of whom volunteered to take early retirement) all permanent government staff were retained. However, capital budgets were dramatically reduced and most work related to optical (as opposed to radar) sensing was either eliminated or scaled back to bare-bones research and applications development – further hardware development basically ceased.

The cuts to the capital budget were not felt immediately, but did cause considerable trouble in future years as old equipment began to fail. As the late Ian Press, then Director responsible for the ground stations told me seven years later in 2002: “Bob, we need more capital – the stations are being held together with duct tape and binder twine.” As is described in Section 6.9.6 the stations were eventually refurbished in 2012 through the efforts of Carolyn Cloutier and Doug Bancroft.

4.5. Changes in Names of the Host Sector

In the early years CCRS was a part of the federal government’s Ministry of Energy Mines and Resources, but to those of us at the working level or first level of management, it seemed like it was almost an independent agency. That, however, was not the case. It always reported to an Assistant Deputy Minister. In the 1990s the name of the host sector changed twice. First it changed from the Surveys, Mapping and Remote Sensing Sector in the spring of 1994 to Geomatics Canada. At that time the first ***Geomatics Canada Annual Report*** was published for FY 1993-94 and the last was published for 1996-1997. Hugh O’Donnell was the Assistant Deputy Minister. In the spring of 1997 the name changed again from Geomatics Canada to the Earth Sciences Sector when the Geological Survey of Canada and Geomatics Canada were combined into one.

4.6. Addition of the Geodetic Survey

The Director of the Geodetic Survey Division (GSD) reported directly to the Assistant Deputy Minister (ADM) of the Earth Sciences Sector. In the early 2000s the ADM decided that the GSD should be added to CCRS. The Director of the Division was at the correct level to report to the DG of CCRS and the GSD

[128] 1995 Budget Speech, Honourable Paul Martin, Minister of Finance, February 27, 1995.
[129] The following is in part conjecture as the author was not privy to the decision-making process – only the results were visible.

worked with satellites and was involved in research and high technology of the sort that CCRS was used to managing. This "acquisition" lasted until 2013 when it was removed from CCRS at the time that mapping was being added to CCRS activities under the new name of the Canada Centre for Mapping and Earth Observation. GSD was added to the Branch responsible for Legal Surveys.

4.7. The End of a Truly National Centre for Remote Sensing

As is demonstrated throughout this document, CCRS was successful, nationally and internationally, over its first three decades. In 2002/2003 a fateful decision was made by the ADM of the day, when this author was Director General. In spite of the legislation (NRCan Act) that we interpreted as putting remote sensing and what CCRS was doing in the department's mandate, the ADM decided that in the future CCRS would only work on applications and topics germane to the portfolio of the Minister of Natural Resources. Thus, CCRS was expected to concern itself only with geomatics, mapping, and Earth observation for natural resources (forestry, geology and elements of hydrology). It was no longer to work on applications in agriculture, ice, oceans, parks, and most environmental topics, nor was it to lead the development of generally applicable remote sensing applications outside of the NRCan mandate, even if world-class. CCRS would no longer be the central agency for research in remote sensing in support of other federal government agencies or departments. This led to the departure of a number of world-class scientists including several authors of this document.

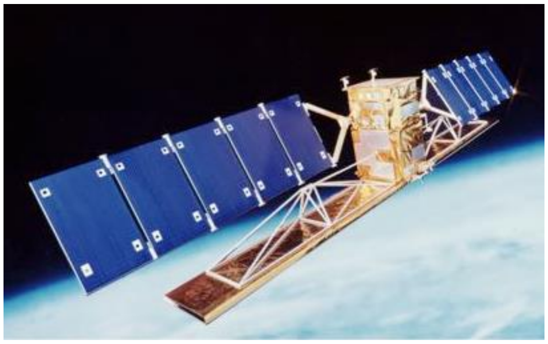
By 2002 other government agencies with thematic responsibilities, such as environmental monitoring, forestry, agriculture, oceanography, wildlife, parks, etc., had often developed their own remote sensing experts and teams of specialists. However, until the decision to limit the topics with which CCRS concerned itself, these other agencies and departments largely depended on CCRS for research – just as CCRS depended on the other departments for an indication of what problems were worthy of attention by CCRS. As noted elsewhere in this document, that research was almost always done collaboratively with CCRS. As a result of the decision to focus on the mandate of NRCan, research in remote sensing became Balkanized within the federal government. Among those who left CCRS for other departments at this time were Heather McNairn, Chuck Livingstone, and Paris Vachon, to name just a few. A number of others took early retirement around this time, or left for positions elsewhere in industry or academe.

With the increasing isolation of CCRS, and the dismemberment of the team of scientists and departure of key leaders, CCRS was neither able nor allowed to provide the scientific support for the broader development and use of remote sensing as was originally intended in the original 1971 Cabinet decision and following legislation. After 2002 CCRS did maintain its strength in polarimetry (as is clearly demonstrated in Section 6.7.2.4) with funding largely from the CSA, and it did keep up in a few other areas of expertise.

In closing on this subject, at the time some suggested that CCRS should become part of the CSA. However, the CSA was concerned with space and not so much with its application – it had left the development of EO applications to CCRS, other government departments and industry. CCRS did embed some scientists into the CSA for a time to provide EO support, but the CSA was not interested in "acquiring" CCRS - especially as it was packaged and with the legislation that existed.

5. RADARSAT[130]
Dr. R. K. Raney

Foreword
RADARSAT-1 was Canada's first remote-sensing satellite, launched in 1995. As summarized on the Canadian Space Agency's Web site:



"*National Aeronautics and Space Administration (NASA) provided the Delta II rocket to launch RADARSAT-1 in exchange for access to its data. Estimates are that the project, excluding launch, cost $620 million (Canadian). The Canadian federal government contributed about $500 million, the four participating provinces (Quebec, Ontario, Saskatchewan and British Columbia) about $57 million, and the private sector about $63 million. RADARSAT International, Inc. (RSI), a Canadian private company, was created in 1989 to process, market and distribute RADARSAT-1 data. RADARSAT International, Inc. (RSI) was later acquired by MacDonald Dettwiler and Associates (MDA). In 2006, RSI was rebranded MDA Geospatial Services International or MDA GSI.*"[131]

This chapter presents RADARSAT's back-story: how it came to be such a major technical accomplishment, and why it was so enthusiastically supported by the Canadian government and provincial agencies. The subsequent Canadian SAR satellites continue the main themes of this story.

RADARSAT-1 was a product of CCRS' initiative, leadership, vision, and technical expertise. Its evolution is best understood against the background of CCRS' primary purpose, to meet the needs of users. The underlying process is outlined in section 5.1. Section 5.2 presents the evolution of RADARSAT's conceptual design, modeled as a "ping-pong" match between users (who set high-level expectations and requirements) and the technical team (which through courage and innovation responded to those requirements). The result was a user-driven design that was six to ten years ahead of all other imaging radar satellite missions, and that met user's principal needs, both domestic and international. Section 5.3 describes RADARSAT-2, which was a mission that continued the technical and operational features of its predecessor, while offering new capabilities. Section 5.4 summarizes the RADARSAT Constellation Mission (RCM)--in the final pre-launch implementation stage at the time of this writing—which benefits from technical leaps forward, indeed a fundamental paradigm shift that is expected to provide user-driven operational capabilities that were unimaginable two decades ago. CCRS played a major role in the conceptual foundations of those three missions. The chapter closes with concluding observations in section 5.5.

5.1. Introduction

This section reviews Dr. Morley's leadership which inspired and shaped RADARSAT-1, describes SEASAT's synthetic aperture radar (SAR) mode, and the birth of Canada's digital SAR imaging prowess. The section closes with an overview of the state-of-the-art in Earth-orbiting remote sensing SAR satellites during the time that RADARSAT-1 was in development.

[130] This chapter is adapted from a keynote presentation at the 2013 Canadian Symposium on Remote Sensing: R. K. Raney, "Application and Inspiration, a Tribute to Dr. Larry Morley from the RADARSAT Perspective".
[131] http://www.asc-csa.gc.ca/eng/satellites/RADARSAT1/

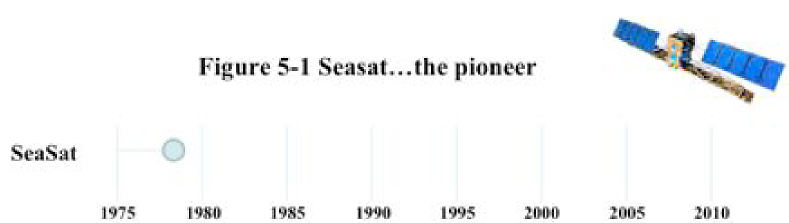
5.1.1. Dr. Larry Morley's Legacy

As described in previous chapters, Larry, the founder of CCRS (1971), was fond of saying that "Canada was made for remote sensing." Although CCRS' early years were built exclusively around airborne sensors and their applications, he had from the beginning a vision of a Canadian Earth-orbiting imaging radar satellite. Why radar? Because he knew that high-quality SAR imagery should be able to go a long way towards meeting the needs of users from coast to coast, due in large part to radar's ability to "see" through darkness, cloud cover, and precipitation. He further recognized the essential value of reliable and routine radar coverage of Canada's boundaries and coastal regions. He appreciated that to be successful such a major enterprise had to have full support, including "buy-in" from users. CCRS capabilities covered many disciplines of interest to users, including oceanography, agriculture, forestry, and the cryosphere, but the operational user agencies needed to be encouraged and enabled to come on board. Due in large part to Larry's promotion, in 1976 the Canadian government undertook an inter-agency study of the benefits such a satellite system would bring to Canada. The result was Satellites and Sovereignty,[132] tabled in 1977. This major report offered a compelling justification for the satisfaction of user needs based on data from a SAR-equipped Earth-orbiting satellite. It quantified the direct benefits to all of the provinces and the national government, as well as the value-added industry. A major contribution was the extensive cost-benefit analysis contributed by Dr. Archie McQuillan of CCRS.

The user's perspective was represented in large part through advisory committees, especially CACRS (section 2.2). During the formative years of the RADARSAT-1 design, regular meetings were held where joint discussions were the central purpose, between CACRS members, and CCRS' technical leaders in various disciplines. This evolved into a dynamic crucible in which "users" became familiar with capabilities and limitations of remotely sensed radar data to meet their needs, while the applications technologists learned more about the demands that users would place on their data. This approach gave life to Larry's vision that remote sensing must be responsive to Canada's user needs, a theme that led to the innovative RADARSAT-1 conceptual design, and in subsequent years, influenced the shape of the entire RADARSAT program.

5.1.2. The SEASAT Story[133]

NASA's SEASAT (July 1978 – September 1978) carried a suite of microwave instruments: an altimeter, radiometer, scatterometer, and a Synthetic Aperture Radar. Its SAR was the first (unclassified) imaging radar in Earth orbit (Fig 5-1). SEASAT was a watershed achievement, influencing several subsequent satellite SAR systems. Indeed, the original instrument payload for Canada's radar satellite (notionally named "SurSat" in the 1978-1980 timeframe) was visualized as having the same suite of microwave instruments as SEASAT. As the SurSat concept matured, soon morphing into the nascent RADARSAT, potential users began asking for more capability from the SAR. In parallel, prospective users showed little interest in data products from other microwave instruments. In response, RADARSAT became a single-instrument spacecraft.



5.1.2.1. Processing

Early in the SEASAT program, NASA sponsored two studies aimed at digital SAR image formation processing (Westinghouse and the Control Data Corporation), while the Jet Propulsion Laboratory (JPL) started development of an in-house digital SAR processor. As it transpired, NASA decided to not continue funding their contractors. (JPL's SAR digital processor project continued, on internal funding,

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[132] Satellites and Sovereignty", Canada Centre for Remote Sensing, Department of Energy, Mines, and Resources, 1977, 172 pages.

[133] See Jordon, 1980.

hence at a relatively low level.) NASA's default baseline processing plan for SEASAT was coherent optics, based on the same system that JPL had used in support of their airborne SAR. The optical SAR processor (Fig 5-2) developed by the Environmental Research Institute of Michigan (ERIM) was state-of-the-art at the time. It was a tilted plane,[134] anamorphic, tracking, and diffraction-limited telescope (*circa* 1977). An example of optically-processed SEASAT SAR data of an oceanographic scene is shown in Fig 5-3.

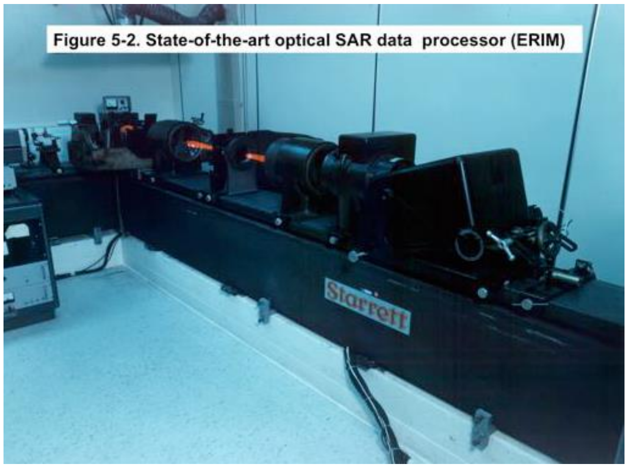


Figure 5-2. State-of-the-art optical SAR data processor (ERIM)

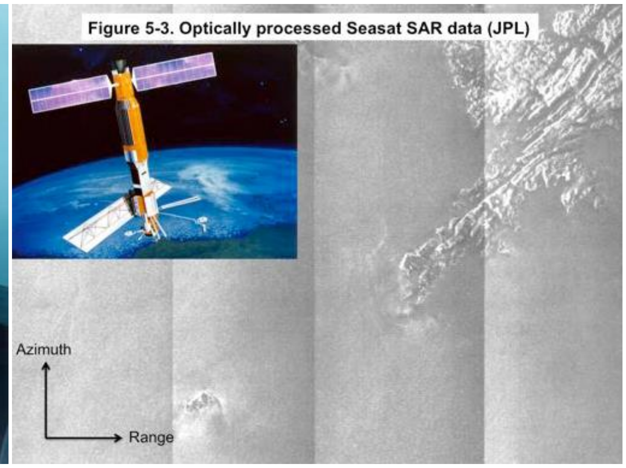


Figure 5-3. Optically processed Seasat SAR data (JPL)

The vertical (azimuth direction) bands are the result of processing four parallel strips through the optics which was necessary due to the large range width of the data (100 km on the surface). As an analog approach, it proved to be nearly impossible to get exactly the same results from repeated attempts. Further, as an analog system, it was nearly impossible to calibrate the relationship between the "whiteness" of the radar's response in the image, to physical characteristics of the reflecting surface.

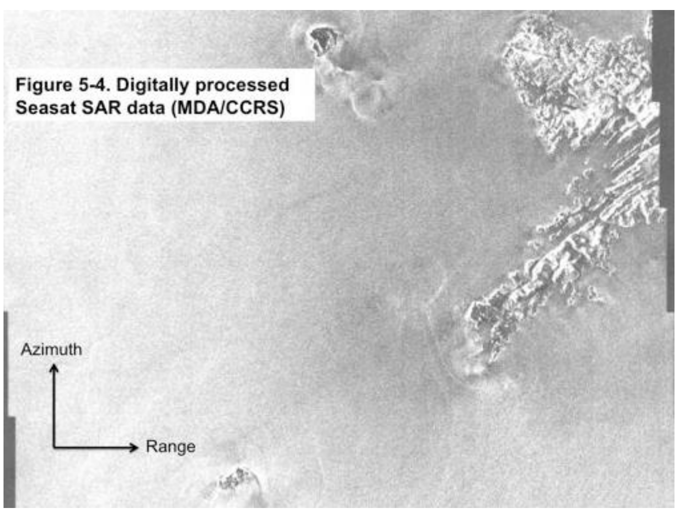


Figure 5-4. Digitally processed Seasat SAR data (MDA/CCRS)

With an eye towards the future, in 1977 CCRS began its own digital satellite SAR processor project. The government let a development contract to MDA, for which CCRS was the technical contracting authority. That project was successful. MDA published the first digitally processed satellite SAR image in the November 1978 issue of ***Aviation Week***. An example of digitally processed SAR image is shown in Fig 5-4, using the same data processed by optical means in Fig 5-3. Note the absence of azimuth banding. Limited primarily by computer hardware at the time, a one-quarter frame of SEASAT data (thus, of an area approximately 50 km by 50 km square) took 40 hours! For comparison, the standard today is real-time (better, real rate) processing. Canada remains a world leader in this specialized technology. Digital SAR image processing has proven to be eminently repeatable, and, judging by the results of RADARSAT-1 and -2, readily calibrated to a tight tolerance.

[134] See Kozma et al, 1972.

5.1.2.2. Early SAR Satellites

After SEASAT in 1978, several SAR satellites were developed and launched in the following 17 years (Fig 5-5). The SIR[135] flights (in parentheses in the figure) were a breed apart, as they were special payloads on NASA's Shuttle, and each mission lasted only a week or two. Like SEASAT, SIR-A and -B were at L-band (23-cm wavelength), and had limited incident diversity. SIR-C had three frequencies: L-band, C-band (6 cm), and X-band (3 cm), and various polarizations. The Shuttle Imaging Radars were technology demonstrations, and therefore supported no long-term operational interest from the user community. JPL adopted digital processing for the SIR missions.

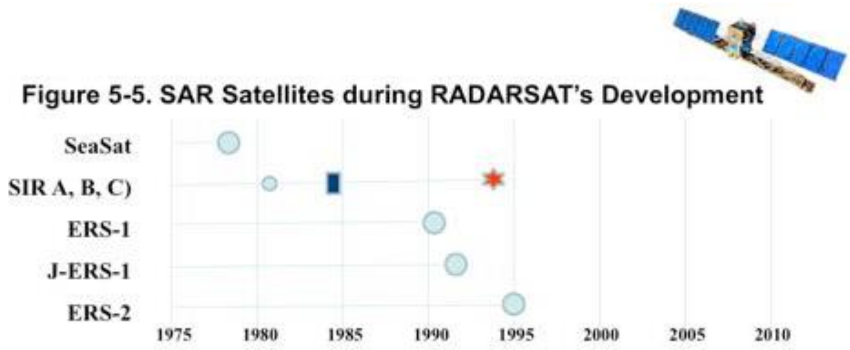


Figure 5-5. SAR Satellites during RADARSAT's Development

The other three missions of the period followed SEASAT's precedent, operating at only one resolution and incidence, and their respective payloads included additional instruments. Japan's J-ERS-1 used L-band. In contrast, ERS-1 and ERS-2 were at C-band.

There is an interesting and relevant story behind the European Space Agency's choice of C-band for the ERS SARs. Shortly after NASA's SEASAT, ESA commissioned two studies, COMS (Coast and Ocean Monitoring Satellite), and LASS (Land Applications Satellite System). One task for each of those studies was to recommend a preferred operating frequency. The results: L-band from the COMS team, influenced in large part by the SEASAT precedent, and X-band from the LASS team, influenced in large part by airborne radar precedent for land applications. ESA then convened a small working group to reconcile the choice of frequency. That group was comprised of radar experts, including individuals from the United States, Europe, and Canada, whose delegation was from CCRS. The common qualification of working group membership was that all were radar-savvy people. Several participants also had some experience in selected applications, although none were operational users of geographic data. After two days deliberation, the chairman of the group (Guert Dieterle, from ESA) declared that (i) ESA had decided to proceed on a single-satellite program rather than two, and (ii) C-band would be its frequency, as it was a logical compromise between the two proffered by the original study teams. Hence ERS-1 and -2 were at C-band. That choice became a factor in Canada's decision to use C-band for RADARSAT.

5.2. Evolution of RADARSAT-1

At its launch in 1995, RADARSAT offered several operational capabilities that were way outside of the single-mode box of contemporary Earth-orbiting SAR satellites. These new features are suggested in Fig 5-6. Incidence could be varied from 20° to 49° in the standard mode set, and steeper or more grazing incident options were available via the extended swaths. There were three ground-range resolutions (from 8 m to 100 m), and four swath widths (Fine, Standard, Wide, and ScanSAR). The system enabled complete global coverage.

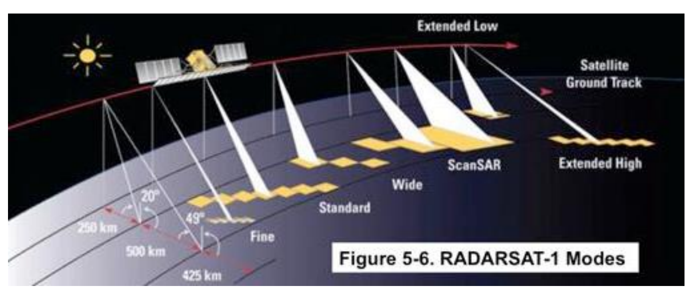


Figure 5-6. RADARSAT-1 Modes

This section describes how this break-through conceptual design came to be. The process may be visualized as a "ping-pong" match between two players, the Users, and the Technical Team. In brief, the

[135] https://directory.eoportal.org/web/eoportal/satellite-missions/s

opening serve is from the Users, whose applications to be adequately met required a variety of incident angles. The challenge for the Technical Team? Invent an antenna that provides that flexibility. Done. Now the Users have the ball again, and they realize that if there is only one (slant range) resolution available, then the steeper (near range) images would have much poorer ground-range resolution than would the far range images. Technical Team response? Include three different bandwidths in the radar, from which there could be comparable ground range resolution across the entire set of standard beams. Done. Ah Ha! Now the Users recognized that if the finer resolution could be used at longer ranges, then that would lead to much finer ("higher") ground range resolution. Done! The Users then pointed out that as a side-looking imager, data could be collected almost to the North Pole, but at the South Pole, only the outer parts of Antarctica could be imaged. The Technical Team response? For certain dedicated orbits, the satellite could be rotated 180^{o} so that the radar would look to the other side, away from the North Pole, but towards the South Pole. Further, extended (longer range) antenna beams were added so that in either orientation, imagery could be collected that would include the poles. The ball is now back in the Users' court. They point out that Canada is very large, the coastal oceans are very wide, and Antarctica is huge. They wanted (required!) extra wide range swath coverage. The Technical Team response? Incorporate ScanSAR, a new mode that no prior operational SAR had implemented. Done…but perfected only after a year or so of on-orbit experience and "fine tuning." All this took many years!

The Users were represented by CACRS (See Section 2.2), augmented by leaders from several of the government's operational agencies. The Technical Team was comprised initially of CCRS staff, later joined by the technical staff of the Sursat office, then the RADARSAT office (see Section 3.3.3.3). As the years went by the Technical Team included an increasing cadre of specialists from other governmental agencies and participating Canadian industry. The essential ingredient that made this process successful was the SAR data and imagery being collected by the CCRS airborne radar program (see Section 6.7.2.2), leading to a more knowledgeable user base.

5.2.1. Incidence

Figure 5-7 sets forth the "playing field" of the User vs Technical Team ping-pong exchanges. Of course, both sides have the same objective, to arrive at a conceptual design of RADARSAT's SAR that would be well suited to a variety of applications. The following sequence of figures and discussions fills in that playing field with the main steps of the process, and provides examples and rationale as needed. The Users presented requirements, some of which were challenging, and all were outside of the single-mode box. The Technical Team developed design changes, and sometimes major innovations, to satisfy those requirements.

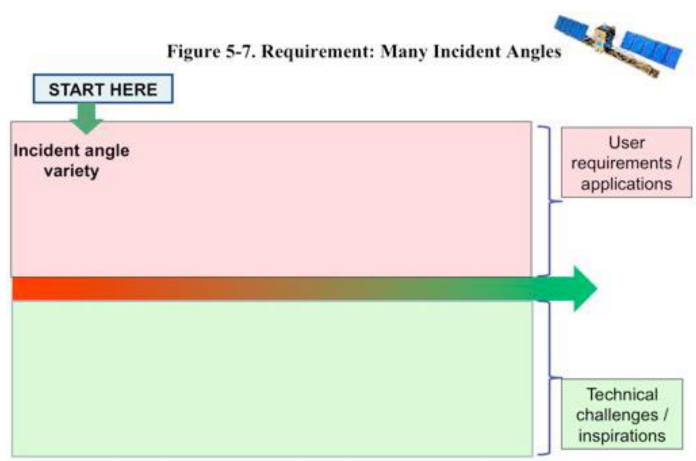


Figure 5-7. Requirement: Many Incident Angles

The game started with angle of incidence. The Users represented a wide variety of federal and provincial agencies each having disparate interests, from forestry and agriculture, to oceanography and the cryosphere, to national sovereignty. Each of their applications had preferred angles of incidence such that the radar data that they would receive from RADARSAT would be most responsive to their particular needs. Two examples illustrate the importance of this requirement.

Figure 5-8 is an image taken by a CCRS/ESA SAR-580 airborne mission (SAREX) from a region in the north-west of Costa Rica. (See Section 3.6.4.) The Pacific Ocean is on the left hand side, at minimum range (and thus steepest incidence). The incident angle increases (meaning that the radar beam is at a more shallow angle with respect to the terrain) at longer ranges. At larger incidence, taller objects, such as the Arenal volcano in the image, tend to "lean" towards the radar. Further, the radar beam is blocked by tall objects so that it cannot "see" the terrain on the far side, relative to the radar. The resulting shadow (the dark wedge in the image) is helpful in certain applications, but may be a nuisance in other situations. Agricultural applications tend to prefer incident angles in the mid-range. (It should be noted that radar imagery gathered from an aircraft has much more incident angle variation across the swath, as in this example, in contrast to images derived from satellite-based SARs that generally have only a few degrees of incidence variation from near-to-far range.

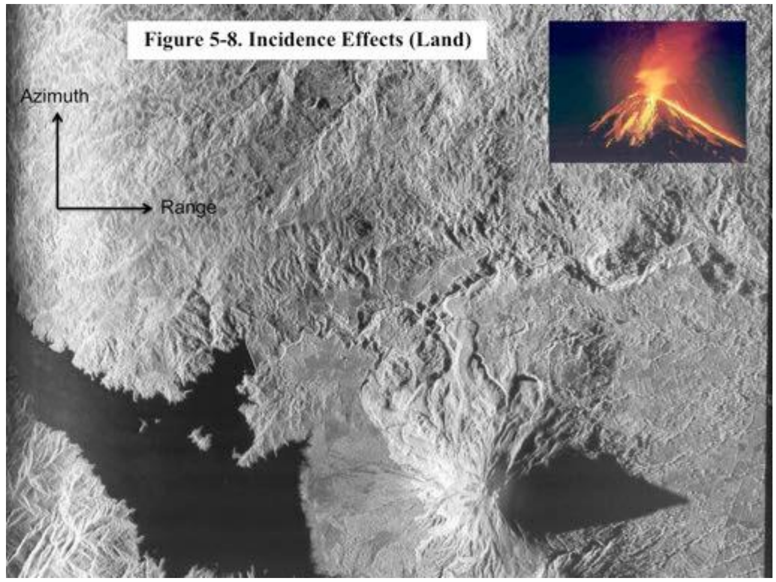


Figure 5-8. Incidence Effects (Land)

Figure 5-9 plots performance curves derived from many SAR images of ships at sea. The chart shows a "figure-of merit" for ship detection (on the vertical axis) as a function of radar mode and incident angle (the horizontal axis). In this portrayal, "smaller is better." For ship detection, it is clear that shallow viewing (larger angle of incidence) is much better, and finer resolution is better.

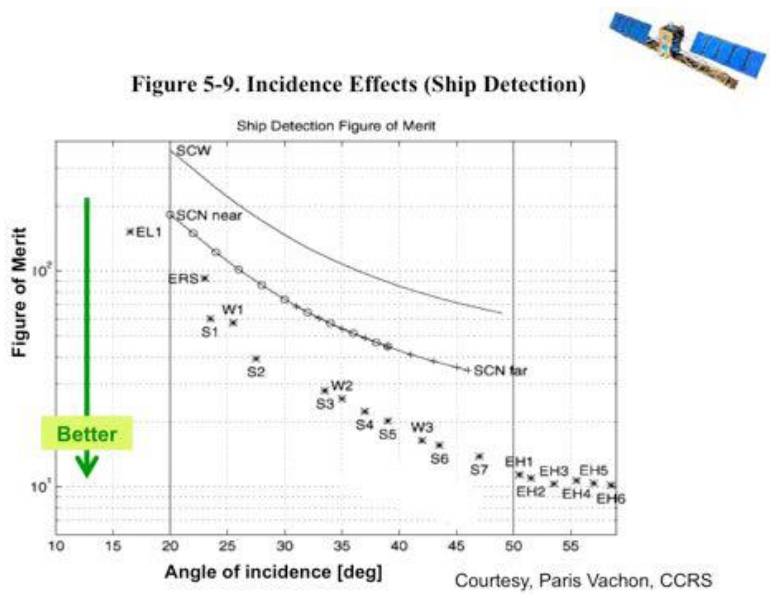


Figure 5-9. Incidence Effects (Ship Detection)

The Users made it clear that a variety of incident angles were required. That meant that the radar's antenna beam, whose width was nominally about five degrees in the vertical direction, would have to be pointed at different elevation angles, depending on the user's requirements. For only one application, that could be satisfied easily by rolling the spacecraft to correctly point the beam to get the required incident angle, or mounting the antenna on a hinge. But what if there were two adjacent areas along track to be observed having different incidence requirements? In such a situation, the beam elevation angle at the spacecraft would have to be shifted rapidly, much faster than any mechanical method would achieve. Elevation beam pointing would have to done via electronic means, but how could that be done within acceptable risk and budget constraints?

The Technical Team came up with an elegant solution (Fig 5-10). Use a slotted waveguide antenna (which was a well-established technique), but so arranged that the beam could be “steered” by electronic means. That thinking led to an array of 32 slotted waveguides, spanning the entire length of the antenna in the along-track (azimuth) direction. Each of those waveguides would be fed at their center, through a solid-state device whose phase and amplitude could be controlled by electronic command. In broad terms, a phase gradient across all of the waveguides would steer the beam in elevation, and (carefully selected) amplitude weightings would control the shape of the beam.

Figure 5-10. Elevation Beam Steering

The RADARSAT antenna was built by Canadian Astronautics Limited (CAL), an Ottawa based electronics specialty firm.[136] Figure 5-11 is an end view of the waveguide array (flight hardware). This innovative antenna was a perfect solution in response to the elevation beam-steering requirement, within the technology available at the time, and the budget constraints of the project. It was a major and critical radar subsystem (15 m length, 1.5 m height, and 465 kg mass).
The elevation beamwidths needed to illuminate a 100-km swath vary with incidence. Along with elevation pointing, the beamwidths had to be selectable as a function of pointing angle. Seven different beams were required to span the notional set of standard operating modes.

Figure 5-11. RADARSAT’s Antenna in Fabrication

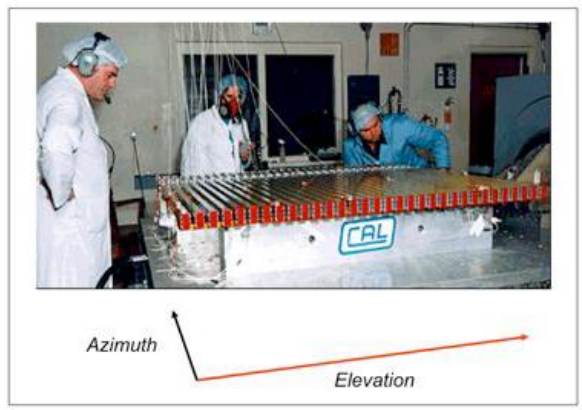
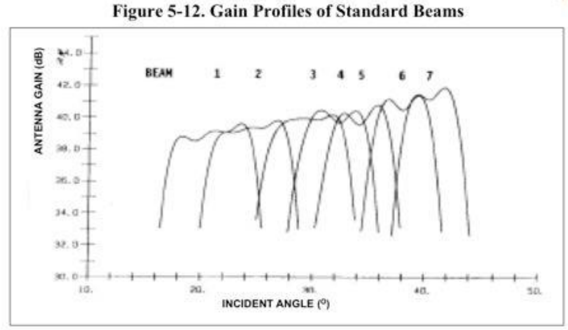


Figure 5-12 shows a gain profile of those beams. Note that the beams aimed at further ranges (thus at larger incident angles) have smaller elevation width, and have more gain (which translates into higher power), thus respecting the needs of the end-to-end power budget of a multi-range radar. Following the initial design, and taking advantage of the ability to control the beam pointing and shape, subsequently additional beams were incorporated into the design to support extended beams, and wide-swath beams. The azimuth (along-track) pattern was the same for all beams.

Figure 5-12. Gain Profiles of Standard Beams



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[136] Editor’s Note: Jim Taylor, President of CAL did one of the early studies on the value of a radar satellite to Canada. The first presentation of this study was at the meeting of the Agricultural Working group of CACRS in Charlottetown, PEI in 1974. (Taylor, 1974)

5.2.2. Range Resolution

Knowledgeable users are a blessing, although they can be challenging! At this stage they realized that if RADARSAT were designed to achieve, say, 25 m (ground) range resolution at far range, that resolution would be degraded, as incidence decreased. The closest ranges would see only about 75 m range resolution. Not acceptable, the users cried, and quite justifiably (Fig 5-13). The resolution geometry is portrayed in Figure 5-14. The radar's range resolution is expressed along the line-of-sight between the radar and the reflecting surface, so-called slant range resolution. Let the truth be known… Users do not care one bit about slant range resolution, but they do care a great deal about *ground* range resolution! As can be seen in the figure, the more steeply the radar looks down, the larger the ground range resolution will be, for a given slant range resolution. The Users appreciated the disadvantageous impact that would have on their work, if that were to be the case for RADARSAT. Hence the User's challenge to the Technical Team: Provide nominally equal ground range resolution for all beams.

Figure 5-13. Requirement: Constant Range Resolution

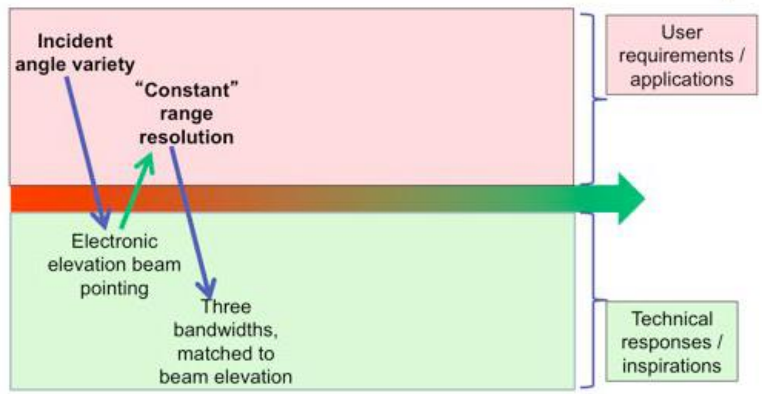
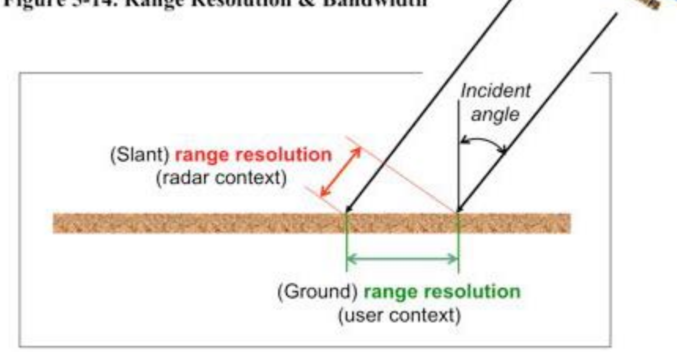


Figure 5-14. Range Resolution & Bandwidth

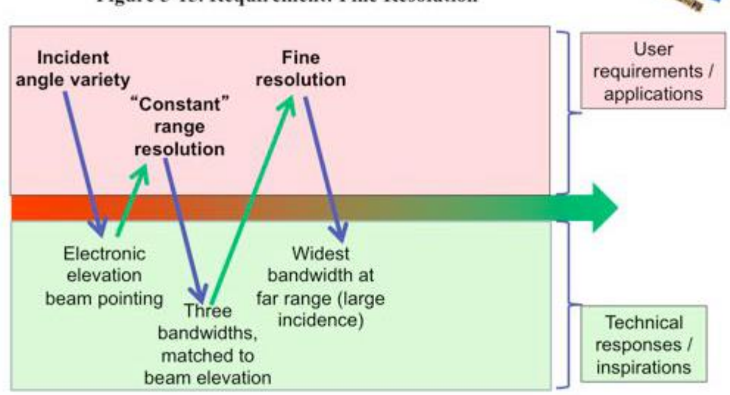


Finer ground range resolution means finer slant range resolution. The Technical Team knew that slant range resolution is proportional to inverse bandwidth. In simple terms, larger bandwidth supports finer range resolution. The Team's answer was easy, in principle: offer three bandwidths, using the wider bandwidth for steeper incidence. However, larger bandwidth comes at a cost. High quality imagery implies low background noise, BUT the average noise level in an image, all else equal, is proportional to the radar's bandwidth. Additionally, the image-to-noise level degrades for longer ranges. Thus, at shorter ranges (implying steeper incidence), where wider bandwidth would be appropriate for range resolution preservation, there is more tolerance in the noise budget. The result? The RADARSAT design adopted three bandwidths (11.6, 17.3, and 30.0 MHz), while maintaining a near-constant noise level of -20 dB or better for the standard beams. That translates into comparable image quality, and also comparable ground range resolution, across the entire span of incident angles.

5.2.3 Fine Resolution

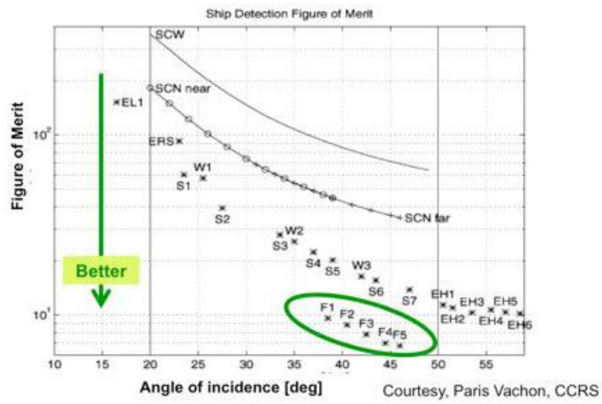
Users recognized that their successful argument for "constant" range resolution in the steeper incidence (near-range) imagery could be run in the opposite direction. Using the wide bandwidth (which was meant for the steeper incidence images) at the longer ranges would lead to about three times finer resolution than the standard beams would support (Fig 5-15). Proponents of certain applications were keen to see the

Figure 5-15. Requirement: Fine Resolution



RADARSAT design take advantage of that near-obvious fact. Their point is well illustrated by the task of ship detection (Figure 5-16), which shows that significantly better results can be realized if finer resolution is combined with shallow incidence (longer range).

Figure 5-16. Finer Resolution for Better Ship Detection

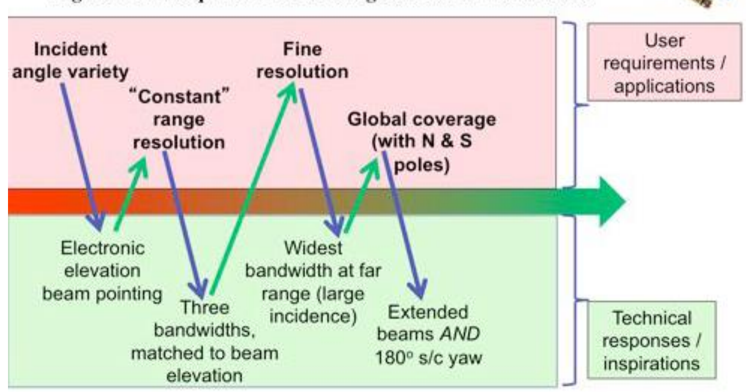


The Technical Team agreed, but noted that the average noise level in such fine-resolution long-range images might be poorer than in the standard beams. That could be at least partially offset by making the long-range beams as narrow as possible, thus increasing their gain to reduce the relative noise level. (The trade-off would be that the range extent of the resulting imagery would be smaller.) Antenna elevation beamwidth[137] would be determined by the computer-controlled amplitude and phase-shifter waveguide feeds. Such a change would substantially offset the use of wide bandwidth at long range. Good. The design adopted a set of fine resolution (long range) modes.

5.2.4 Global Coverage

The original primary purpose for RADARSAT was to meet domestic environmental data needs. International demand was expected, even encouraged,[138] but it was anticipated that such data collection would be allocated after Canadian needs were satisfied. That priority was modified when NASA wanted something in return as a condition for their agreement to launch the satellite into orbit. Through negotiations between the RADARSAT project office, Canadian cryospheric scientists, and NASA-affiliated scientists interested in Antarctica, it was proposed that RADARSAT data should be collected from that continent, and made available free of charge to NASA. If that could be implemented, then RADARSAT would be capable of complete global coverage (Fig 5-17).

Figure 5-17. Requirement: Coverage of Both N and S Poles



The Technical Team noted two constraints that would prevent complete coverage of Antarctica. The first constraint, orbit inclination, was non-negotiable. To maximize power replenishment from solar illumination, the orbit had to be sun-synchronous, and phased to assure dawn-dusk equatorial crossings. The only orbit that satisfied those conditions was in a plane at 98.6^{o} inclination. RADARSAT's orientation was chosen such that it looked toward the North Pole (favoring coverage of Canada's north), which of necessity implied that it looked away from the South Pole along its southern hemisphere passes. As a side-looking imager, the SAR had to keep that geometry, and the orbit had to stay the same, to conform to the laws of physics. The solution was, for South-Polar imaging passes, to rotate the satellite 180^{o} so that it would be flying "backward". When doing so, the SAR would be looking to the opposite side, thus away from the North Pole, and towards the South Pole. First problem solved

[137] Note: The antenna height—1.5 m—provided the limiting factor, as the elevation beamwidth could be no smaller than about 2.5^{o}, the diffraction limit.
[138] See section 3.3.3 and 3.6.4 for an overview of Canada's international SAR adventures.

(although it had implications for SAR processing, other applications, orbit maintenance, and spacecraft thermal control).

The second problem was that the standard beams, even at furthest range, could gather image data only up to about 2 degrees away from the pole, thus leaving a donut hole around the pole with no imagery. The solution to that problem was to add a set of extended beams so that full coverage to the pole could be satisfied. Thanks to RADARSAT's programmability of elevation beam steering, which at this stage had been incorporated into the design, extended longer range beams could be accomplished.

Figure 5-18. RADARSAT Map of Antarctica

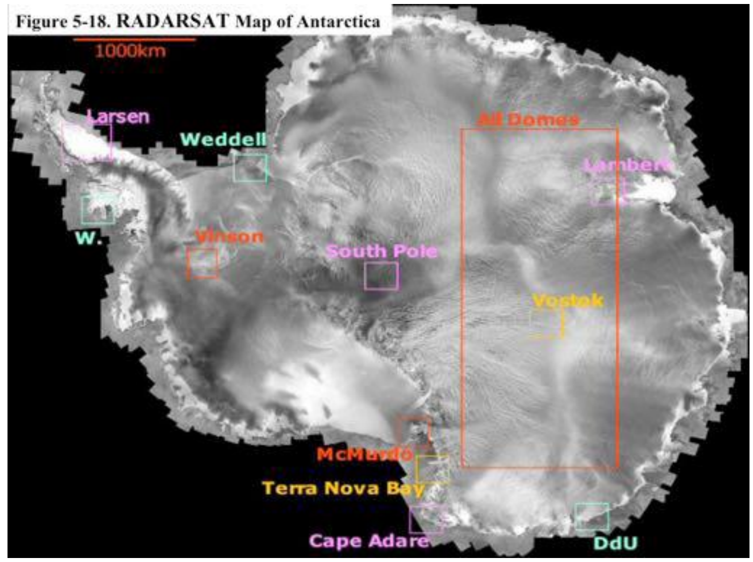
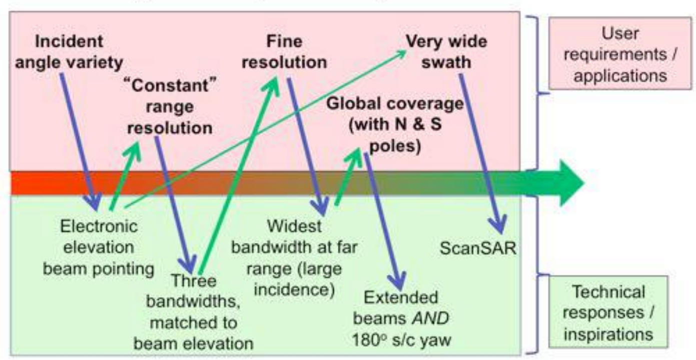


Figure 5-18 is one product of RADARSAT's Antarctic Mapping Mission[139] (AMM, or RAMP in the Alaska SAR Facility jargon). That image was constructed as a mosaic of many RADARSAT passes. It is the first complete image of Antarctica gathered by any sensor. The data were sufficiently good to support repeat-pass interferometry, from which the rate of glacial movement of the ice sheets could be measured.[140]

Figure 5-19. Requirement: Very Wide Swath



5.2.5. ScanSAR

By "very wide swath" (Fig 5-19), the Users meant range swath widths up to as much as 500 km. The primary driver for such aggressive data collection was to cover very large areas, especially in the Arctic and Canada's coastal and off-shore waters. This was a big request, since at the time, it was accepted that the physical upper limit on swath width was determined by the timing of the radar's transmitted and received signals, coupled with the requirement that the azimuth sampling rate had to be high enough to adequately support the desired along-track resolution. For 25-m azimuth resolution, that upper limit in swath width was about 100 km for RADARSAT, as it was for SEASAT.

The technical response was brilliant. Tony Luscombe (then the lead radar engineer at Spar Aerospace, Montreal) observed that the ScanSAR method (first proposed several years earlier by J. P. Claasen, a student of Prof Richard Moore, University of Kansas), should satisfy the new requirement. ScanSAR looked good on paper, but it had never been flown before. ScanSAR's "secret" is that it trades resolution for coverage, thus circumventing the conventional 100-km swath width upper bound. Hence, ScanSAR images have more coarse resolution, but are able to image very wide swaths. The "trick" is that once the SAR gets sufficient data in one swath to meet the relaxed resolution requirement, it then switches to the next swath, then to the next, then again, then back to the first swath. It is all straight forward if (and that is a big IF) the antenna is able to switch from one elevation beam position to the next very VERY quickly. The Technical Team recognized immediately that RADARSAT's antenna, already designed to

[139] https://www.asf.alaska.edu/other-data/ramp/overview/
[140] http://science.sciencemag.org/content/286/5438/283 (L. Gray, CCRS, co-author of this important paper)

accomplish electronic beam steering, could be programmed to meet the new ScanSAR antenna beam control requirement. (Luscombe, 1988)

The devil is in the details. Figure 5-20 is an example of a RADARSAT ScanSAR image from early in the mission. The four separate sub-swaths are easily seen at their boundaries, due to abrupt changes in average radar brightness. The problem was that the processing algorithm did not equalize the mean signal levels at the cross-overs from one sub-swath to the next. "Seamless" ScanSAR image formation requires that the processor accurately and adaptively matches signal levels across sub-swath boundaries (Fig 5-21). After a series of fine-tuning exercises, RADARSAT ScanSAR images routinely had much improved image quality across the full swath (Fig 5-22 – next page)

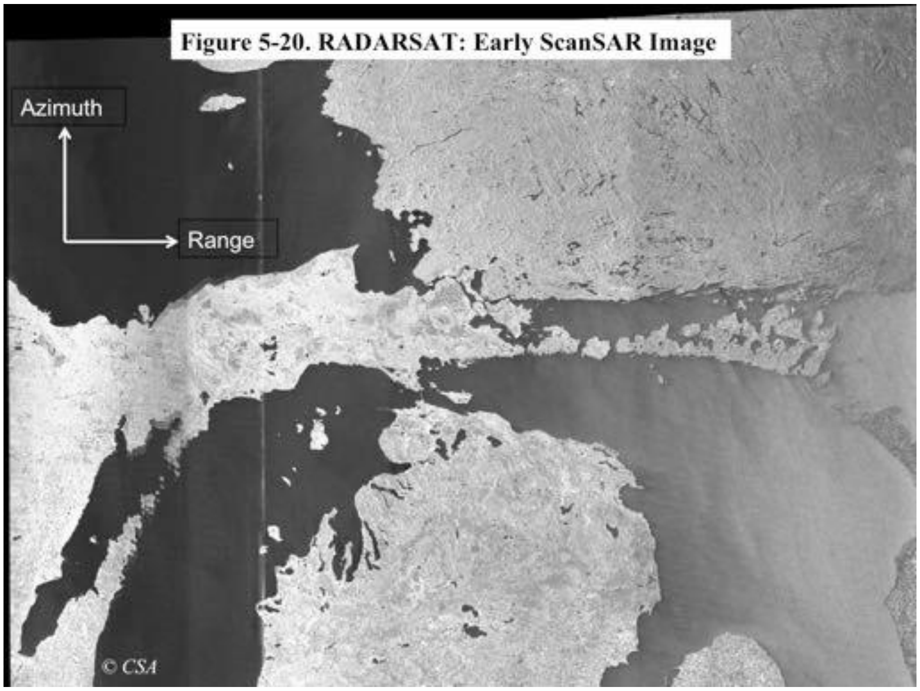
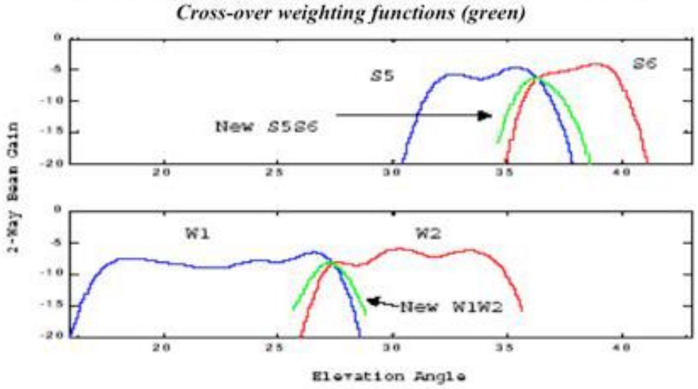


Figure 5-20. RADARSAT: Early ScanSAR Image

Figure 5-21. RADARSAT: ScanSAR Sub-image Matching

Cross-over weighting functions (green)



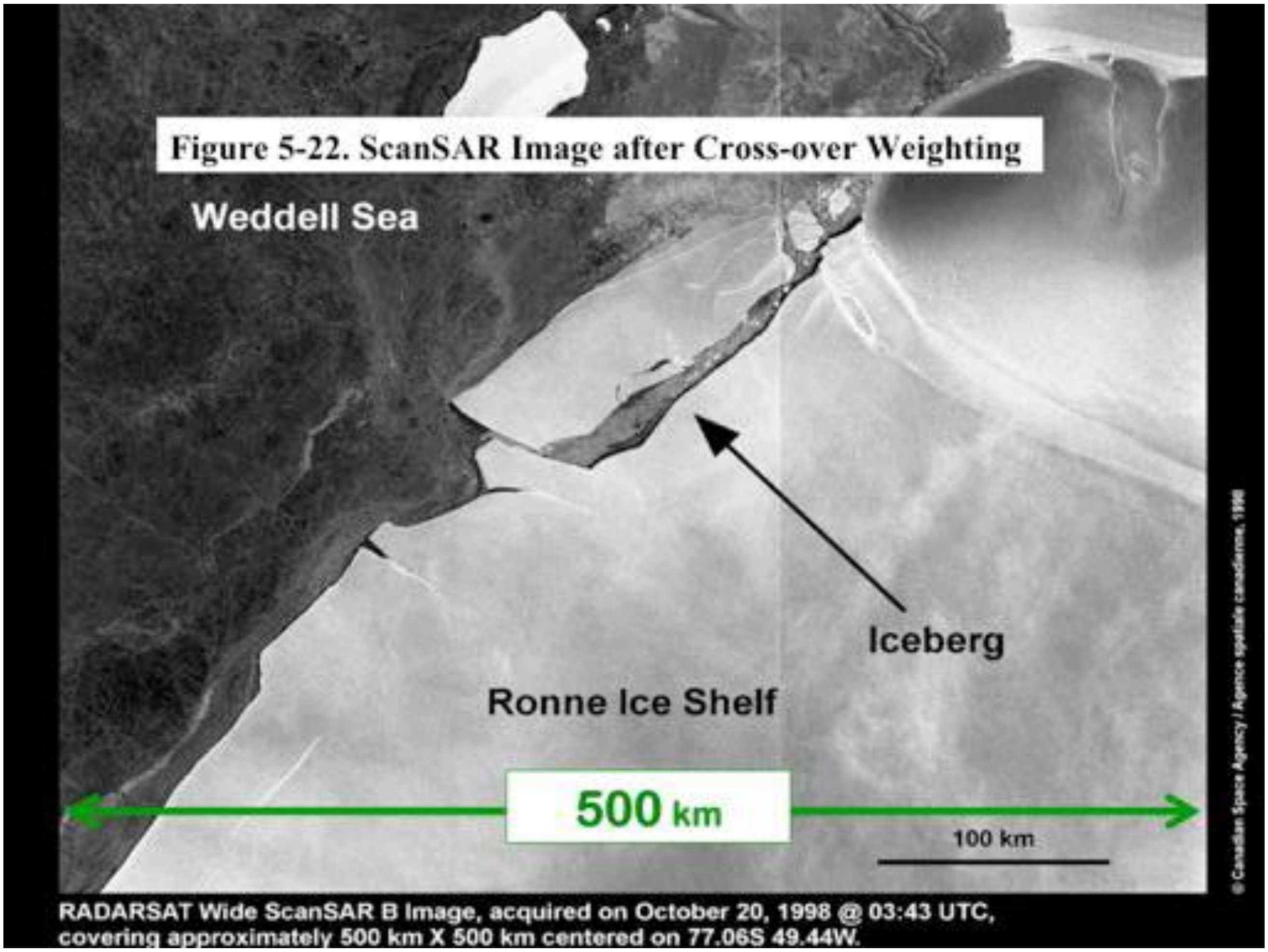
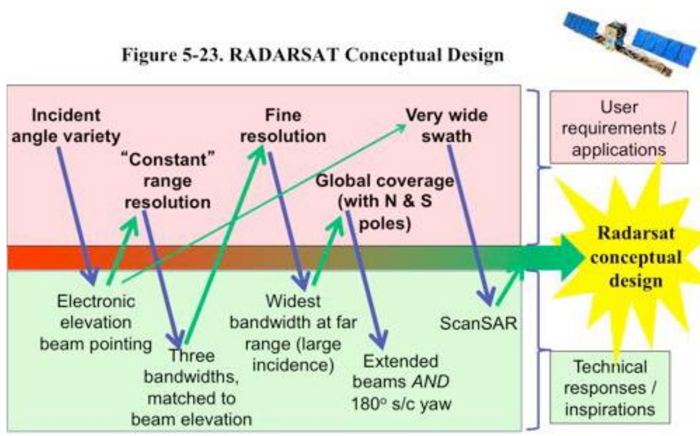


Figure 5-22. ScanSAR Image after Cross-over Weighting

5.2.6 Break-through Design

RADARSAT-1 was built and flown according to this conceptual design (Fig 5-23), a product of the user's (ever-expanding) set of requirements, whose demands were met by the technical team's creative responses. In turn, its on-orbit success was due to solid user subscriptions, supported by a highly reliable space-qualified instrument. (Raney *et al*, 1991) Its operational lifetime spanned 17 years (04 November 1995 - 29 March 2013), 12 years longer than the 5-year baseline design-life requirement. By the end, RADARSAT had accumulated 90,828 orbits gathering 625,848 images for 600 clients and partners from 60 different countries.[141] In addition, it collected imagery for 244 disaster events (such as oil spills and large earthquakes), from which the data were made available promptly, and free of charge.

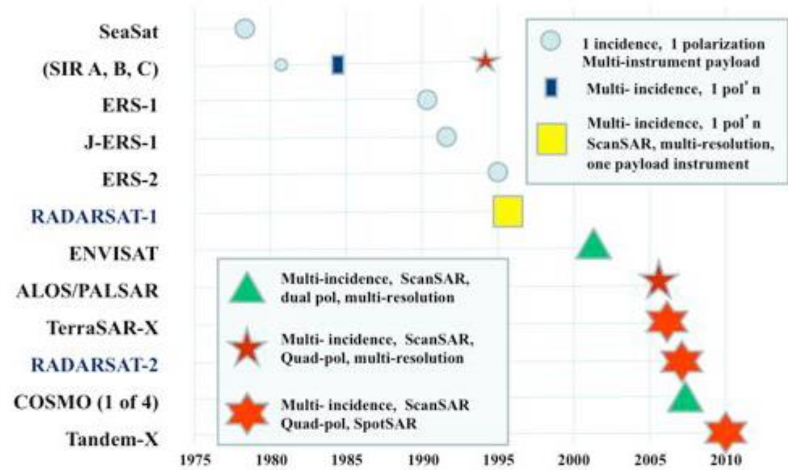
Figure 5-23. RADARSAT Conceptual Design



[141] https://en.wikipedia.org/wiki/RADARSAT-1

Thanks to the user-driven technological innovations that shaped the final design, RADARSAT became the first orbital SAR mission (Fig 5-24) that broke out of the "SEASAT box." With the exception of JPL's short-lived Shuttle Imaging Radar technology demonstrations, all of RADARSAT's predecessors carried other instruments. On ERS-1, for example, the SAR was of secondary interest, out-ranked in priority by its altimeter and scatterometer. A little-known fact…For a period of several months during its early planning days, a SAR was not included in the ERS-1 notional payload manifest. It had been "disqualified" by ESA management for perceived risk and cost reasons. The SAR was only returned to the ERS-1 suite of instruments when Klaus Hasselman, the eminent German oceanographer, suggested that the scatterometer could be "improved" at minimal marginal cost by adding an elementary small-frame imaging mode, to be exercised periodically during oceanic observations. That "peekaboo" mode morphed into the ERS-1 SAR as flown. RADARSAT was the first SAR satellite to embark only a SAR, in a word, putting all of its ergs into one basket.[142]

Figure 5-24. RADARSAT-1, in Context



The new modes of RADARSAT were major paradigm-shifters. Six years would pass before any of those innovations would be included in new earth-observing SAR satellites. The first of those, the European Space Agency's ENVISAT, included a ScanSAR mode, as well as a variety of incident angles and resolutions. (It is no coincidence that ESA's expert planning committee for ENVISAT included Canada's Tony Luscombe, who had done so much to enable the success of RADARSAT.)

RADARSAT-2 was launched in 2007, one of five SAR satellites launched in the 2005 to 2010 time frame. All included innovations introduced by RADARSAT-1 more than a decade earlier.

5.3. RADARSAT-2

Once users began to appreciate the importance of RADARSAT-1 SAR data for their work, they were adamant in their request for continuity. For example, the Canadian Ice Service had become dependent on RADARSAT data for their routine ice charting products. In anticipation of continuing and useful SAR ice data from space-borne assets, they closed down their airborne radar surveillance program, due in large part to the leadership and vision of John Falkingham. Other agencies expressed their respective need for continuity, especially the Department of National Defence, the Canadian Forest Service, and the Department of the Environment. Hence the government committed to RADARSAT-2, for which the first requirement was to provide continuity of RADARSAT-1's capabilities. There were also requirements for increased coverage, and improved revisit opportunities. Beyond that, the user-driven requirements moved to a new level. Through experience with the capabilities of CCRS' SAR-580 airborne system, users of satellite SAR data wanted RADARSAT-2 to support interferometry, and to incorporate a SpotSAR mode. They also wanted polarization diversity, ranging from HH or VV to dual- and quadrature-polarimetry.

These requirements, to be met, had major technical consequences. Better coverage implied a simpler procedure to change from right-side to left-side radar viewing. Interferometry implied tighter navigation

[142] Editor's Note: An "erg" is a unit of work or energy used in astrophysics and mechanics.

tolerances. Polarimetry required a two-channel receiver (to accommodate both H and V polarized backscatter), an antenna to manage H and V receptions simultaneously, and, perhaps most significant, an antenna that could alternate between H and V transmissions, pulse to pulse. These requirements were met.[143]

Figure 5-25 illustrates the roll method of RADARSAT-2 to change SAR viewing from one side to the other, enabling "equal opportunity" viewing orientations, unlike the "special case" maneuvers required for RADARSAT-1 to look towards the normally unused side. Figure 5-26 presents an example of improved revisit intervals, facilitated in large part by the flexibility in viewing orientation enabled by the new roll maneuver. The principal motivation for quadrature polarimetric SAR data is that it allows differentiation between backscattering objects based on their polarimetric characteristics. A good example is San Francisco Fig 5-27, derived from the Jet Propulsion Laboratory's airborne data set (available on line).

Figure 5-25. Left or Right Looking

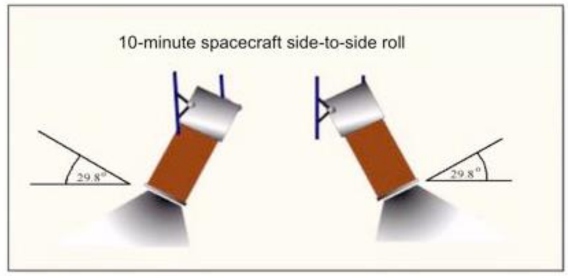


Figure 5-26. Revisit times

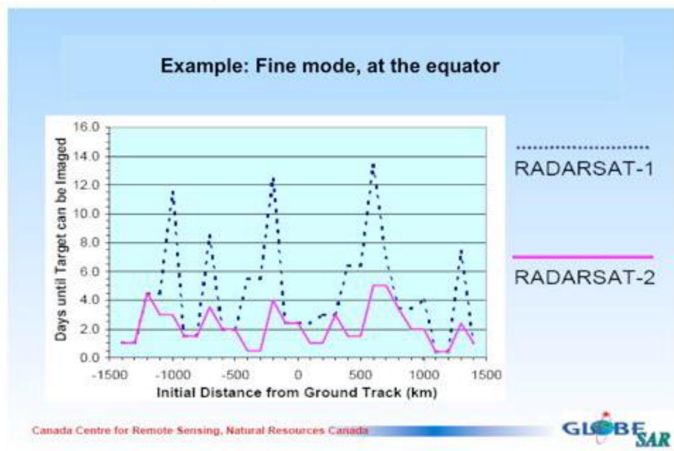


Figure 5-27. Quad-pol image of San Francisco

The ocean, urban development, and forested areas, here colorized by the Pauli method, are rendered as distinctly different classes. The technique applies to all scenes of interest to users.

RADARSAT-2 was launched in 2007, and is still in commission (as of this writing, August 2018).

5.4. RADARSAT Constellation Mission (RCM)

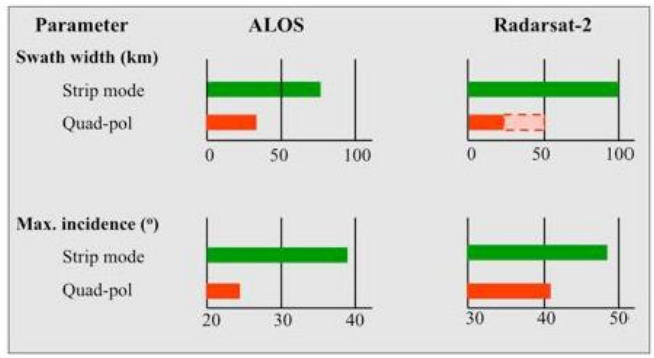
As with RADARSAT-2 after its predecessor, the RCM user community required continuity from the previous RADARSAT missions to the new generation of Canadian SAR satellites. There were two other top-level requirements: (i) increased coverage and more frequent revisit compared to RADARSAT-2 capabilities, and (ii) operational quadrature polarimetry.[144] Those two requirements were mission drivers. Improved coverage and revisit characteristics taken together, early on, led to the decision to have a three-satellite constellation. An essential corollary to that objective was that each satellite with its SAR payload had to be substantially less costly than RADARSAT-2. Those objectives were met; RCM (in 2018) was progressing into the final stages of implementation.

[143] See: http://www.asc-csa.gc.ca/eng/satellites/RADARSAT/RADARSAT-tableau.asp#RS2

[144] For a complete description and definition of Quadrature polarimetry see Section 6.7.2.4.1.

The operational quadrature polarimetry requirement presented its own challenges. Previously there had been several quad-pol-capable satellite SAR systems (see Fig 5-24 for the earlier examples). Their data products often had impressive added value relative to single- or dual-polarized images, sufficiently appealing to generate serious demand from users. The problem is that the quad-pol mode from an orbital platform has never merited "operational" status, for several reasons. Chief among these are limited swath width, limited span of incident angles, poorer image quality (range ambiguities), doubled data volume per image pixel, and twice the average power required of the transmitter. Of these limitations, reduced coverage (swath width) and limited choice in incidence (Fig 5-28) are the most significant for users.

Figure 5-28. Quad-pol Swath and Incidence Constraints



A working group was assembled at CCRS (chaired by François Charbonneau), comprised of users from Canadian agencies (Ice Service, Agriculture, Department of National Defence, and the like), and SAR experts (CCRS and non-CCRS professionals) to address this challenge. The working group discovered a creative solution: compact polarimetry. (Raney, 2011) The "hybrid-polarity" version of that approach takes advantage of a unique combination of polarizations in a coherent dual-polarized mode: transmit circular polarization, and receive two orthogonal linear polarizations such as H and V (circular transmit, linear receive, CTLR). Members of the study team, using data that emulated image products from a hybrid dual-polarized radar, applied the method to their particular fields of interest. The CTLR method avoids all of the disadvantages of quad-pol cited above. The results of the working group are compelling. (Charbonneau *et al*, 2010)

Compact polarimetry from the outset has been controversial. According to Tapan Misra (lead engineer, RISAT-1, the Indian Space Research Organization), "hybrid-polarity is hated by theorists, but loved by operational agencies." The CTLR mode has flown on two lunar missions.[145] and on India's RISAT-1, both delivering excellent results.

Figure 5-29. CTLR Image of San Francisco

Figure 5-29 shows San Francisco again, this time as it would be seen through a hybrid dual-polarimetric SAR using the m-chi method of declassification ("decomposition"[146]). Question--if there are no CTLR data available, where does an example such as this come from? Answer--one advantage of quad-pol digital data is that it can be transformed (by matrix algebra) to represent any combination of transmit and receive polarizations. The original (H; V) quad-pol data file[147] for this image was transformed into an exact replica of the data field (C, L) which a CTLR radar would produce.

[145] NASA's Lunar Reconnaissance Orbiter (LRO), and India's Chandraayan-1
[146] See Section 6.7.2.4 for a further discussion of decomposition.
[147] Original data source: AirSAR C-Band quad-pol data, courtesy JPL

The critical issue is, how does the quality of the classification information in a CTLR image compare to that of its quad-pol cousin? That question is addressed in the following discussion.

Figure 5-30 shows an agricultural area as seen by a quad-pol SAR (using the Freeman-Durden classification algorithm), and the same area (using the same initial data set) as it would be seen by a hybrid dual-pol SAR (using the m-chi classification algorithm). The images, color-coded to indicate three different backscattering types, appear to be essentially the same.

BUT, how good is the CTLR version, quantitatively, when compared to the quad-pol method?

Figure 5-30. CTLR: Agricultural Application

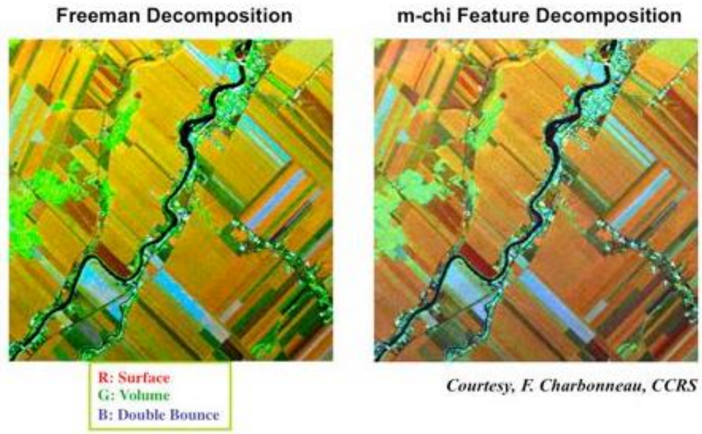


Figure 5-31 is another look at the ship detection application, as seen through four different levels of SAR polarimetry. As the polarization methodology gets richer, the results improve. Quad-pol is best, but the CTLR approach is a close second, significantly better than dual- or single-pol alternatives. The agriculture team tried several different classification methods on a sequence of image data sets taken over the same test plot for four dates during the growing season (Fig 5-32) CTLR results are nearly as good as the quad-pol (Freeman-Durden) method, and in one case, the hybrid-pol classification is best. A survey (Raney, 2016) over several dozen papers that have made similar quantitative comparisons arrived at the conclusion that, when properly done, CTLR classifications are comparable to quad-pol classifications, to within 3%. The users agreed that a possible 3% loss in classification accuracy would be an acceptable price to pay in exchange for elevating polarimetric classification to an operational mode.

Figure 5-31. CTLR: Ship Detection

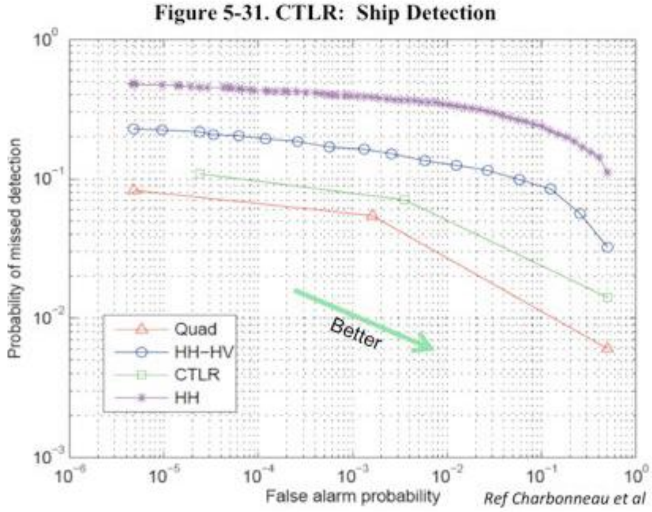


Figure 5-32. CTLR: Crop Classification Accuracy (%)

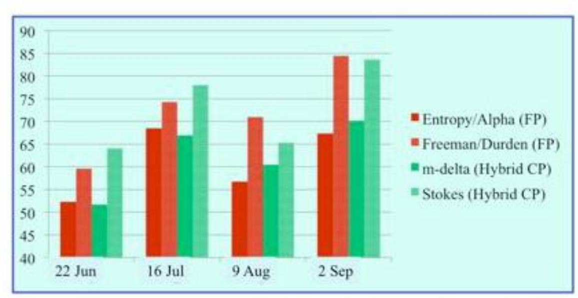


Table 1 (H. McNairn), in Charbonneau *et al*

Finally, CTLR is compatible with the ScanSAR mode, unlike quad-pol. Figure 5-33 is an example from India's RISAT-1, the first earth-orbiting SAR to include this mode, which has become very popular with their users.

For these reasons, together with the small marginal cost of implementation, the RCM program adopted the CTLR mode as a baseline polarimetric configuration for all imaging modes. Quad pol was retained as an experimental mode, which also will be helpful to aid calibration.

5.5 Concluding Observations

"RADARSAT is a great Canadian success story" according to the Minister of Industry, the Honourable Christian Paradis. CCRS has played a major role in that story, from inception, through conception, to reception. The abiding themes are recognition of and service to the interests and needs of users as pertains to remotely sensed information, grounded in the technical excellence, inventiveness, and courage of CCRS personnel and associated Canadian industry.

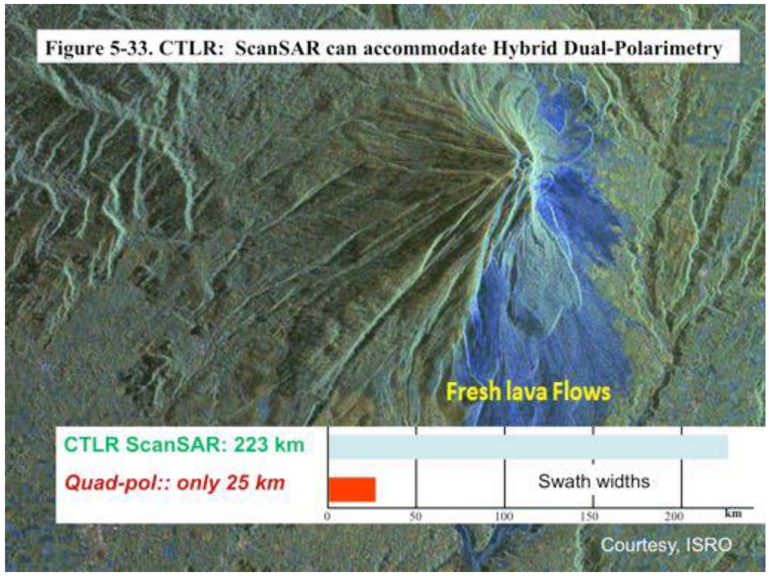


Figure 5-33. CTLR: ScanSAR can accommodate Hybrid Dual-Polarimetry

The evolution of the conceptual design of RADARSAT-1 captures those themes. Its break-through synthetic aperture radar instrument was driven by user's needs, which turned into formal requirements on the emerging radar and mission design. Constructive user input is enabled through two-way transactions: motivation-transfer from the users to the technology team, and technology-transfer from the technology team to the users. In other words, the users must know what they should ask for, and the technical team should apprehend the technical aspects and practical consequences of their requests, and demonstrate initiative, creativity, and courage in their response. In an enterprise such as RADARSAT, both users and the technical folk work best when they are willing, able, and enthusiastic about exploring solutions outside of their comfort zone.

The strong user base enjoyed by the RADARSAT project was due in large part to the advisory committees set up in the early days of CCRS, nurtured by the topical radar data being collected and provided by CCRS SAR-580 field programs. The backbone of the technical team was the high caliber of CCRS and affiliated personnel.

Long-term enterprises become successful only to the extent enabled by the steadfast leadership of their management, sustained by enthusiastic quality staff, and high level support. Leadership and senior management need to be willing to accept risks, when the road ahead is well prepared, and the benefits of success are clear. RADARSAT-1 is a good example. The all-important user advisory groups set up by management (inspired by Larry Morley) in the early 1970s became essential resources leading to a remarkably responsive satellite SAR launched two decades later. The CCRS SAR-580 program that provided radar data products and user-oriented analysis techniques were an essential component in developing and expanding a knowledgeable user base, both in Canada and world-wide. Senior RADARSAT-1 leadership was responsible for navigating Canada's governmental challenges (thanks due to Ed Shaw), negotiating the Memorandum of Understanding between Canada and NASA, which went through at least 26 revisions (thank you Ed Langham), and managing the **F**abrication, **A**ssembly, **I**ntegration, and **T**est phases of the program (thank you Shabeer Ahmed). FAIT accompli!

6. Science and Services

6.1. Introduction

Bob Ryerson

This chapter, the longest in the document, describes the science and technologies with which CCRS was successfully engaged and the supporting activities that contributed to this success. Simply stated, our small budgets and huge area of the country demanded that our solutions be simple, low cost and easily scalable up to the size of the country we were dealing with. In Section 6.6.3 Dr. Heather McNairn nicely summarizes the CCRS approach to science: "underlying the approach was the belief that science is not built on a single experiment, but rather the accumulation of knowledge from repeated probing." Over many years this approach was coupled with the drive to develop simple, elegant and low-cost solutions to problems in virtually all of the work done in CCRS.

We have decided to begin with the supporting activities inasmuch as they were, in retrospect, critical to the long term success of CCRS and the growth of the industry that CCRS nurtured. It is believed that it is particularly important to emphasize these supporting activities inasmuch as most scientists and science advisors tend not to give them the attention that they deserve if the goal is to create a successful and sustainable science-based activity to support the national interests of a country.

We begin with a section that underlines the importance of marketing to gain support for a program – and then to sell or commercialize the results of that program. While Dr. Morley was an award winning scientist, when it came to remote sensing, he was just as brilliant in his approach to marketing and public awareness. The second topic covered is another supporting activity – the library system RESORS. The section on the library underlines the importance of providing support to the science and the importance of establishing an international presence. It also demonstrates that well-thought-out activities can have several different outcomes or benefits – another hallmark of how CCRS worked. The last of the sections describing the supporting activities outlines the approach to innovation that led to the international success that CCRS enjoyed.

With the supporting background covered, the remaining sections describe the science that was done and note some of the more significant results. Words that are often misused when describing science, such as "world-class," "first-ever," and "award-winning" appear quite often in this section – and the description is correct in every case. The depth in which each subject is covered varies depending upon the availability and willingness of authors to contribute.[148] While some of the material (such research on polarimetry, for example, further explained in Appendix E) is difficult to explain to a lay audience, most is believed to be readily understandable.

6.2. CCRS Marketing of Remote Sensing

Bob Ryerson (with inputs from Paul Hession and Larry Morley's papers)

6.2.1. Introduction

There was an inherent understanding within the early leadership of CCRS that marketing both the need for the technology and its application was important to gain support for a growing national program. As noted in Section 2.1.3, marketing and public awareness, the so-called "dog and pony shows" that started in the US and which Larry Morley adapted for Canada, began long before the creation of CCRS. Looking back these can be seen as the first attempts to create awareness and market remote sensing. Over time the sophistication of marketing grew, as the following sections and other material on international marketing shows in Sections 2.2.6.3.5, 2.2.6.3.6 and 3.3.4.5.

[148] Unfortunately some of the early leaders have passed away, been incapacitated by illness, cannot be located, or are otherwise unable to provide material.

6.2.2. The Early Years

The dog and pony shows evolved into two streams of marketing – one for airborne remote sensing and one for satellite remote sensing. The head of the Airborne Section, Ernie McLaren,[149] was ideally suited to the marketing role of the airborne program. He understood the technical side of flying sensors (beginning with colour and colour infrared aerial photography) and was backed up by the technical expertise of Jack Fleming (for aerial photography) and the sensor development team at CCRS for other sensing systems.

An important decision was made at the beginning of the Airborne Program: for all airborne projects the user was to prepare a report that included detailed specifications of what was done, with what sensors, why and with what result. These reports, each filed in its own file box identified by the project number, provided excellent material to both demonstrate benefits and market applications, as is described in Section 6.5.3 below. As is today recalled over forty years later, Ernie McLaren broadened his focus to market airborne and satellite data and started a more formal marketing activity at CCRS. McLaren's defining characteristics of integrity, practicality, and a desire to provide accurate and useful advice were well suited to the time. Elsewhere remote sensing was often oversold,[150] which resulted in long-term distrust of the technology, something that future marketing had to overcome.[151] McLaren went on to teach at what has since become the highly regarded College of Geographic Sciences (COGS) in Lawrencetown, Nova Scotia. (See section 3.2.3.2 for more detail on COGS.)

As noted in Section 2, at the outset airborne remote sensing was seen as a valuable technology in its own right. However, over time the airborne sensing industry (notably Optech, Itres Research and service companies like Intera, Bercha and Associates, the Airborne Sensing Corporation and many others) grew and the CCRS airborne program became more a supporting activity for space borne remote sensing. With this change the marketing focus shifted to satellite remote sensing.

6.2.3. CCRS: Selling Data, Selling a Program

The setting up of a formal marketing unit at CCRS coincided with the realization that CCRS was a long way from making progress towards realizing the benefits that had been projected in agriculture, forestry and other areas. Quite simply Landsat MSS data had lower resolution than what was required by most potential users, delivery was often slow, and overselling was rampant.[152] At the same time there was a need to sell the science CCRS was doing to senior levels of government – and that led to a continuing public awareness campaign. The CCRS User Assistance and Marketing Unit began following a recommendation at CACRS in 1977. The first head of the User Assistance and Marketing Unit was Jean-Claude Henein whose primary role was as head of planning. Jean Game was the only full time person, although Techical Information Service (Library) staff helped out if needed. Tom Alföldi was seconded for 6 months (Feb 1, 1978 to July 31, 1978) and Carolyn Goodfellow was seconded for about 12 months (1981-82).

The hiring of Paul Hession as the head of the User Assistance and Marketing Unit within the planning function at CCRS in 1979 led to market understanding being more formally built into project planning, international activities, and technology development. With Hession's arrival there was also a more

[149] Ernie McLaren, who retired as a Major in the Canadian Forces, was the first head of the Airborne Sensing Unit. The Unit's pilots were all former military pilots.

[150] See, for example Section 6.6.3.3.2 where it is noted that bare rock was mapped as urban in a US study of the US side of the Great Lakes!

[151] Like many new technologies remote sensing seemed to attract its fair share of those who climbed on the bandwagon and claimed expertise that they did not have. In one instance one such individual in another country ended up in jail after perpetrating a massive fraud. Here in Canada I recall giving a workshop for neophytes. A few weeks later one of the neophytes, armed with a new business card, was at a conference selling his services as an expert in remote sensing.

[152] Over selling was primarily an issue outside CCRS. The early leaders and key scientists at CCRS ensured that those speaking on behalf of CCRS generally avoided grandiose claims.

professional approach to marketing and public awareness, including providing assistance and advice to users. On the side, Hession also became an early proponent of the use of personal computers in remote sensing and on the importance of economic studies – topics that found their way into the 1983 CACRS recommendations. Hession left in 1983. As with many CCRS alumni he went on to an illustrious career in both industry and government.

Hession's departure coincided with Ryerson's return from a secondment at Statistics Canada at which time he won the competition to head the User Assistance and Marketing Unit (referred to by its initials "UAMU"). The UAMU, which consisted of Ryerson and Jean Game, was put into the Applications Division under Director Jean-Claude Henein. Additional help in graphics design was provided on contract by
Intera: most notable among the graphics designers were Marguerite Trindade and Bonnie Harris. A valued but under-appreciated characteristic that they brought to the design of materials for CCRS was the ability to design materials that were seen as high quality in both English and French cultures.

It was a good time to be involved in selling satellite data and selling a program through a public awareness campaign. Landsat 4 had been launched on July 16, 1982 and by 1984 the production and quality control bugs associated with the Thematic Mapper (TM) Sensor had been worked out. (See Section 6.6.2.3 for the important role CCRS staff played in solving these problems.) This led to much higher resolution data that were able to meet many more users' needs <u>and</u> be of interest to the general public. The arrival of SPOT satellite data provided even higher spatial resolution data. To support data sales the UAMU had tools to search for satellite data for use by those buyers who either visited CCRS in person or who asked their questions by telephone. An important consideration given the number of exploration geologists who came to use CCRS-produced satellite data was that the main contact, Jean Game and those filling the orders, were trusted to keep who ordered what data confidential.[153]

While it was a good time to be involved in selling satellite data, there were problems left over from the over-selling of the early Landsat MSS data. Foresters, for example, were quite wary of even the new Thematic Mapper data – "once bitten twice shy" was what one forester said to this author. To promote the new, higher resolution, and better Landsat TM data a series of high quality professionally designed[154] six page fold-out information sheets were produced on forestry, agriculture, and geological applications. Each showed high resolution, full colour imagery with suggested band combinations to extract specific data or parameters of interest to each user group. Written by CCRS scientists (Frank Ahern and Bill Bruce for forestry and geology respectively), these information sheets were produced in both English and French.

The information sheets were promoted in the mosr relevant industry publications. In addition the forestry and agricultural publications were mailed to professionals in those fields, while that aimed at geologists was distributed at the Prospectors and Developers Conference in Toronto, where CCRS always had a booth staffed by Jean Game. Over the years CCRS data were used by a number of the key exploration geologists who were involved in the discovery of some of Canada's major mineral finds, including Hemlo and Voisey's Bay. The department's Communications Branch was especially helpful in this period, assigning a talented communications specialist (the late Les Gallagher) to work with CCRS. The function of user assistance and marketing was seen as sufficiently important that Ryerson was added to the CCRS Management Advisory Committee. (See Section 2.3.4.2.)

As noted elsewhere (2.2.5), in 1985 the 1984 National Advisory Committee Meeting on Marketing attended by Minister Layton and chaired by Ryerson resulted in a comprehensive marketing strategy and plan for CCRS and industry. This led to an expanded role for the UAMU. As part of the industry strategy

[153] Knowing which company was buying data over what geographic area would be very useful intelligence for exploration and mining companies.
[154] The graphics design was done by staff provided on contract by Intera. See Section 3.3.3.

the UAMU planned and led technical marketing missions to India and South East Asia. With its market assessment expertise UAMU also contributed to the RADARSAT Economic Review and assessment of policy implications.

As indicated above, the UAMU did not just sell data and deal with the industry's exports. It was also charged with developing public awareness and was the first point of contact for users who wished to buy data or who needed advice or had a question. To better respond to users' questions the UAMU was co-located with the library and the Applications Division. If the UAMU staff could not respond to the query, Applications Scientists were asked to help prepare the response. The UAMU also organized tours of the CCRS facilities for college and university groups as well as for visitors from overseas, senior bureaucrats, Ministers, and others.

With regard to public awareness, as part of his annual performance requirements Ryerson was to obtain four national media coverages (such as CBC National News) and twelve regional coverages (a regional newspaper like the ***Fredericton Gleaner***) every year. CCRS took media relations seriously: as the designated media spokesman for CCRS Ryerson took a course on how to answer questions from the media on live television and radio – something he did dozens of times over his career. It seems strange in today's world, but Ryerson and Game were <u>expected</u> to actively seek media coverage. As a result, significant media contacts were developed in the national and regional media. If there was a significant forest fire, tornado, flood, or any other noteworthy event that could be seen on satellite data, imagery was offered to the media and different story lines were developed for competing media outlets. Ryerson and Game worked closely with the late Ian Press who was at that time responsible for satellite data production. A number of innovative ideas to increase awareness came from across CCRS. As one example, at the time there was one object on or near the desk and telephone of every federal public servant and politician – the Government Telephone Book. It was Ian Press who came up with the idea of putting a Landsat TM satellite image of Ottawa on the cover. That one idea led to broad awareness of satellite remote sensing across the entire federal government. In another case Tom Alföldi came up with the idea to have a birthday party on CTV National News – the party was to celebrate the "birthday" of Landsat.

Another aspect of what the UAMU did was to prepare briefing notes for senior bureaucrats and the political level. When Mr. Chretien was the Minister he met with all of those who would be writing briefing notes. His advice was simple. A briefing note should never be more than one page. He explained his logic in the following way: if you couldn't prepare the note in one page, you didn't know enough about the topic to properly brief him. It made sense and this approach to briefing notes was quickly adopted by CCRS and used with some success in the decades to come.

From 1984/85 to 1989/90 CCRS sales of satellite data grew from about $350k to over $1.2M with zero increase in the selling price of the data.[155] The dramatic increase in sales created a serious budgetary problem within CCRS. The cost of producing the data was borne by the CCRS budget. However, the income from the sale of data went to the Receiver General of Canada – not to CCRS. With every increase in sales the stress became worse. In 1990 the production and sale of data was given over to the private sector. This led to a refocusing of the UAMU, a new name for the unit and a new title for Ryerson. The UAMU became the Industrial Co-operation and Communications Section and reported to the Director General.

[155] To put that into perspective, by 1989/90 data sales were over 20 times Ryerson's salary.

"Mr. Canada" and a New Title for the Head of UAMU
Bob Ryerson

In the late 1980s and early 1990s one of the best known media personalities in Canada was Peter Gzowski, who hosted the popular CBC national radio program ***Morningside***. Gzowski, also known as "Mr. Canada," interviewed an eclectic range of people – from Prime Ministers to everyday Canadians with something interesting to say. The book ***Satellite Images: Photographs of Canada from Space*** (Banks, 1989) had just been published and the distributor organized an interview of me with Peter Gzowski. As preparation I was asked to send a short CV on who I was and my background. I noted that I had a PhD, had been a scientist and was now Head of the User Assistance and Marketing Unit. The interview conducted by Peter Gzowski on live national radio began with the following statement/question. "Dr. Ryerson, I have read about your background and it is quite impressive…can't the government find a better title for you than Head of User Assistance?" He later asked if we could see his golf ball on the green and, as I recall almost thirty years later, I said that you could see the golf course and the fairways – but not the ball. It wasn't much later that my title changed to Chief of Industrial Cooperation: thank you Peter Gzowski!

6.2.4. CCRS: Selling Science, Selling Our Industry Internationally

The new industry- and international-focused Section was responsible for projects dealing with external relations (primarily with other countries, but also with other government departments), industrial liaison, and policy advice and development in these areas. The industry and marketing strategy adopted a few years before continued to focus on placing Canadians in key international advisory bodies, production of marketing materials, technical trade missions,[156] and pro-actively seeking media coverage.

There was a much closer relationship with some departments than others. An especially close relationship was developed with Industry Canada, to which the Space Agency reported. As explained in Section 4.3 it was with Industry Canada officials (notably Glen MacDonnell) that the industry-based justification for the $800 million Earth Observation component of the Long Term Space Plan II was developed. This experience again underlined the importance and value of linking remote sensing to policy areas important to government. Without that linkage the new program would never have been approved at a time of massive budget cuts.

As a result of the activities of the Section, CCRS had a significant presence at a number of national and international conferences, in international technical publications, as well as on international advisory panels dealing with remote sensing. Activities included chairing conferences, being as an editor of international journals, serving on panels, doing regional or country-based market assessments, and providing an exhibit to wave the flag – both that of CCRS and that of Canada. Another aspect of international marketing and public awareness saw Ryerson volunteer to be Editor-in-Chief of the ***Manual of Remote Sensing*** for the American Society for Photogrammetry and Remote Sensing. The thinking was that with this position more Canadian work would be featured – and it was.

The experience of CCRS resulted in its staff being approached to serve on a variety of committees and groups dealing with the promotion of science and international marketing. As one example CCRS provided a member for the Interdepartmental Task Force chaired by External Affairs developing a policy on providing strategic market information for industry. (External Affairs and International Trade Canada, 1993) That task force developed policies and approaches on the collection and dissemination of market intelligence.

[156] A technical trade mission involved giving a seminar or workshop, disguising to some extent the focus on selling the product or service.

The level of trust between UAMU and industry built up through dealing with industry buying data evolved into new trust-based activities. One such activity was the creation of a confidential record of what companies were going after what opportunities internationally as well as what opportunities were coming on line from development banks and UN agencies. With this information at hand the Section could identify new opportunities for Canadian industry, support companies where there was no competition for an opportunity and keep out of the way if there were competing companies from Canada. Over the years there was never a complaint about how the Industrial Co-operation and Communications Section worked with industry. With the budget cuts of 1994/95 providing the opportunity to take an early retirement, Ryerson volunteered to leave CCRS and joined the private sector in 1996. His departure marked the end of an official marketing function within CCRS.

6.2.5. Marketing Conclusion

For the first twenty-five years of its life marketing played a key and expanding role in CCRS. The activity not only gained support for CCRS's science and helped sell CCRS's products; it also played a role in introducing the products and services of a competitive industry on the world's stage. With the departure of Ryerson the formal marketing function ceased to officially exist, although one might argue that the technology transfer and web-presence activities that continued were elements of a marketing activity with a different focus.

6.3. Library and RESORS

Bob Ryerson

6.3.1. Introduction

The library began as a means of organizing the growing volume of papers in the new field of remote sensing.[157] It soon became a key part of the CCRS plan to avoid duplicating work done elsewhere while building an international reputation. The library did this by serving as a window on the world's activities in remote sensing for Canada and, as important, as a window on Canada's remote sensing expertise for the world.

Today the concept of having a searchable data base of papers on a specific topic may seem almost quaint – but in the late 1960s and early 1970s it was ground-breaking. The beginning of RESORS was described by Larry Morley in his paper "Remote Sensing Then and Now," and is given in the text box below.

6.3.2. The Strange Beginnings of RESORS

The concept was simple. Remote sensing papers would be read and keywords (some 1500 in number) that described each paper would be assigned a certain weight and this information would be put into a searchable data base. Scientists or others could find literature on a certain topic. It should be kept in mind that this searchable data base was being used almost a quarter century before Google was launched!

The Strange Beginnings of RESORS (As written by Larry Morley in 1991. Edited text in brackets.)
RESORS, standing for the Remote Sensing, 'On-Line Retrieval System' was an integrated indexing and computer-based retrieval system concerned with the instrumentation, techniques and applications of remote sensing, photogrammetry, image analysis and G.I.S. It contains titles, authors, publishers and keywords for most of the world's literature published in English and French on these subjects from 1969 (until its closing in the late 1990s). It also contains many unpublished, unclassified documents which CCRS and RESORS were able to get their hands on.

[157] Authors' Note: The growth in remote sensing literature was astounding. At the time of my PhD comprehensive examination in 1972 there were perhaps 1000 papers in the entire field – and I had read most of them. Several years later there were several thousand and by the late 1990s there were about 100,000.

It is unique and was subscribed to internationally. It was initially managed in house by the CCRS head librarian, Brian McGurrin. Later, it was contracted to Gregory Geoscience Ltd., and even later to Horler Information Inc. of Ottawa.

It was started by Len Pomerleau, a systems science graduate from Ottawa University, hired by the Program Planning Office in 1970. Among other more scientific duties, he was asked to make a systematic manual file of several hundred brochures and 'separates' of papers on remote sensing which had been collected by various members of the staff. In the confusion of those days, they were thrown on the floor in a heap in a spare room that was to become the boardroom. After putting off this horrible task for several weeks, he came to me with the recommendation that the only way to be able to retrieve specific information required was by a computer system. In 1969, however, there were very few such systems in existence - certainly none in Ottawa, and those that did exist were experimental and costly. Pomerleau tracked down a Master's student at Carleton University by the name of Andy Smith who was interested in designing a system to serve as his Master's thesis. A contract was given and he designed the RESORS system that, with some updates, is practically the same as the present system. There was, however, a catch. Knowledgeable people had to be employed to acquire, read, keyword and enter the data from the documents into the computer. Four people were hired for this job, some of whom, twenty or more years later are still doing this painstaking and important job. This system has enabled the remote sensing population in Canada to remain current and competitive in this fast-moving technology over the years.

6.3.3. Putting Canada on the Remote Sensing Map

Soon after launch RESORS became the “go-to” source for information on the burgeoning field of remote sensing. People from all over the world used the system and (more importantly) people from all over the world contributed material to the system. CCRS became not just the Canada Centre for Remote Sensing, but it became the *world’s centre for remote sensing information*. By so doing CCRS and Canada benefited in several ways. First, CCRS scientists (who made up almost one-half of the remote sensing expertise in the country at that time) were able to quickly see what else had been done by others. This allowed CCRS to avoid duplicating the work by others, a central theme promoted by the leaders of CCRS. As a result of RESORS a number of manuals, bibliographies and review publications were written by CCRS Scientists. (See, for example Cihlar, 1976; Fleming and Dixon, 1981; and Dixon and Cihlar, 1979.) At the same time, CCRS work and the work by Canadian industry was seen all over the world, since all the work by CCRS and the industry it supported was in the RESORS collection and access was provided for free all over the world. It is no accident that Canadian industry secured from 50% to 90% of the technology market in such key niches as image analysis systems and satellite data reception.

Over time RESORS grew to contain over 100,000 documents and a slide collection was added.

The original value of the system to support the work of scientists and industry continued into the mid-late 1990s. Indeed, RESORS was mentioned in the Pecora Award received by CCRS as one of the seminal contributions of CCRS to the field. The value of the RESORS Collection is still significant. RESORS contained many one-of-a-kind documents from around the world; some of the documents are original documents not known to exist elsewhere.

Simply stated RESORS is not a source that is or was replicated anywhere else. RESORS provided and still could provide a very large and comprehensive time-series overview of the development of a scientific field in which Canada provided a leadership role to the rest of the world. Some might argue (as this author has done) that RESORS is one of the reasons FOR that leadership position. While its scientific value has decreased over time, it was still being used to provide background studies on the value and use of remote sensing to important issues of the day as well as to avoid duplication of previous work. (In 2002 it was used to create a review of an important application by one of the author’s companies. In 2004 when the author was Director General a CCRS scientist was advised to use the collection to find a document that described work that the scientist was about to duplicate!)

Today the value of RESORS should be seen more as an archive consisting of unique documents and imagery. While some of the material is from scientific journals contained in libraries, the true value is more from the unique documents and imagery. Having used the system for almost 30 years and having personally given hundreds of documents from overseas colleagues to the collection as well as various manuals, specialized materials on the technologies and their applications, etc., this author can attest to both the uniqueness and the comprehensiveness of the collection.

The second part of the collection that has significant and unique value is the slide collection. It contained the only surviving visual record of the presentations and much of the project work carried out by many CCRS scientists, and the only remaining evidence of some of the systems and technologies with which CCRS accomplished so much over its forty year history to date. In an increasingly multi-media world, the value of such a visual record (showing people, photographs of the features being studied with remote sensing, the remote sensing imagery, as well as the technologies used) is becoming of greater importance, not lesser importance. While some of this work (including some of this author's) was displayed in the National Museum of Science and Technology, most of it remains only in the RESORS slide collection and in the scientific literature. The fact that some of the work so documented has been carried out by scientists now deceased adds more value to it as part of the historical record. It should be noted that the slide collection was at one time in two parts – there were the originals (which no-one was allowed to borrow) as well as duplicates.

While a number of CCRS alumni have argued that the RESORS Collections should be kept at least in an archive that could be consulted, its "fate" is not clear. To "get rid of" the paper and hard copy archive would be to throw away documents that have had and will continue to have great value to Canada. It is a given that RESORS helped CCRS develop as a world-class centre of excellence and supported an industry and technology that has led the world – and in many cases still does. (Think Optech, MDA, PCI, Intermap.) In the future we can expect that the RESORS Collection could be used to better understand how and why Canada was able to do so much with so little in a field of technology that is today changing the way we think and approach some of the major policy issues of the day.

6.3.4. The Value of Leadership in Information

As intimated above, value of RESORS was several fold. It showed the importance of establishing CCRS as what amounted to a reputable clearing house for information on a new field. This allowed CCRS to not only easily obtain information, but created a desire on the part of researchers elsewhere to share their work with CCRS. This in turn was beneficial for the research mandate of CCRS inasmuch as it did not waste scarce resources on duplicating research done by others. The visibility was also helpful to the nascent industry in Canada. RESORS provided industry with an idea of what worked and what didn't, what competitors were doing, and introduced Canada's industry to the world.

In today's internet world one might achieve some of the same results by volunteering to establish the Secretariat for an international working group on a new topic – and provide the Chair for the working group, as well as the venue and support for meetings. Indeed, CCRS did something like that as one of the founding members of the Committee on Earth Observation. To gain more credibility a new group might get some form of formal approval through an agency of the UN – something the French, British and Australians have been doing to great effect for their national programs and export development across a wide range of scientific areas.

6.4. Approach to Innovation and Resulting International Success

Bob Ryerson

6.4.1. Introduction

Innovation was not something that was hoped for, or that we relied on luck to achieve. The organization – from management structures to the library – was built to foster innovation. It had to be, given the limited budget of CCRS and the enormous size of the country we were setting out to monitor and help map. As Dr. Morley always said "Canada was made for remote sensing."

While Canada may have been "made for remote sensing," we had to think through problems and proposed solutions very carefully to be able to scale solutions up to the size of the region of Canada we were dealing with – we could not simply throw money at the problem as our US colleagues often seemed to do with ten times the population and similar land area. We had to do more with less. We also had to be cognizant of the simple truth that remote sensing could not solve some problems in a cost effective manner. For example it did not take us long to learn that crop area estimation for large area crops such as wheat in Western Canada was better and more cost-effectively done with the sampling procedures developed by Statistics Canada than with satellite data.

6.4.2. The Approach

A large part of the approach to innovation was built into the project selection and review process, as described in Section 2.3.4.3. Projects had to be based on sound science, involve the users or those who would benefit from the work and, for larger projects, formal cost-benefit analyses (including an idea of the market for the innovation) were often required. Budgets were carefully managed and discrepancies between planned and actual budgets were closely monitored. It was excellent training for work in the private sector, where many former CCRS employees were successful.

One of the fundamental elements of the approach to innovation was that CCRS was a safe place for new ideas: calculated risk was encouraged if the pay-off was projected to be large enough. While failure was tolerated, both project managers and senior management knew when to cut losses – and the members of the Project Selection and Review Committee and senior management were not be afraid to do so.

A second element was to break problems down into their constituent parts to understand where there were opportunities to find solutions and where there may be obstacles. One way of achieving this was to have scientists and engineers with different backgrounds on the same project team – as well as the potential users who understood competing or existing approaches to meet the information need. By so doing many unique and highly successful innovations resulted. Another way was to engage industry early in the process of finding solutions. MDA's ground station business, the base upon which their future success was built, can be seen as a result of the Canadian approach to innovation in remote sensing.

A third element was to do more with less – every time. One way to accomplish this was to ensure that every project or activity had more than one potential beneficiary and more than one purpose – i.e. projects should be planned to meet multiple objectives or outcomes with the same output. Here marketing can play a role to assess where else a particular outcome may lead to a corollary benefit. At the same time a market assessment may determine that competing solutions offer a far better result than remote sensing can achieve and thus the project should be dropped from consideration.

A fourth element was that new ideas must be presented in the context of what has gone before – hence the importance of RESORS. CCRS scientists and engineers were encouraged to build on the verifiable research of others – but do not do "me-too" research (research that simply proves that someone else was right in their conclusions). McNairn has been quoted in the introduction to this Section "science is not built on a single experiment, but rather the accumulation of knowledge from repeated probing." One must know where previous probing has led and with what result.

6.4.3. Some of the Ground-breaking Achievements

Several contributors have identified a variety of achievements that put Canada on the map as a leader in remote sensing. A comprehensive list appears in Section 8.2.3 that provides the background for the nomination of CCRS for the William T. Pecora Award. Here is a list of a few of the more prominent.

- RESORS – was the first searchable key-word indexed library of remote sensing publications in the world. Not only did CCRS subscribe to all of the major journals, we encouraged scientists from around the world to provide their publications to the library and we would provide search results to anyone anywhere. We in Canada were then able to showcase what we had done (including our industry) to the world and were able to avoid duplicating the mistakes of others.

- CCRS and Environment Canada did the first large area integration in a GIS of data acquired from visual interpretation of both satellite and airborne data, census data, and existing land use maps. The area covered was the Great Lakes Basin covering much of Ontario.
- CCRS, under the leadership of Scientist Dave Goodenough, was the first civilian agency in the world to purchase a digital image analysis system. The Image 100 System was used by CCRS and other scientists from across Canada for a number of years to develop applications expertise as well as expertise in building such systems. Improvements to the system contracted by CCRS led to a still successful industrial image analysis capability.
- Betty Fleming, an engineer in the Surveys and Mapping Branch (a sister branch to CCRS), developed an approach to index all Landsat data. Her approach was adopted by the entire world.
- CCRS scientists and engineers (Frank Ahern and Jenny Murphy) were able to determine the cause of and correct systematic errors in early Landsat data. The approach was adopted by all of the countries receiving Landsat data worldwide.
- CCRS and Statistics Canada did the first near-real-time pre-harvest operational crop area estimation using satellite data. The potato area estimate produced in August 1981using satellite data was 53,827 acres. This was only 34 acres more than the 53,793 acres released almost a year later by the 1981 Census of Agriculture – an error less than 0.06%.
- CCRS (Tom Alföldi) developed an approach to measure sediment loads in water;
- CCRS (Ron Brown and Frank Ahern) developed an approach to measure standing brown biomass in rangelands. The approach was adopted operationally and the paper won an award for the best paper in the English language on remote sensing in 1983.
- CCRS led in the development of RADARSAT (See Section 5.)

6.4.4. Conclusion

The happy corollary of the CCRS approach to innovation was that CCRS developed low cost, efficient ways to both "do" RS and apply it. These "CCRS" solutions found their way into both developed and many developing countries – countries with small budgets, a growing need for information, and which lacked the information infrastructure that already existed in Canada and other developed countries. Developing and developed countries alike appreciated low cost approaches and Canada's industry was ready to help all of them do more with less.

6.5. Airborne Program

Bob Ryerson[158]

6.5.1. Introduction

The airborne program is an appropriate place to begin the historical discussion of CCRS's science and services in that the airborne program had its beginnings before CCRS was formally established and it had a bearing on much of what CCRS and Canada was to accomplish in remote sensing in the coming decades.

In effect the airborne program was a child of NRC's airborne geophysics program merged with some of the concepts that Larry Morley picked up from the US. It was to enjoy a number of years of successful activities, including supporting a world-class research program and spawning an industry. The last of its aircraft, the Convair-580 which contained what was to become known as a "flying SAR laboratory" was eventually turned over to Environment Canada before landing at the Canada Aviation and Space Museum on June 23, 2015.

[158] Except where noted this section has been written by Bob Ryerson.

The Canadian Forces Airborne Sensing Unit under Major Ernie McLaren became the Airborne Operations Section of CCRS. As noted elsewhere Ernie McLaren became a key player in the early success of the CCRS Airborne Program, the CCRS marketing activity and the College of Geographic Sciences.

6.5.2. The Aircraft
Lee Godby and Ralph Baker[159]

The Airborne Operations Section began with two DC-3's and the CF-100 which were "given" to CCRS by the Air Force, and the Convair was bought directly from a US broker by me[160] with a certified cheque (for US$640,000) provided by DSS. Memory has it that the Falcon was bought from a private company in Texas called RSI - for Remote Sensing International.

The purchase of the Falcon is explained in this paragraph from Lee Godby. “I went into the office one Saturday and Larry was there. I said: "what are you doing here on a Saturday?' He said Ernie Gardiner[161] and I are on a "Save the Falcon" Mission. I said "Where are you going to get the money? Larry said "We are going to buy it on time" I said "Can you do that in the Government?" He said: "I don't know but we are going to find out." That was at a time when we didn't have a budget or as I recall even an approved program. Anyhow Larry sent this submission off to Treasury Board. A few days later he got a phone call from a person in the Treasury Board – I always wished I had written down his name because he is a hero. He said "I got your submission – you can't do that in the Government – but do you really want that aircraft?" Larry replied with an argument like the fate of Canada is at stake. Then the Treasury Board officer said. "Well there is some money available that we might tap!" He did and we got the Falcon – and that is the true story of ‘How we got the Falcon.’ And I got a great lesson from that "If you don't know what to do – do something."[162]

The purchase of the Convair was much less dramatic. In the words of Ralph Baker: “The buying process had quite a few preliminary steps, the final step was delivery to Ottawa by a US broker, acceptance by the Canadian government – in effect CCRS, then payment by certified cheque and a bit of signing all around. As of that moment it was no longer certified to fly. DSS had a fellow who brought the cheque to the airport along with a few papers to have signed. On arrival, he said he was sick, handed me the cheque and papers and disappeared. By pre-arrangement the CV-580 was then towed to an Air Force hangar where it "rested" for some months while contracts were arranged to have it refitted, including certification of airworthiness in Canada.”

6.5.3. Airborne Projects: Analysis, Benefits and Sample Projects
Bob Ryerson

Before CCRS began there was a vibrant and successful aerial mapping industry in Canada, primarily built up by returning veterans from World War II. However there was limited work being done on anything that might be considered to be airborne remote sensing outside of geophysics. There was the previously mentioned work by Harky Cameron with U-2 imagery and Dieter Steiner at the University of Waterloo had four 70 mm Hasselblad cameras in which he used films and filters of different sensitivities ranging

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[159] Details of the provenance of the aircraft (and much of the wording) come from an e-mail from Ralph Baker on April 21, 2018. The paragraph on the purchase of the Falcon comes from an e-mail from Lee Godby on April 23, 2018.
[160] Ralph Baker
[161] Ernie Gardiner was Chief Pilot for some years .
[162] Personal Communication by e-mail from Lee Godby, April 23, 2018.

from the blue to the near infrared.[163] Otherwise, Canada was largely untouched by airborne remote sensing.

As noted in Section 3.2.4.2, every project carried out by the CCRS airborne program for a user required that a report be prepared to document what the project objectives were, what data were acquired, the results, and in general terms the benefits of doing the work. These reports were also intended to show that the project was research and development focused – not something that could have been done by industry. These documents provided the basis of studies that would support the value of the airborne program for some years into the future as described in the next paragraph.

In the late 1970s it was decided that a CCRS Applications Scientist should be attached to the airborne program to advise users and carry out an assessment of the program for senior management. The first Applications Development scientist assigned to this task was Josef Cihlar who had already established a strong reputation in airborne thermal sensing for heat loss from buildings.[164] In addition to providing advice to users, Cihlar produced an "Assessment of the CCRS Airborne Program." (Cihlar, 1978) That study began to show the value of the airborne program activity. The next Applications Development scientist assigned to the airborne program was Ryerson whose expertise was in optical sensing as applied to topics such as agriculture, land use mapping and environmental studies. Following on Cihlar's study Ryerson applied the approved Treasury Board of Canada approach to cost benefit analysis to produce an analysis of the CCRS Airborne Program. (Ryerson, 1980; Ryerson 1981) The study assessed 42 projects conducted for 19 users – about 10% of the projects that had been flown to that date. The benefits were (in 1978 dollars) $5 million.[165] The important conclusion was that using approved methods of measuring and assessing costs and benefits, the benefits for these sample projects alone exceeded the total cost of the airborne program from its inception to 1978. (Ryerson, 1981)

There were literally hundreds of projects flown by the CCRS airborne program. Some were successful and some not. What catches the attention of one reviewing the projects that were flown is the diversity of topics that were addressed. The following examples show the range of projects that were flown.

Heat Loss in Buildings – and Marijuana Grow Ops: One of the more interesting projects concerned the aforementioned heat loss in buildings using the recently acquired Thermal Scanner. The topic of heat loss in buildings was of some interest across the country during the oil crisis of 1973 when OPEC members declared an oil embargo. Imagery of downtown Toronto not only showed which buildings were poorly insulated, but they also showed where there was heat loss from buried heating pipes. Heat loss from buried pipes in Canada's prisons was also assessed by the Government of Canada's Correctional Services. (Projects 74-135 and 75-115) The same technology was later used to identify very warm buildings which may be marijuana grow ops, as is further discussed along with the legal ramifications in Section 6.6.1.

Oil Sands: The development of the oil sands of Alberta was another high-profile activity over which the CCRS aircraft flew several projects. Aerial photography (colour and colour infrared) and heat sensing data were acquired from a range of altitudes yielding a range of scales. These data were used by commercial companies in their studies for Governments (notably by Diane Thompson and colleagues at Intera for the Alberta Oil Sands Environmental Research Program – Project 77-13) as well as by students, including Stan Aronoff, then a Masters student at U of Calgary whose thesis clearly showed some of the

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[163] The four sets of imagery acquired were subsquently scanned, registered one to the other using custom designed software, and then viewed on a system used for airborne geophysics in the University of Western Ontario's geology department.

[164] See for example Cihlar and Brown, 1977 and Brown et al, 1981.

[165] Over $18 million in 2018 dollars.

environmental issues that were associated with the development of the oil sands and subsequent reclamation.[166]

Oil Spill: Oil spills were a major topic of interest to a range of CCRS clients and CCRS itself. Early work done by CCRS in the Grand Bahama's (de Villieres, 1973) pointed to laser fluorsensing as a possible solution. The primary interest was of spills in Canada's northern waters in the presence of ice. Much has been written on the Arctic and Marine Oil-spill Program (AMOP) in workshops and conferences held featuring CCRS data (as in 1978) and many years after the airborne program of CCRS ceased to exist.[167]

Whales in the Arctic: Doug Heyland, then of the Canadian Wildlife Service and later Head of the Technology Enhancement Program at CCRS, obtained Kodak Water Penetration Color Film that was originally intended to locate submarines under water. This film at a scale of 1:2400 was used to identify and count beluga whales in Canada's Arctic. The imagery has appeared in a number of highly regarded text books including that by Lillesand and Kiefer (1994, p 228).

Thermal Plumes in Water: The Ontario Ministry of the Environment used CCRS thermal data to identify thermal plumes at the Bruce Nuclear Power Plant on Lake Huron in projects undertaken over several years – Projects 75-22, 76-36 and 37 and 77-54. Color aerial photography was also used to identify submerged vegetation. These projects, which cost under $40,000 eliminated the need for $150,000 worth of *in situ* equipment and it subsequent operation.

Mine Spoil Reclamation: Tailings ponds and other remnants of mining present a number of challenging monitoring requirements – as was also demonstrated by the work by Aronoff on the oil sands. Project 74-28 assessed reclamation of mine sites in Saskatchewan at a cost that was 1/3 of traditional approaches.

Aerial Hydrography: The efforts in aerial hydrography by CCRS and a variety of commercial partners are documented elsewhere and in the text box following. The precision and total coverage offered by the technology (compared to ship-based hydrographic surveys) provides better and more complete information contributing to safer navigation and drastically reducing potential problems of ships running aground.

Insect Damage: Spruce budworm was a major problem in both Nova Scotia and British Columbia. CCRS data from Projects 76-56 and 77-66 were used to plan spraying (which was subsequently stopped) in British Columbia. The data had significant value in helping to understand the disease and future outbreaks.

Land Planning and Land Use Mapping: High altitude and small scale imagery (on the order of 1:120,000) was acquired over much of Ontario for the Ontario Ministry of Transport's Sen Mathur. The data were used for transport planning and by many others to map land use at a scale of 1:50,000 as was required for planning in the province. Previously imagery at a scale of 1:15,000 or greater was used for such purposes with all of the added costs of handling so many more images.

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[166] The close inter-relationships of people who were in the field early on can be seen from the fact that Ryerson was one of the external examiners for Aronoff's thesis and they eventually became colleagues and wrote a book together (Ryerson and Aronoff, 2010).

[167] Seminars or workshops on AMOP have existed at least since 1978 (ftp://ftp.library.noaa.gov/noaa_documents.lib/NOAA_related_docs/oil_spills/AMOP_proceedings_1978-2011.pdf) to as recently as last month in British Columbia. (https://www.canada.ca/en/environment-climate-change/services/science-technology/arctic-marine-oilspill-program/information-postponement.html) Accessed November 7, 2018

Crop Disease: Dr. Vic Wallen of Agriculture Canada used 1:12,000 CCRS colour IR imagery to demonstrate the value of using certified disease-free seed for white beans. The imagery clearly showed the losses associated with the use of seed that was not certified.

There were, of course, many projects associated with internal CCRS sensor testing, quality control and research into a variety of applications including ice monitoring. One of the more important activities for the commercial aerial survey industry at the time was the work that was done by Jack Fleming on ***Standardization Techniques for Aerial Colour Infrared Film***. (Fleming 1978 and 1980) He found that the colours were often inconsistent on the exposed film as a result of minor variability from one batch of film to another. As with many other important findings of days gone by, this one would seem to have been rendered irrelevant with digital cameras. Of course, that is not completely the case inasmuch as todays digital cameras will vary depending upon the sensors within the cameras and how they are calibrated. Testing, calibration and quality control remain even more important today than they once were.

A Personal View of the Airborne Program
Bob O'Neil[168]

My view of CCRS and the world in which we worked has been tempered by my having worked as a scientist, Section Head and Division Director in several areas of CCRS.

My career steps were underscored by a need for effective cooperation with and participation of other government agencies, the academic sector, private industry, and international partners. The point should be made: I was a government scientist doing government science (which is very different from academic or science for commercial purposes). We focused on issues important to the government of the day – we focused on specific applications.

Remote sensing, as we were trying to develop it at the time, was based implicitly on four fundamental characteristics of an EO data stream that were essential for the success of its application:

1. It offered regional, national or global coverage;
2. It offered observations of regions that were otherwise inaccessible. The most common example used was sea ice in the Arctic night;
3. The observations were consistent in space and time, or could be made consistent through radiometric and geometric processing; and
4. The observations could be repetitive over a useful temporal and/or spatial interval.

As a scientist I successfully demonstrated lidar bathymetry and created an operational system to collect, process, and disseminate results. To move oil spill detection away from qualitative science I led a team that utilized airborne imaging sensors and created the first laser flurosensor for this work.

Over a period of years I had a unique view of the growth in microwave remote sensing within CCRS's Data Acquisition Division and in Canada as a whole. This view has led to my response to a number of questions one can pose:

1. **Question:** Why was microwave remote sensing development considered so important to Canada that it was funded so generously in the period 1970 to 1995? **Answer:** The biggest issue, it seems to me looking back, was the oil exploration in the MacKenzie Delta and the Beaufort Sea. This was in support of seismic

[168] Editor's Note: This text box was first prepared as a series of answers to questions for an interview Bob O'Neil was to have related to airborne microwave sensing. Bob first joined the Sensor Section in the Data Acquisition Division of CCRS in 1975 as a Research Scientist. He completed his PhD in nuclear physics in 1972 at McMaster University, followed by a Postdoc in the Water Quality Sub Division (laser fluorosensor) and Glaciology Division (620Mhz) radio echo sounding), Inland Waters Branch / Environment Canada. He was head of the Sensor Section from 1980 to 1985. He was later Director of the Major Projects Office and GeoAccess Division.

exploration, drilling operations and production. This activity had all the right groups involved from the outset (oil companies, Intera etc.) as well as enough money in the economy to justify something as big as and operational RADARSAT.

2. **Question:** What kind people (background, drive etc.) worked in the early days of RS at CCRS? **Answer:** This is an important and interesting question to answer properly. CCRS hired people with a range of backgrounds with two common attributes: pride in what they did and the drive to meet what sometimes seemed like unattainable goals.

3. **Question:** How was it that for such a small country economically, Canada seemed to find a niche in airborne remote sensing and punched way above its weight in leading in this area on the world stage? **Answer:** There are several elements needed to answer this. First, Canada, even to Canadians was unexplored. It was Canadian to see Canada as the wilderness beyond where we lived in a narrow band at our southern border. Second, after World War II, Canada was mapped with aerial photography – completely and this data set was, until very recently, the only complete data set at a reasonably large scale that was high quality and accessible. Third, the Canadian geophysical survey industry was second to none in innovation and global activity. Fourth, and this is very important – we were not the USA or Europe! We were relatively small and generally seen as non-threatening. Many other countries could visualize the potential for their application of remote sensing in the success of the Canadian "model" and how we partnered with the US and Europe. It also opened up our industry for international contracts.

4. **Question:** How is it that CCRS got involved in the Arctic and Marine Oil-spill Program (AMOP) AMOP program? **Answer:** We had the interest, expertise and the gear to map oil spills in ice infested waters. It is somewhat ironic in retrospect that there was a lot of reluctance to actually spill oil in the Arctic to see if it worked as well as we thought. There was a natural oil seep off Baffin Island that we investigated as well as a small tanker that broke apart in the ice off PEI. As you might expect, the ice added another layer that could hide the evil oil so, as I recall, the excitement of managing an oil spill in an ice infested open ocean was a nice idea but really almost impossible. There were some good experiments though. The one in the New York Bight with NASA Wallops and the USCG was probably one of the most important (ERIM was also a sort of partner because they had access to the CV-580 with their SAR onboard. (On this topic I opened my mouth when NASA and ERIM were commiserating about not having enough time on the CV-580 over the spill and I naively suggested that if this was an issue they could have asked me with the implication that I could have made it happen. I got smacked around back at the office at Limebank Road as there were other people who thought that they were in control (which was true – but … I had access to the DOE funding which, with a little justification, could have been used for a few more flight lines.)

5. **Question:** What achievements were important in your mind in showing the utility of microwave techniques early on? **Answer:** There is one that I mention because it is extremely important, it shows how our work was done, and it is often forgotten (if anyone every really knew). It is the story that starts with the Side Looking Radar (SLAR) providing qualitative observations of sea ice in Baffin Bay and elsewhere to scientists at DREO, Rene Ramsier of Atmospheric Environment Service (AES) , the Arctic Ice Dynamics Joint Experiment (AIDJEX), and others. There followed work by Laurence Gray with the Ku-band scatterometer leading to quantitative scattering of microwaves by sea ice as function of angle allowing classification of ice age. Paris Vachon's work was important bringing in wind velocity. Things were much more difficult over land and, equally important, there were not early partners with land data requirements willing to commit at this moment in the development. A lot of smaller experiments were carried out tickling the problem for insights that could be built upon.

6. **Question:** What were the strengths of the microwave remote sensing program at CCRS? **Answer:** As with all of these things it was a combination of people, opportunities and resources. I think we were very fortunate to exist in a collection of insightful people (staff, scientists, executives and partners). We should never forget the Interdepartmental Committee on Space – their support was exceedingly important to CCRS from Day 1 but particularly as the concept and implementation of the RADARSAT Program evolved and was launched.

7. **Question:** How did the Radar Data Development Program (RDDP) begin – what was it and how did the CCRS airborne SAR program fit into it? **Answer:** By 1995, EMR faced program review and this resulted

in the cancellation of the airborne program. RADARSAT-1 was due for launch later that year. The CSA seemed to be taking more and more control of the R&D budget for remote sensing through initiatives like the Long Term Space Plan as CCRS's budget shrank.

8. **Question:** What lessons from the work carried over to RADARSAT-1 (launch 1995) and RADARSAT-2? **Answer:** The work on polarimetry and the response of radar to a variety of targets formed the basis for how these programs developed and how radar data were eventually used – both in Canada and overseas.

The Airborne Program was a remarkable experience for me and there are many aspects in which I was but a part and yet I am proud to say that I believe that I played my part well. I offer an anecdote, which I have never shared, but which demonstrates the nature of the organization and why I am proud of my role. At about the time the CV-580 was coming on line, the L-band ERIM SAR was installed we were talking about a ground based scatterometer for Applications Division, an X-band and a C-band SAR. I was told that the lidar (bathymeter and fluorosensor) projects were the lowest priority activities in the Division. I was surprised and disappointed about this and initially I did not understand how this was possible. It took me several years to appreciate the remarkable irony of the revelation. The airborne SAR activity leading to RADARSAT was big and was going to need all the resources that one could find in the organization. Unlike almost any project or program in CCRS at the time the lidar projects at CCRS had:

- Created a private sector supplier of the technology (Barringer Research and Optech);
- Successfully demonstrated the use of the technology in joint missions over targets of interest to clients who had actual operational requirements;
- Seen major monetary contributions from the Department of Environment and Canadian Hydrographic Service for the development and demonstration of the technology and both agencies had committed staff to move the technology from the demonstration stage to operational; and
- Cultivated the private sector throughout the demonstration stage so that they were ready to assume responsibility for actual operations and to begin to expand the service offerings and markets.

Of course, this was what was supposed to happen in all CCRS activities. In effect I was being asked to terminate the activities because they were a success! Not many scientists and engineers have had such an honour!

6.5.4. The First Airborne Sensor in the CCRS Stable
Wally McColl

As noted in section 2.1.1., the concept of an airborne remote sensing program began in 1964. Long before CCRS officially came into existence the planning began with Larry Morley, Lee Godby and his team at NRC Uplands.

The first "airborne sensor" purchased by EMR was a Reconofax IV Thermal Imager from HRB Singer Co,[169] This unit, developed in the Vietnam War era, was still a classified system when it arrived with Lee Godby's name stenciled on the boxes. The author was the individual from EMR tasked to assist in evaluating data applications. Initially the first trials focused on geologic applications such as identifying fault lines and structures often obscured by forest cover. However, in acceptance testing over relatively uniform water surface the system demonstrated a high sensitivity for delineating surface currents, internal waves and convergent zones. The availability of such data was timely for the work of the International Great Lakes Science Program. The sensor, installed in the NRC Northstar Aircraft (the Canadian version of the Douglas DC-6), saw extensive use developing temporal surface thermal image mosaics for Lakes Ontario and Erie. Overflights were coordinated with research ship programs operating out of the then new Canada Centre for Inland Waters, my home office. The mosaic consisted of adjacent image strips acquired by parallel flight lines across the lakes. This flight pattern was old hat for the flight crew since the principal application of the Northstar aircraft was mapping the Atlantic rift zone by tracking remnant

[169] HRB Singer was perhaps better known for sewing machines, but like many other companies, it had a military activity. This is similar to Bendix (the automobile brake manufacturer) and GE (household appliances) making image analysis systems.

magnetism. Parallel low level flights across the Atlantic towing a magnetometer close to ocean surface mapped the entire ocean to mid latitudes.

This long introduction on the marine application leads naturally to an application with a long research thread, the one that first came to mind when the history of CCRS history was being discussed: oil spills.

With the Reconofax installed in the Northstar we were able to respond quickly to the tanker accident in Chedabucto Bay NS in February 1970. The tanker SS Arrow carrying Bunker C oil went aground on a rock spilling most of cargo and sinking with an estimated 20,000 liters trapped in the hull.[170] The planning and logistics of the first day / night data flights tracking the oil spill provided an interesting challenge that was met by the team.

The success of this infrared imaging test was significant if not immediately understood. Imaging at that time had to be directly to photographic film. No digital or even analog tape systems existed for this data rate. We did manage to get good time sequential coverage of the spill with day and night images in the mid infrared, 4 to 6 micrometer and long wave infrared, 10 to 12 micrometer bands. The surprise was that the images from the two infrared bands showed the spill to cover areas of different extent. This apparent anomaly, discussed, theorized and argued among the scientists at subsequent oil spill trials and accidental spills continued until Dr. Bob Neville solved the mystery. The differences in the images came from quarter wave positive interference in emission from water.

The result being that we now could define the boundary of the relatively thick oil separate from the optically thin slick distribution. Being able to target the thicker oil is most valuable for the spill managers to assign assets, direct clean up and prioritize sensitive environments. This remote sensing capability aided in spill management for several Canadian spills, and notably the Exxon Valdez in Alaska and the Persian Gulf oil wells sabotaged during the first Gulf War.

6.5.5. Airborne Sensor Development and Processing Systems
Howard Edel

Sensor Development was based on sensors demonstrated on CCRS aircraft. For much of its history the fleet consisted of DC-3, Falcon and Convair-580 aircraft. Early on it also had access to a CF-100.

Over time the CCRS scientific and engineering team undertook the design and implementation of imaging sensors based on the latest civilian electronics technology available at the time. CCRS purchased the Daedalus two channel UV/IR imaging sensor. It was mounted in the Falcon aircraft nose cone and therefore did not require modifications to the air frame of the aircraft.

The imaging sensors’ multi-channel data were recorded on high density digital tape along with the time code and the aircraft inertial navigation data to enable correction of image pixels with attitude changes correcting for role, pitch and yaw of the aircraft. Matching the time code acquired with the profiling sensors enabled the synchronization of data from all sensors deployed on a given flight. In one example, the Laser Fluorosensor-acquired oil detection signature was overlaid on the UV/IR image data to provide a measure of the type and extent of the oil spill. In another application, the Infra-red sensor was flown over Ottawa, Ontario to demonstrate the sensor’s ability to monitor heat loss from house roofs, windows and walls.[171] The infra-red images of Ottawa homes identified those homes that would benefit from increased insulation. These images supported the Energy Mines and Resources’ program for home owner assistance to upgrade older home’s insulation for increased home energy efficiency and decreased winter heating costs.

[170] While doing the background research to prepare this short note, the author learned that after more than 45 years, the Arrow is now releasing the 20,000 litres that were trapped in the hull. Divers are now investigating.
[171] As discussed in more detail in Section 6.6.1 the same concepts were used to identify marijuana grow-ops.

CCRS focused on the new generation imaging sensors by purchasing a Daedalus multi-band optical scanning sensor detector module which emulated early Landsat Multi-Spectral Scanner (MSS) systems. This enabled CCRS applications scientists to collaborate with federal departmental research scientists in developing algorithms to enhance monitoring of land cover and vegetation. The release of the electronic two dimensional CCD arrays provided image capture in a push-broom mode enabling the acquisition of many narrow spectral channels in the visible spectrum at a higher spatial resolution. Dr. Harold Zwick[172] was the Scientific Authority for a contract to MDA to design and construct the Multi-Element Imaging Sensor (MEIS). The MEIS sensor provided multi-spectral image data for applications scientists to develop analysis algorithms emulating the satellite based sensors such as those on SPOT and later Landsat imaging sensors. CCRS also contracted the construction of the Short Wave Infra-Red (SWIR) Full Spectrum Image sensor (SFSI) to provide short wave infra-red spectra for enhanced geological feature detection. CCRS later transferred the SFSI sensor to Borstad Associates Ltd. where it was further enhanced for commercial surveys by small aircraft.

CCRS also undertook the development of laser sensors for emerging applications. Dr. Susan Till worked with Optech Inc. who supplied a Laser Fluorosensor built to facilitate the capture of the fluorescence signature return from features subjected to the laser pulse. In 1995 DFO transferred the FLI sensor to the Canadian Aviation & Space Museum. Dr. Bob O'Neil led the team developing the Scanning Laser Bathymeter which enabled shallow water bathymetry mapping from aircraft. Accurate shallow water bathymetric measurement is a challenge faced by the shipborne acoustic systems which are used for reliable deep water bathymetric measurements.

Just as there was a technological revolution in sensor development, there was an equal one going on in data recovery and analysis. One could not progress successfully without the other.

In 1977, CCRS implemented near-real-time Landsat image acquisition and transcription at the Prince Albert Satellite Station (PASS). At PASS, CCRS installed and implemented a Laser Beam Image Recorder (LBIR) built by MacDonald Dettwiler & Associates (MDA) to provide near-real-time image recording. (See the Text Box in Section 7.7.) The LBIR provided faster delivery of the Landsat MSS imagery for users wishing to use film based image analysis interpretation. In a related development at the CCRS Sheffield Road Facility, a staff and contractor team used the available PDP-10 to develop the Airborne Processing System (APS) providing a time-sharing operating system environment to process the airborne sensor data acquired by CCRS. This facilitated a time-sharing computer environment for CCRS and contractor software development in Ottawa, Ontario.

The CCRS software development team, led by Howard Edel, was supported by contracts to the Genesys Group. George Choma and Mike Gough implemented the software for the standardized CCRS built PDP-10 computer interface to transcribe the digital data from the instrumentation tape recorded on the aircraft to either a standard Computer Compatible Tape (CCT) or on to a disk drive in the "Non-Imaging Disk Data Format" (NIDDF) unique to CCRS. The NIDDF data files provided a user Infrastructure to enhance the on-line processing of the various data sets acquired onboard each of the aircraft. The digital image data acquired on the aircraft were transcribed to the standard CCT or stored on disk for printing with a dedicated RC-10 camera on black and white film. Plot and print routines were developed to access NIDDF stored data to provide quick viewing of profiling data. When Edel joined DFO/Science in 1980, CCRS contracted George Choma Associates to operate and maintain the APS system.

The CCRS engineering staff led by Trevor Butlin and Alexander Baillie designed and implemented the hardware interface to control and transcribe data from the time code reader and the instrumentation tape digital image files. The CCRS software staff implemented the diagnostic and operational software

[172] Dr. Zwick went on to lead Moniteq, a small company building sensors and eventually became the Chief Scientist of MDA, the position from which he retired.

routines to control the operation of these unique components utilizing PDP-10 operator/user device interface system routines.

In 1984, the Department of Fisheries and Oceans, with Canadian Space Plan funding, contracted Moniteq Ltd and Itres Ltd to build the first Fluorescence Line Imager (FLI). Dr. Harold Zwick, formerly at CCRS, and Dr. Allan Hollinger were the FLI project managers at Moniteq and Dr. Cliff Anger of Itres Research led the sensor development team. At DFO, Howard Edel was the government scientific authority and Dr. Jim Gower was the scientific applications team leader for the FLI project. DFO confirmed that the FLI met sensor performance specifications and promoted the applications development by Canadian government and foreign users. The FLI provided unique programmable optical spectral band selection by enabling spectral band width selection from 2 nanometer bands on up in 2 nanometer steps. The FLI provided enhanced low noise optical spectral sensitivity which enabled the detection of the solar stimulated red edge emission, a six (6) nanometer wide signal, from chlorophyll-A in the concentrations of phytoplankton in marine and aquatic environments. The FLI was deployed on the CCRS DC-3 and Falcon aircraft, in collaboration with Dr. Bob O'Neil, when DFO undertook demonstration flights, guided by Dr. Jim Gower and Dr. Gary Borstad (Borstad and Associates Ltd.), to verify the FLI detection and mapping of the phytoplankton concentrations in aquatic and marine applications. Neil Anderson at DFO/Canadian Hydrographic Service contracted Dr. Bob O'Neil to deploy the FLI imaging of shallow Lake Ontario shore water areas demonstrating the feasibility to provide optical sensor based shallow water bathymetry maps.

Moniteq scientists, led by Dr. Allen Hollinger, undertook commercial demonstrations of the FLI imaging applications capability with MBB in Germany under the direction of Dr. Roland Doerffer, then at DFVLR in Oberfaffenhoffen, in collaboration with Dr. Jim Gower of DFO. These successful demonstrations in Germany resulted in the European Space Agency (ESA) implementing the MERIS sensor based on the FLI system design. ESA deployed the MERIS sensor on the ENVISAT satellite launched in 2002. Canadian Space Agency (CSA), a cooperating partner in ESA, negotiated access to MERIS data for Canadians scientists. Dr. Richard Fernandes led the CCRS land applications development and Dr. Jim Gower led the DFO marine applications development. Dr. Michael Rast led the ESA scientific applications of the MERIS sensor data contracting Dr. Jim Gower to implement a red edge algorithm for ESA program processing MERIS image data into derived phytoplankton concentration image products.

In a follow-on development of the FLI technology, Itres Research Ltd. in Calgary, led by Dr. Cliff Anger, a subcontractor on the initial FLI project, collaborated with Dr. Gary Borstad (Borstad and Associates) to implement the Compact Airborne Spectral Imager (*casi*[173]). Itres Ltd. undertook the marketing of resulting single camera imaging spectrometer *casi* sensor. Dr. Borstad purchased the first *casi* and began providing contracted aircraft based imaging services to national and international customers. The British National Rivers Authority contracted Borstad Associates to undertake coastal water quality monitoring of the entire coast line of England. Itres continued with further engineering developments to meet additional user requirements leading to a family of *casi*-based imaging spectrometers which they have sold to national and international customers.

Starting in the 1970's, CCRS led the Canadian Federal Government development of a next generation Synthetic Aperture Radar (SAR) sensing capability. In 1977, CCRS implemented a Canadian SAR data reception and digital processing facility in Newfoundland acquiring the digital data from the civilian SAR sensor on the SEASAT satellite system deployed by NASA. The Newfoundland facility, built by MDA, acquired SAR data for monitoring the east coast and eastern Arctic ice and that region's marine environment. While the SEASAT mission was cut short by an onboard failure, CCRS scientists led by Dr. Keith Raney and Dr. Chuck Livingstone gained valuable radar reception and analysis experience.

[173] The *casi* instrument was always referred to as *casi*, perhaps because CASI referred to the Canadian Aeronautics and Space Institute.

PCI undertook the commercial implementation of standardized SAR image analysis on their PC-based image analysis system which they market world-wide. The analysis of the available SAR data motivated other Canadian scientists to explore the usefulness of the SAR sensor active signal imaging of the ice, vegetation, land and water surfaces in all weather conditions.

In parallel, and as noted elsewhere, CCRS acquired a commercial Convair-580 aircraft later outfitted with a SAR from the Environmental Research Institute Michigan (ERIM). The CCRS scientific and engineering team, led by Dr. Chuck Livingstone, modified the SAR sensor system purchased from ERIM and in the following years implemented many SAR sensor enhancements. Many multi-disciplinary applications were developed, including improved ice monitoring and land applications using enhanced digital signal algorithm analysis for environmental applications. As is detailed in Section 3.3.3 Intera Inc. developed a SAR sensor deployed on their company aircraft and provided on-board SAR images of ice conditions for the oil exploration companies operating in the Beaufort Sea area.

Under the direction of Julius Princz, the data from the Convair-580 SAR was processed at the CCRS Sheffield Road computer facility using the CCRS Sharp processing system built under contract by MDA. The Sharp system used a mini- computer augmented with an array processor which provided operational processing of all X, L and C band SAR modes available from the SAR-580 aircraft sensor. CCRS offered digital SAR products on CCT's with either unprocessed video signal data or digitally processed image data. MDA licensed the SHARP technology from CCRS, building a Generalized SAR (GSAR) processor which they successfully marketed internationally. The GSAR is being used by all of the countries acquiring and processing RADARSAT data.

Several foreign countries contracted Intera Inc. (later Intermap) to demonstrate the SAR deployed on the CCRS Convair-580 aircraft on local flight missions. These Convair-580 flights demonstrated the Canadian SAR technology capabilities to meet local user requirements and prepared potential foreign users to acquire SAR data from the RADARSAT-1 upon its' launch in 1995. The key foreign requirement of local SAR data utilization and control was provided with an on-board processing system implemented by Chuck Livingstone. Livingstone led the development of the enhanced SAR capabilities on the Convair-580. Dr. Keith Raney led the CCRS testing and deployment of the active SAR antenna emitters to provide programmable SAR swath and resolution capability, used on the RADARSAT satellites, for enhanced, wide swath, marine ice monitoring and mapping by the Canadian Ice Centre in Canadian coastal zones.

In 1993 DFO contracted Satlantic to build the Ocean Work Station (OWS) on a computer workstation platform and then integrated it with the SAR reception system at the Gatineau Satellite Station. Dr. Paris Vachon then of CCRS provided scientific support deriving near-real-time marine information products (sea surface winds, waves, convergent zones and vessel detection) on the OWS. The DFO/Conservation and Protection Branch (Wade Barney) evaluated the vessel detection product, produced by the OWS for enhanced fishing vessel monitoring in the Atlantic Canada fisheries region. Under a government license agreement, Satlantic and later Nova-Consult undertook the marketing of the OWS for national and international marine user applications information products.

In the late 1990's, Dr. Laurence Gray of CCRS led the development of the Interferometric SAR (INSAR) processing of SAR data for monitoring ice and land movements. Dr. Bert Guindon (CCRS) led the development of the software tools for digital terrain mapping with RADARSAT SAR data. Dr. Bob Hawkins developed algorithms for land surface and vegetation SAR signature analysis.

The movement of CCRS scientists, from the airborne sensor systems development, to scientific departments in the federal government, Canadian Industry and universities provided significant transfer and dispersion of SAR sensor remote sensing technology in Canada and abroad. Dr. Keith Raney had joined CCRS from ERIM when the Convair-580 was acquired and later moved to John's Hopkins University, USA. Dr. Neil de Villiers left CCRS to join the European Space Agency to lead the development of the suite of sensors on the ENVISAT satellite launched in 2002. Dr. Murray Strome joined PCI Inc. on an executive exchange program to lead the development of their PC based image analysis system. Strome then returned to government at the Pacific Forest Research Centre where he led the team including Dr. David Goodenough doing forestry remote sensing applications development. Howard Edel moved from CCRS to DFO in 1982 where he undertook the departmental coordination of sensor systems and applications development of marine environmental monitoring with both optical and SAR sensor systems.

As noted in detail elsewhere, Canadian scientific expertise in remote sensing technology enabled Canadian scientists and industry to undertake significant collaborative projects with international scientific teams to develop a wide range of remote sensing applications. The foreign and the Canadian RADARSAT polar orbiting satellites equipped with optical and/or SAR imaging sensors provide global environmental data acquisition – and technology developed in Canada allowed countries around the world to acquire and use these data.

CCRS also hosted foreign scientists in Post-Doctoral Fellowship (PDF) programs enhancing international scientific ties between Canadian and foreign remote sensing scientists in both optical and SAR technologies. Drs. Ade Abiodun and Victor Odenyo followed their PDFs at CCRS with careers in the United Nations. Many other visiting scientists came from the UK, New Zealand, Australia, Thailand, India and elsewhere. A number of these went on to establish companies including Dr. Geoff Tomlins (Pacific Geomatics) and Dr. David Horler (Horler and Associates). Dr. Gary Borstad completed his PDF in marine remote sensing under Dr. Jim Gower at DFO and established the Borstad Associates team. They developed a Canadian and international expertise and market presence for airborne environmental monitoring of marine and aquatic targets of interest with a *casi* sensor and undertook geological applications with the SFSI sensor. The United Kingdom National Rivers Authority contracted Borstad to provide twelve airborne multispectral image maps around the entire coast of England and Wales.

While PDFs and early contact with CCRS led to the establishment of some companies, far more came as a result of contracts let by CCRS for the development of remote sensing systems and services. A number of companies were developed to market the technology and services based on the technologies described in this Subsection. As noted previously, Intera acquired and equipped an aircraft with a SAR sensor to provide commercial tactical ice monitoring support to Arctic exploration companies, Arctic communities and provided Canadian Ice Service at Environment Canada Arctic ice monitoring before RADARSAT was launched. MDA established an international reputation in ground station technology by implementing SEASAT/SAR reception and digital signal processing, as well as Landsat. MDA developed and marketed ground stations for ERS series of SAR satellite as well as for the current the ESA Sentinel-1. MDA has also provided Canadian and international ground stations for the Canadian RADARSAT series of satellites. CCRS engineers and scientists continued to provide expert advice on commissioning ground station services for the RADARSAT satellite SAR data reception at foreign client sites with reception licenses.

6.5.6. Conclusion
Bob Ryerson

This section began with the statement that the CCRS airborne program had a bearing on much of what CCRS and Canada was to accomplish in remote sensing in the coming decades. Support was given to this statement in this section, but the thread of the program's importance also runs through much of the discussion on RADARSAT, the complex topic of polarimetry, industry development (Optech, Intera and others), international relations, education, and marketing. While it died an early death as a result of budget cuts (See section 6.7.2.2.9), as Bob O'Neil has said, there was much to be proud of in what was accomplished. It has been regarded as sufficiently important that the CV-580 flew one last time in 2015 to its final home in the Canadian Aviation and Space Museum as described in the following text box.

Canada Day Came Early at the Canada Aviation and Space Museum![174]

June 23rd, 2015 marked a special day in the history of aviation and space in Canada. A very special aircraft, a Convair-580, with its advanced Synthetic Aperture Radar (SAR) sensors made its final flight after setting records and breaking down barriers both political and scientific for several decades. The former Canada Centre for Remote Sensing (CCRS) CV-580 completed its last flight on Tuesday June 23, 2015 and will be part of the collection at the Canadian Aviation and Space Museum (CASM) at the Rockcliffe Airport in Ottawa. This aircraft served the radar remote sensing research community since 1974 when it was purchased by CCRS. It was operated by CCRS until 1996, then by Environment Canada until 2014, and finally by the National Research Council (NRC) before the transfer to CASM.

The flight by NRC pilots Paul Kissmann and Anthony Brown and veteran engineer Theo van Westerop was under gusty and overcast conditions with a strong wind up the runway to assist with the shorter than normal runway at Rockcliffe. There was an appreciative crowd which included former technicians, scientists and senior managers to greet the aircraft on this happy occasion. The aircraft first made a low overpass and then circled around for the landing. The photograph of the near perfect touchdown below was taken by Tom Alföldi, one of the original CCRS Applications Division Scientists.

The landing came almost two years after museum curators first visited the Environment Canada Hangar to look over the system. Their determination to see the system enter its rightful place in Canada's showcase for aviation and space was understandable: the system not only crossed over between aviation and space, it did so with great success at home as well as on the international stage. The linkage to space was obvious – the system provided the research behind Canada's RADARSAT series of satellites, as well as several other satellites launched by the European Space Agency and the Japanese Space Agency. And it was not simply the aircraft or the all-weather imaging radar that was of interest: it was the whole

[174] This was prepared for GoGeomatics by Bob Ryerson with inputs from Bob Hawkins, Chuck Livingstone, and Tom Lukowski. Tom Alföldi provided the photograph..

package, a flying radar laboratory that was the best in the world in its time.

The system was not just a success in research. It is an example of Canadian innovation and technological excellence that has led to great success in the export market, as well as providing the proof-of-concept for an estimated ten billion dollars of investment by Japan, Europe and Canada in radar remote sensing satellite systems.[175] What is perhaps not as well-known is the international imprint of this aircraft and sensors on board. In the 1990s it was the first foreign sensor/camera equipped aircraft allowed to acquire data over China since 1949. Furthermore, it was the first western aircraft to acquire such imagery over Vietnam since the conflict ended in that country.

Unlike most other countries, we in Canada used aircraft to prove and develop concepts before launching spaceborne systems – a cautious but effective Canadian approach. This flying laboratory is thus a symbol of how we approach scientific research: cautiously and in support of our economic, environmental, and foreign policy goals. The aircraft and the systems on board were also used to provide SAR imagery, share our experience, and demonstrate our excellence in Asia, Africa, the Middle East, Latin and South America, and, of course, Europe. In many ways one may regard MDA as a creature born in part from its success.

Ultimately the system and its success were the result of collaboration between managers, scientists, engineers, and technicians in government, industry and academe who came together to build the system and use its data to establish its well-deserved reputation. It is unfortunate that a number of those responsible for its success are no longer with us – but their names were certainly spoken and their accomplishments remembered by those of us who were there on June 23rd. We also owe our thanks to Environment Canada and the Department of National Defence which operated and supported the system most recently, the National Research Council, and the Canadian Aviation and Space Museum as well as the volunteers who cooperated to make the final step happen. In the coming years we expect that there will be a significant volunteer effort to ready the system for display so all Canadians can see yet another example of Canadian excellence in science, engineering, and its application for the benefit of us all.

Detailed below are just a few of the wonderful accomplishments that came from this aircraft and its on-board equipment and data handling systems:

- It was the test platform for the billions of dollars already spent or committed to Canadian satellite systems that are now (and will in the future) be protecting our sovereignty, our environment and our way of life;
- It was also the test platform for Europe’s early radar satellites (particularly ERS-1 and 2) and strongly influenced the development of national airborne radar test beds that are still being built and used in Europe and elsewhere;
- The technology developed helped MDA become a world-class provider of technology and data;
- Under Environment Canada research and development continued that supported Radarsat-2’s advanced capabilities in polarimetry and along track interferometry and led to the addition of the Moving Target Indicator modes of RS-2 funded by DND;
- Many other companies such as Intermap, PCI Geomatics and others providing services and technology world-wide have been successful as a result of the system;
- The system has directly led to some of the world-wide success of our mining industry through improving exploration. This gave our industry an early “leg up”;
- In the first two decades of service the system spanned the gamut of emerging and complex all-weather SAR imaging technology including high resolution, multi-frequency, multi-polarization, polarimetry, and along- and cross-track interferometry;

[175] The $10 billion is based on the reported costs of Canada’s three RADARSAT programs, Japan’s ALOS series and ESA’s ERS-1, 2 and Envisat.

- The technology was used to test and develop methods to predict landslides and subsidence associated with oil exploration and pipelines as well as applications dealing with ocean waves, surface wind speeds and directions, and moving target characterization;
- The systems associated with the Convair have allowed us to better understand ice and how to accurately map it to protect Canadians and our environment;
- The fact that we were trusted by China to be the first to be approved to operate a sensor-equipped aircraft over China is an important statement about us as a nation;
- The aircraft has flown as an ambassador for Canadian expertise in the science of remote sensing in more than twenty-five countries including China, Vietnam, Thailand, Malaysia, Taiwan, Jordan, Tunisia, Morocco, Kenya, Uganda, Germany, UK, Norway, Sweden, Brazil, Guyana, Costa Rica and USA; and lastly
- The net economic benefit of the system reaches into the billions of dollars including the ongoing employment of thousands of Canadians in well-paying and rewarding careers.

6.6. Applications Development

6.6.1. Introduction: Setting the Stage

Bob Ryerson

This section reviews the work done in the key areas on which applications development work focused. The coverage is not as complete as one might hope. Unfortunately some of the early leaders have passed away, been incapacitated by illness, cannot be located, or are otherwise unable or unwilling to provide material. Some of the application areas are very well covered since the material has been written by the scientists who did the work. Some of the areas not as well covered are ones that were abandoned by CCRS in the early 2000s timeframe. For those areas where a scientist-author has not contributed, only a short summary statement is provided that will at least underline that some work was done in the area.

With the stage set, this introduction provides the background to what work was done and why and how the focus changed over time. There were several common elements in most applications development projects: they were based on good science, hard work, and the desire to meet the user's needs.

CCRS was clearly innovative in many ways as has been discussed above. One of the basic tenets of CCRS was the concept of what this author has come to call "image understanding." Images must be understood on two levels. Obviously the individual doing the interpretation must "understand" what he or she is looking at. Ideally a forester should be involved in interpreting forest features, while an oceanographer would be working with imagery over the ocean. At a second level, as Tom Lukowski has explained in the text box below, one must understand the image and how it is formed.

Image Understanding[176]
Tom Lukowski

Exploitation of the information available from a remote sensing sensor for applications is best done when there is a clear and detailed knowledge of all of the steps that have been taken to obtain the data which are then used as inputs to further analysis. As might be expected, processing from the raw signal, calibration including (residual) errors, and the resampling and averaging which have been applied can all impact the data that are received by a user for input to further study. To exploit the data in an optimal fashion, the data's "history" should be known as this directly affects the results obtained and impacts the conclusions that can be drawn. This knowledge is especially important in quantitative remote sensing where "meaningful" numerical values are being obtained from the data. For these

[176] Personal Communication Received March 26, 2018.

reasons, there are advantages for remote sensing organizations whose areas of expertise begin at the development of a sensor and progress through the data processing to the exploitation of those data for applications.

Another innovative approach by CCRS was the way in which it carried out cost-benefit analyses and assessed other studies done on the benefits of remote sensing before it actually began developing applications. (Clough, 1972) These assessments identified the areas in which applications work might lead to benefits and also identified the levels of risk associated with many of the applications. The studies continued over many years (Clough 1972; McQuillan, 1973; Clough 1974; McQuillan, 1975a; McQuillan, 1975b; McQuillan and Strome, 1979.) and helped shape work that was being done in an attempt to maximize returns. These studies led to an early interest in applications in ice, agriculture, forestry and land use or land cover mapping.

As interest in climate change and its impacts increased, this too became a topic addressed by CCRS as did issues related to environmental monitoring. At the same time, key issues faced by the government of the day were always kept top-of-mind by CCRS management – and scientists. For example there was an early focus on thermal imagery for assessing heat loss in buildings in response to the energy crisis in the early 1970s. Commercial services evolved out of that activity. Like many of the activities of CCRS and its partners, new uses for remote sensing often surfaced. In the case of the heat loss work, it was later applied by the police to find buildings that were much warmer than neighbouring buildings. The higher level of heat was often an indication that a marijuana grow-op was located in the building. This also led to the first major court case in Canada arguing that remote sensing being used in such a broad fashion was an invasion of privacy. The Supreme Court found that such use in the interest of the public good was, in fact, legal.[177]

One of the innovative approaches that CCRS developed was seen in the Applications Division and how its Applications Development scientists were engaged in projects with users. Scientists were expected to provide expertise in remote sensing to users who had an information need that might be met through remote sensing. This often led to a scientist advising a number of users on a number of projects at the same time. Indeed, some of the key scientists, such as the late Dr. Ron Brown, were involved in two or three high profile projects at the same time. In almost all cases the user ended up being trained in how to effectively use remote sensing, while the scientist learned about the user's topic, broadening the skill set brought to the next project. Since many people from across the country were involved over many years, there was a substantial growth in the number of users of remote sensing from this small but concentrated group of scientists.

Over time, however, there were to be subtle but substantial changes in CCRS's Applications Development and how it worked. This author has identified three factors that came to change Applications Development at CCRS from the mid-late 1980s through to 2002.

The first change factor was that there was a subtle shift in the make-up and job category of staff in the Applications Development Section. Originally Applications Development scientists were in the Physical Scientist (PC) bargaining group of the Professional Institute of the Public Service, while Methodology Scientists were in the Research Scientist or RES group. Being a PC was advantageous during the energy crisis in the early-mid 1970s inasmuch as the PC category was the relatively well paid category of many of those who worked in the energy sector of the department. Over time, however, the potential for higher

[177] In 2004 the Supreme Court of Canada overturned the decision of the Court of Appeal of Ontario which in effect said that the state did not have the right to use forward looking airborne infrared technology to look for marijuana grow operations for to do so was an invasion of privacy. (Her Majesty the Queen v. Walter Tessling: Supreme Court of Canada Docket 29670: http://csc.lexum.umontreal.ca/en/2004/2004scc67/2004scc67.html .

pay was far greater in the RES category[178]. At the same time, some scientists in the RES category transferred from Methodology to Applications Development. Since many of the Applications scientists had PhDs, transferring to the RES category was a relatively simple process, but with significant potential implications.

To advance in the RES category at that time required that scientists publish and play a major role in the research community relevant to their area of specialization. Simply stated, at that time helping users develop applications, or transferring technology to industry, did not earn a person in the RES category a promotion – unless many publications came with that work. As a result there was somewhat more emphasis on doing publishable research, although many scientists were able to work with users and publish, as can be seen in the Sections on Forestry, Agriculture, Geology and Global Change and Environmental Applications where a number of CCRS scientists (e.g. Ahern, Brown, Cihlar, and Singhroy) rose to the highest categories of RES while working closely with users developing operational applications.[179]

Another result of the move to more Research Scientists and fewer Physical Scientists was that the technology transfer arrangement with contractors such as Intera (Section 3.3.3) changed. Originally the idea was that the companies would provide staff members who would support CCRS scientists, gain knowledge and expertise by doing so, and then rotate out to provide a commercial service using what they had learned. With more of a research focus there was a move towards hiring research assistants who were more research oriented and less commercially oriented. It is telling that a number of the early research assistants at CCRS named in Section 3.3.3 (including Mssrs. Kirby, Hornsby, and O'Neil) went on to be senior executives of major corporations, while many of those from after the change often became academics, or scientists or managers in the Federal Government (Lambert, McNairn, Manore, Flett, etc).

The second factor resulted from the massive budget cuts in the 1995 Federal Budget (See Section 4.3 for more detail.) combined with the 1995 launch of RADARSAT. The budget cuts saw close to a 40% reduction in the CCRS budget. This led to the effective demise of the optical airborne program and a reduction of the capital budget to almost zero.[180] At the same time RADARSAT was coming on the scene with a November 1995 launch. The only significant increase in the entire 1994 Budget went to the space program – some $800 million over ten years. (See Section 4.4) Most of the increase was originally targeted for Earth Observation following a successful lobbying effort by industry and a well-written submission prepared by CCRS staff and Industry Canada's Glenn MacDonnell.[181] To achieve the forecast benefits that were expected to come from RADARSAT (St. Pierre, 1989), a concentrated effort was needed to develop radar applications. The Applications Division of CCRS became the primary vehicle for doing so with funds that came from the CSA, while it was also funding from the CSA that kept the CCRS CV-580 radar facility in the air. The majority of funding was directed to radar applications development.

The third factor was the change in focus brought about by the Assistant Deputy Minister of the Earth Sciences Sector in 2002. Up to that time those who worked at the Centre and those who used the services

[178] Ryerson began as a PC-3 which at that time had the same salary as a RES-3 – then the second highest level of the Research Scientist class. In 2013 the top of the PC-3 was $93,989, while the top of the RES-3 was $109,760 and the top of RES-4 (now the penultimate category for the RES) was $121,834. These relative differences have existed since the 1980s. With a minimum 17% to 30% difference, and the potential to reach a RES-5 level with a top-end salary of over $133,000, the rationale for scientists to choose the RES category over the PC was clear and understandable.

[179] Dr. McNairn reached the same high level after joining AAFC.

[180] As is discussed elsewhere, the cut to the capital budget came back to haunt CCRS in that it was unable to refurbish its ground stations or invest in new technology or the companies that might have made new technologies as they had before.

[181] The amount set aside for EO was eventually lowered after President Clinton asked that budget for the Space Station to be increased. How these budgets came to be submitted as they were is an interesting subject, but unrelated to CCRS.

and advice of the Centre were always clear that the mandate of CCRS as stated in the Cabinet Document (and later in legislation) was to be the CANADA[182] Centre for Remote Sensing. It was to meet the needs of Canada. CCRS did so through joint projects with a number of Departments and agencies and other levels of government as described previously and in the following sections. In the 2002 to 2003 timeframe the Assistant Deputy Minister of the day insisted that CCRS should focus only on those areas that fell under the mandate of the Minister of Natural Resources. At least in terms of Applications, CCRS became the "Natural Resources Centre for Remote Sensing" and a number of key scientists in the areas of ice, oceans, agriculture, and environment left the organization. A new strategic plan aimed as re-invigorating CCRS as a national centre was developed in 2004 by the Director General of the day (Ryerson) working with representatives of industry and government. The plan was not implemented after his departure in early 2005.

6.6.2. Applications Development in Forestry
Frank Ahern and Carolyn Goodfellow

6.6.2.1. Introduction
When the Applications Division was first established, forestry was considered one of the key applications. The Applications Development Section (ADS) quickly established linkages with the Canadian Forest Service, which was part of Environment Canada at the time. Our aim was to enable it to carry out its mandate in forestry. Two important contacts were developed in the early 1970s, with the Forest Fire Research Institute (Peter Kourtz), and with the Forest Management Institute (Leo Sayn-Wittgenstein, who eventually became a Director General of CCRS). Dr. Kourtz partnered with Dr. Martin Taylor of the Defence and Civil Institute of Environmental Medicine (DCIEM) in Toronto to develop specialized ways to enhance Landsat MSS data based on DCIEM knowledge of human visual perception.

Contact with Dr. Sayn-Wittgenstein resulted in much greater understanding at CCRS of how forests in Canada are managed, and how foresters work from high resolution black-and-white aerial photography, at scales ranging from about 1:10,000 to about 1:40,000, corresponding to resolutions of about 10 cm to 40 cm on the ground. By contrast, the Landsat MSS technology had four spectral bands, but a ground resolution of 80m! It was immediately apparent that it would require considerable effort to find a forestry niche for Landsat. However, Dr. Kourtz' enthusiasm and research results provided encouragement. He was able to develop an application for Landsat MSS data in characterizing fire danger and creating fuel maps for large areas that could not be done with existing technology. Kourtz also demonstrated the importance of close and continuing relationships with end user agencies in getting the new technology adapted to their working environment and accepted for operational use. Kourtz' model was emulated at CCRS.

In 1979, the Canadian Forest Service moved the Forest Fire Research Institute and the Forest Management Institute to Chalk River, Ontario, to become part of the Petawawa Forest Research Institute. Dr. Kourtz moved with his organization, while Dr. Sayn-Wittgenstein formed a private company, Dendron Resource Surveys, with two fellow researchers Alan Aldred and Udo Neilsen, and remained in Ottawa. Shortly thereafter, a younger research scientist, Dr. Don Leckie, was brought to PNFI and eventually became the lead researcher in forestry applications of remote sensing. With Dr. Leckie, CCRS enjoyed a very close and collegial working relationship with CFS, which continued after PNFI was closed in 1995 with the remote sensing group moving to the Pacific Forest Research Centre in Victoria.

6.6.2.2. Getting Started
In the 1970s and early 1980s, several researchers from the Canadian Forestry Service used the CCRS Image Analysis System (CIAS) to analyze digital remote sensing images of forests in different regions of Canada, e.g., Jean Beaubien from the Laurentian Forestry Centre, Ron Hall from the Northern Forestry

[182] Author's emphasis.

Centre, Jim Lee from the Pacific Forestry Centre, and Peter Kourtz from the Petawawa National Forestry Institute. Prior to their CIAS sessions, a CCRS Applications Division scientist met with them to provide information on different digital methodologies applicable to their objectives and assistance with specific aspects of their image analysis projects when needed. During the sessions, a CIAS analyst operated the CIAS. This research led to several early forestry applications of digital satellite imagery – digital updating of forest roads, monitoring of new clear cuts and forest fire burns, detection of insect damage, in particular the spruce budworm in Quebec, and estimates of forest fire fuel loads.

The project Télédéection-Foresterie Québec was first proposed at the annual meeting of CACRS in 1977 by the Association québecoise de télédétection. The objective was to demonstrate the capabilities and limitations of remote sensing (LANDAST and high-resolution air photography) for existing cartographic requirements of the Service d'inventaire forestier. Project participants included the Laurentian Forestry Centre, Laval University, CCRS and three groups within the Ministry of Lands and Forests (MTF): the Quebec Centre for Coordination of Remote Sensing, the Forest Inventory Service, and Research Service. Some results were reported at the 2ième and 3ième congrès de l'Association québecoise de télédétection (1979, 1980) – mapping forest roads from Landsat and updating forest maps at 1:20,000 from high-resolution air photography and Landsat. During the project (1977-1981), it became clear that access to digital image analysis equipment and training was hindering progress in Quebec, and that more effort and resources needed to be allocated to engage all partners in the project, especially the operational end users.

In 1977-78, the Inventory Branch of the B.C. Ministry of Forests (BCMF) was in the process of upgrading their existing forest inventory system. They were converting from the imperial to the metric measurement system, and entering the forest inventory data into their newly acquired Interactive Graphics Design System. The new system would facilitate data management and regular updating of their more than 7000 forest cover maps. Frank Hegyi and Robin Quinet, senior managers in BCMF, analyzed several Landsat images on the CIAS to better understand the potential for incorporating information derived from remote sensing data (grid-based data) with the new BCMF interactive computer graphics system. In 1980 Carolyn Goodfellow spent two months working in the Inventory Branch to gain some familiarity with their functions and to study the procedures for updating the inventory data base and the flow of information to and from the regions. (Harvie and Goodfellow, 1982) Her report described the potential role for satellite remote sensing in meeting Inventory Branch requirements and provided details on new forest cover data base structure and operation. In addition, she selected Landsat MSS images for 1975 and 1979 for B.C. for regional environmental monitoring. Unfortunately there were no cloud-free satellite images for some areas of B.C. CCRS also provided airborne MSS data for two test sites. The cooperative relationship between CCRS and the Inventory Branch continued for many years

In addition to the work with BCMF described above, several researchers undertook projects with the CIAS that resulted in significant contributions to the body of knowledge at the time, but most were not in a position to invest the time and effort to see their advances through to operational applications. Simsek Pala of the Ontario Centre for Remote Sensing (OCRS) in Toronto consulted with CCRS and initiated the development of forestry applications for Ontario. OCRS became one of the first purchasers of the Dipix Image Analysis System, a made-in-Canada commercial follow-on to the CIAS. That purchase provided a great leap forward for both OCRS and Dipix, and enabled OCRS to become something like a mini-CCRS for the Province of Ontario. With their technical capability and several able and enthusiastic researchers in addition to Pala, resource management agencies in Ontario became early adopters of satellite remote sensing applications.

In one unusual development, two of the I-100 image analysists did some research on their own (with the approval of Bob Ryerson), and made a finding valuable for forestry. Al Banner (who later worked at Dendron) and Tim Lynham (who subsequently had a productive research career at the CFS Great Lakes Forestry Centre) worked with the CIAS to develop a change-detection technique that facilitated the visual delineation of clearcuts using before and after images. (Banner and Lynham, 1982)

Ahern transitioned to ADS in 1981 to maintain involvement with "real world" users, and became the lead scientist responsible for applications in forestry. Data had been acquired in Nova Scotia with an airborne multispectral scanner flown by the Data Acquisition Division in 1980. Images were obtained at spatial resolutions of 20 and 5 m, and these were resampled to several different pixel spacings using several different resampling techniques. They were also used to simulate data from the upcoming Thematic Mapper sensor (see next section). These were evaluated by personnel supervised by Ed MacAulay at the Nova Scotia Department of Lands and Forests. This work resulted in valuable guidelines for subsequent developments in data acquisition instrumentation and image processing. (Ahern *et al*, 1983)

6.6.2.3. The TM Breakthrough

Landsat-4 was launched in July 1982 with great excitement, because the new Thematic Mapper[183] scanner was a major advance over the earlier Multispectral Scanner. The spectral bands were increased to seven in number, with narrower and more carefully-positioned bandwidths. Compared to Landsat MSS, the spatial resolution was increased from 80 m to 30 m for the same image field of view (185 km wide), and the radiometric resolution was increased from 64 to 256 gray levels. These advances were expected to increase the utility of the data dramatically for forestry, and indeed they did. However, a great deal of work was needed in Canada to realize the potential.

Landsat-4 returned very little useful data for Canada in its first year because most of the summer of 1982 was used for commissioning the satellite, and in February 1983 the direct downlink system failed. Data could be sent to US receiving stations using the Tracking and Data Relay Satellite System, but very little data of Canada was available. However, some early data gave CCRS' Data Processing Division the opportunity to understand, model, and correct various systematic errors introduced by the sensor itself (see section 6.8.2.5.1.).

Because of the problems with Landsat-4, Landsat-5 was launched ahead of schedule, in March, 1984. It became the workhorse of the Landsat program, providing data for nearly 30 years.

ADS work on simulated Thematic Mapper (TM) data began in 1982 by using CCRS airborne Multispectral Scanner data from Nova Scotia (Horler *et al.*, 1983), which identified a preferred colour assignment of TM band 3 (red) assigned to blue, TM band 4 (near infrared) assigned to green, and TM band 5 (shortwave infrared) assigned to red. Early work continued with a rapid assessment of actual TM data acquired between 1982 (a fall scene with Landsat-4) and 1985 in New Brunswick, Ontario, Alberta, and British Columbia. (Ahern and Archibald, 1986) This showcased improvements in mapping forest clearcuts, roads, and powerlines compared to the MSS. The new shortwave infrared capability of the TM sensor was found to be particularly effective for detecting insect damage (spruce budworm in the east and Mountain Pine Beetle in the west), as well as for mapping the intensity of burns. Regeneration after logging and fires could be detected and approximate regeneration success assigned, suitable for ecological studies but not with the detail needed for commercial forest operations.

This preliminary investigation led to professional contacts in New Brunswick, Ontario, Alberta, and British Columbia and a greater appreciation of the forest information needs at the provincial level. This work also demonstrated the value of working directly with the people managing the forest resources. The initial investigation was followed by a number of more specific projects to address the identified forest information needs.

[183] Thematic Mapper is a strange name for a multispectral scanner. The idea at the time was that computer technology would advance to the state where the radiometric data collected by the satellite could be converted directly to thematic maps, possibly directly on-board subsequent satellites. For various reasons, that goal has still not been realized.

6.6.2.4. New Brunswick, British Columbia, and Alberta

To be most effective in getting the new earth imaging technology adopted, it was apparent that our efforts should be directed toward provinces that were the most interested in adopting advanced technology. By the 1980's GIS technology was becoming a major interest for provincial forest management agencies. GIS appeared to offer many benefits over the vast stores of large paper maps (typically at a scale of 1:20,000) used up to then, to enable forest management decision making. It will probably seem amusing to today's and future generations, to learn that many university students were put to work colouring paper maps as their summer jobs in provincial (and private) forest management agencies.

However, GIS technology was expensive, required a massive change in worker skills, and seldom lived up to the vendors' promises. Many provincial forest management agencies were understandably cautious. Two provinces stood out as leaders in the adoption of GIS technology, New Brunswick and British Columbia. Each of these had a technology champion, Dr. Thom Erdle in NB and Frank Hegyi in BC. Needless to say, in many other respects, forest management in these two provinces was a vastly different problem with very different approaches. New Brunswick is small, and the provincial crown land is even smaller, with the K. D. Irving Company privately holding nearly 1/3 of the forest area. Erdle was innovative in forest management approaches for New Brunswick as well as in the adoption of GIS technology. GIS enabled some of his advanced planning innovations (notably growth forecasting) when fully implemented. New Brunswick had selected the ESRI Arc-Info system for its GIS, but was relatively unaware of the potential of satellite remote sensing technology.

British Columbia has large forest areas of high-commercial-value: forestry has always been a centerpiece of the BC economy. Frank Hegyi, as Chief Forester, had selected a GIS derived from the Intergraph CAD/CAM system for implementation, and had committed to maximum use of Landsat data.

Finally, Alberta was chosen as a province for detailed research because of the good relationship and support that existed between the Alberta Remote Sensing Center and CCRS as a result of the rangeland efforts described in section 6.6.3.7 and other joint projects.

In New Brunswick, CCRS was able to support Erdle's efforts at DNR by providing geometrically-corrected TM data to be used in conjunction with the Arc-Info GIS. A persistent problem that took a long time to resolve was the incompatibility between vector-based systems used for GIS and raster-based systems used for remote sensing imagery and classified products. A conceptually-simple approach was to use a remote sensing image with good radiometric and geometric corrections as a backdrop for "heads-up" digitizing. In many cases a human interpreter could (and often still can) to a better job of extracting needed information from a remote-sensing image than any computer code. If the image can be displayed as a backdrop, and the interpreter provided with tools (often just a mouse) to create and edit vectors, vector information appropriate for the GIS can be easily produced. Unfortunately, the marriage between vector and raster took the better part of a decade, and the delay hindered efforts to introduce TM data in many applications.

Research efforts that CCRS made in New Brunswick centered on the problem of the loss of timber to spruce budworm damage, and the resulting changes in harvest planning that these losses entailed. CCRS/ADS initially devoted research efforts using airborne (MEIS) data to map annual current defoliation. (Ahern *et al*, 1991a) When it became apparent that the airborne technology was not soon going to be available, Landsat TM data were investigated to determine whether the long-term effects of spruce budworm damage could be assessed. This project showed that calibrated TM data could be used to determine growth loss in stands affected by the spruce budworm. (Ahern *et al.*, 1991b) It should have been relatively easy to transfer this technology to the New Brunswick Department of Natural Resources. However, the Canadian Forest Service insisted that the technology transfer be done through a small facility they had established in Edmunston. For various bureaucratic and personnel reasons, the transfer was never successful.

In British Columbia, ADS helped ensure a consistent flow of high quality radiometrically and geometrically corrected TM data to the BC Forest Service. This was aided by a close working relationship with MDA in Richmond, BC, who produced the digital processing systems for TM data. In particular, it was possible to quickly incorporate upgrades that resulted from CCRS investigations. We first worked with BCFS to document the accuracy they could expect when updating forest inventory maps for clearcuts. (Archibald and Ahern, 1985)

Subsequent research focused on a serious problem in BC: the growing mountain pine beetle infestation. While research with satellite imagers (including the new SPOT-HRV sensor) demonstrated the ability to detect infested areas where extensive mortality had already occurred (Ahern and Archibald, 1986; Sirois and Ahern, 1988), the primary interest of the BC Forest Service was "pre-visual" detection of so-called "green-attack." The idea was to enable foresters to remove infected trees before the young beetle moths moved to adjacent trees. Our research into the foliar spectral reflectance trees clearly showed significant differences in the reflectance of new shoots of attacked vs unattacked trees. (Ahern, 1988) However, a sensor with a resolution of a few centimeters would have been needed, and such a sensor would detect far more infected trees than the Province could cope with.

In the province of Alberta ADS established a relationship with the Department of Natural Resources, through the help of the Alberta Remote Sensing Center, and with the CFS Northern Forest Research Centre in Edmonton. An extensive test area was established near Whitecourt where numerous investigations were carried out. These included:

- Updating forest inventory maps (paper and digital) for clearcut logging and burns;
- Assessment of regeneration; and
- Distinguishing trembling aspen from balsam poplar.

As well there were some other studies on applications judged to be less important.

Our contacts with provincial forest departments rapidly showed that updating forest inventory maps would be the application with the best overlap between user needs and satellite capabilities. The actual forest inventory required far more detailed data than satellite imaging could provide. But forest inventories become outdated very rapidly, thus requiring frequent (often annual) updating. The greatest need was for the most dramatic changes: road construction and clearcut logging, burns, large areas of insect mortality, and other disturbances. While some disturbances, particularly seismic line cuts (important in Alberta) could not be mapped reliably with the 10 m (SPOT) to 30 m (Landsat) resolution, the majority could be. The SWIR bands of Landsat-5 were found to be particularly effective for detecting burns and insect damage. (Ahern and Archibald, 1986; Ahern *et al.*, 1991b) Roads and clearcuts were clearly visible on Landsat and SPOT images, but we put considerable effort into a careful assessment of the accuracy with which clearcut boundaries could be mapped in order to ensure the technology could meet the users' requirements. (Ahern and Archibald, 1986) We also researched the ability of satellite sensors to detect mortality from the spruce budworm in New Brunswick (Ahern *et al*., 1991b) and from the mountain pine beetle in BC (Sirois and Ahern, 1988), with positive results.

We worked closely with the forest ministries in New Brunswick, British Columbia, and Alberta to try to see our results through to operational implementation. There was very good uptake in New Brunswick and British Columbia, but in Alberta we met with difficulty. The problem seemed to be that the provincial government in Alberta was always reorganizing and changing linkages and mandates. The civil servants seemed reluctant to make any major changes because they were never sure what would happen next.

Our early investigations with Thematic Mapper data made us optimistic that we could use the data to track regeneration. As clearcuts regenerated, there was a distinct colour progression, and it was possible to distinguish situations where desirable coniferous trees were being replaced by undesirable broadleaf trees. However, when we visited regeneration sites with provincial foresters, we found that they needed detailed information during the first 15 years following logging. Satellite data could not provide the information they needed, though we had some promising results with the MEIS sensor. (Kneppeck and Ahern, 1987)

The problem of distinguishing trembling aspen from balsam poplar was of interest in Alberta but not in New Brunswick or British Columbia. With the close similarity of the trees, their canopies, and their leaves (both are members of the genus *populus*), we were not optimistic. We designed and carried out a rigorous study, using both TM and MEIS data, but did not achieve satisfactory results.

6.6.2.6. Getting Ready for RADARSAT

As the 1980s drew to a close, CCRS became more and more focused on the RADARSAT-1 mission. Through a combination of CSA-funding and managerial directive, research efforts were moved away from optical sensors and towards SAR sensors, with the objective of knowing as much as possible about proposed RADARSAT-1 applications.

Research began using airborne sensors that were operated by JPL (Way *et al*., 1988) and Intera (Dams *et al*, 1990), followed by data from European and Russian SAR satellites (Ahern and Raney, 1993).

The advent of the CCRS airborne multi-polarization C-band SAR-580 enabled research to be more closely aligned with RADARSAT-1 needs, as well as providing some insight into what might be expected from the polarimetric SAR proposed for RADARSAT-2. Progress was rapid, with numerous experiments and publications expanding our knowledge immensely. (Ahern *et al*, 1993a and b; Banner and Ahern, 1995a and 1995b; Landry *et al.,* 1995; Ahern *et al*., 1996)

The upshot of all of this work was that there was little prospect for RADARSAT-1 data being used in significant quantities for forestry needs in Canada. The primary obstacle was the success we had had using Landsat and SPOT data. The spatial resolution of RADARSAT-1was similar, but it only had one band. The ability to "see" through clouds was not a real advantage, since one optical image per year would usually be sufficient for foresters' needs. More importantly, the basic physics of the microwave interaction with the target provided fundamental limitations in distinguishing different targets of interest. Even roads and clearcuts could be poorly mapped if roads were rough or if there was a lot of slash in the clearcuts. The advertised "all-weather" capability of RADARSAT was not technically correct in forests. Contrast between forested and open areas was very high during the spring melt season with wet snow, fairly low (by radar standards) most of the year, and decreased even more when the area being imaged was wet with rain. (Ahern *et al*, 1993 a and b) Don Leckie of the Canadian Forest Service researched this topic extensively and wrote several publications including a chapter in the ASPRS ***Manual of Remote Sensin.g*** (Leckie and Ranson, 1998, Leckie and Walsworth, 2019)

As a result, we turned our efforts to develop forestland applications for RADARSAT-1 in the tropics. This work is described in detail in Section 3.6.4.

6.6.3. Agriculture and Land use
Bob Ryerson[184], Heather McNairn and Frank Ahern

6.6.3.1. Introduction

6.6.3.1.1. Setting the Stage: Cost-Benefit Studies

The cost-benefit studies done in both the US and Canada showed significant benefits from more timely and more accurate crop reporting. A US study suggested that the value of an improved "world-wide wheat forecast" could be as high as $114 million (in 1971 US$). (Interplan, 1971) Clough (1972) concluded that given the importance of wheat, the benefits to Canada of a better system would be significant. Woodward (1974) outlined the importance of accurate crop forecasting, especially in the developing world. He noted that while demand is relatively easy to forecast, the forecasting of supply or production isn't. It was assumed that remote sensing would be useful in assessing production.

Clough (1974) addressed the question of crop supply forecasting by developing a model to assess the relationship of the price for wheat to supply, exports and carryover – the amount of crop carried as inventory from one year to the next. This in turn led to better understanding the potential value of more accurately prediction of crop production. His conclusions were prescient and, in effect, laid out what in retrospect seems to have been a blueprint for remote sensing applications development in agriculture and related work for several decades into the future in Canada. [185]

Clough's summary conclusion was that developing a new crop information system better able to predict production, soil moisture and biomass would be worth the expenditure. In his detailed conclusion he stated that the system "should be aimed at: (1) improved domestic surveillance, statistical reporting and surveillance; (2) developing better domestic crop weather forecasting models for application before and during the growing season; (3) developing domestic applications of remote sensing for pre-season soil condition and growing season crop condition surveillance; (4) developing better econometric market models; (5) improving existing international surveillance, statistical sampling and reporting; (6) developing better global crop-weather forecasting models for application before and during the crop season; (7) developing international cooperative schemes for the exchange of global remote sensing data concerning soil and crop conditions; and (8) integrating all of the subsystems for fast and reliable reporting. " (Clough, 1974, p 465)

Given the importance accorded agricultural information and land use mapping in cost-benefit studies (Clough, 1972, 1974) it should not be surprising that in 1973 the first Senior Environmental Scientist hired in Applications Development (Bob Ryerson) and one of the three Research Scientists hired in the Methodology Section (Fred Peet) had an interest in agriculture and land use mapping. These were the first topics addressed in the CCRS Applications Division.

6.6.3.1.2. The Management Push

The importance of crop and rangeland information to CCRS management at the time is clearly shown in the following text box. It also further explains the emphasis placed on crops and rangeland in the Applications Division from the mid-1970s to the early 1980s. The space devoted here to agriculture is in part a reflection of that importance as well as the access the author has to information.

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[184] Section 6.6.3.6 was written by Dr. Ahern and Section 6.6.3.9 was written by Dr. McNairn. Ryerson authored the rest of Section 6.6.3.

[185] Clough's conclusions could well have been the blueprint for the US programs LACIE and AgriSTARS – see Section 6.6.3.4.

Produce Working Methods…or we will find other scientists who can…
Bob Ryerson

At one point in the mid-late 1970s it was decided by CCRS senior management, after prodding from CACRS and certain world events, that crop area estimation and rangeland assessment were key applications for Canada. The scientists involved in this area were called to a meeting in the board room of our offices at 717 Belfast Road and challenged by the Deputy Director General to either develop methods to do this … or "we will find scientists who can." Given that our division chief had been replaced a year or two before, we took the "encouragement" quite seriously! In the end the objectives were met and successful methods were developed. The approach to monitor rangeland, whether green or standing brown biomass, worked wonderfully well and won an award for Drs. Ron Brown and Frank Ahern for the English speaking world's most outstanding paper in remote sensing in 1983. (Brown *et al*, 1983.) Other recognition and awards came from other crop-related work. CCRS worked with Statistics Canada to produce the first real-time pre-harvest operational crop area estimation done anywhere, and an operational crop monitoring system was developed with and for the Canadian Wheat Board. The latter eventually became a key activity of Statistics Canada that resulted in a government-wide award. (See Section 6.6.3.5.)

6.6.3.1.3. The Influence of Marketing on Agricultural Remote Sensing

The first major marketing initiative was a re-assessment of the market for agricultural applications of remote sensing. After several years of effort on wheat, a number of questions were raised about the market for remote sensing to provide information on other crops. This led to the examination of the so-called specialty crops including crops such as potatoes, beans, sugar beets, corn, fruit, other vegetables – all crops other than grains and oil seeds. At the time specialty crops accounted for 12% of farm cash receipts and 25% of receipts from crop production. (Statistics Canada, 1975) At that time these higher value crops tended to have higher input costs (seed, fertilizer, insect and disease control, storage, packaging, etc.), were more susceptible to disease and insects, had a short storage life (leading to the need to better match annual supply and demand), and highly fluctuating prices and acreage grown.[186] In addition, except for potatoes and corn, specialty crops were often in competition with imports, leading to fluctuating prices when imports and local production overlapped. Specialty crops were often harder to sample and inventory because of smaller farm and field sizes, the combination of production being both concentrated in small geographic areas as well as being widely dispersed. Furthermore, some of the crops grown for urban markets are often grown on land more susceptible to development. The lack of uniformity of crop cover within fields, field sizes, and intercropping led to the conclusion that methods developed for inventorying or monitoring crops such as wheat would not work to generate the information needed for specialty crops. This suggested a need for higher spatial and spectral resolution, timely processing, availability of cloud-free imagery at the right time, accurate final estimates, and low cost of using remote sensing to supplement existing methods – not replace them. (King, Mosher and Ryerson, 1977)

Two more formal market-focused studies of Agricultural data needs were carried out by CCRS in 1978 and 1980. The first study involved interviewing over twenty agricultural specialists to determine what data they needed and why. Included was John Benci the Director of Weather and Crop Surveillance of the Canadian Wheat Board, representatives of several specialty crop marketing boards, and officials involved in agriculture in PEI (Mr. N. Stewart), New Brunswick (Dr. P. Mosher), Ontario, Alberta (B.R. Shaw). (Ryerson, 1979) The two studies in PEI and New Brunswick opened up several new areas of research and development, involving a number of those interviewed. Many of the resulting projects are reviewed in Section 6.6.3.8.

[186] For example the Census reported that dry field bean area in Ontario went from 49,299 hectares in 2001 to 61,775 in 2006 and then down to just 37,477 hectares in 2011. (OMAFRA, 2017)

In the 1979 study users were engaged. The engagement of the users was noted by Brown *et al* (1981) as the missing element in much of the work that had been done to that point on crops – most notably the authors were referring to the work on wheat. “In spite of the substantial evidence showing the potential contribution of satellite data to crop production estimation, there has been little actual utilization of these data in operational crop prediction systems in Canada. The major reason responsible for this situation appears to be the gap between groups having R&D-only mandate such as Canadian Department of Agriculture’s Research Branch and agencies having operational only mandate (e.g. Canadian Wheat Board.” (Brown *et al*, 1981, p.1)

Brown *et al* (1981) then identified three crop-related uses of remote sensing: to aid in marketing, improve production and to assist in research. For each of these uses information needs were identified, as were availability of data, existing methods of analysis, and current operational use. They concluded that operational agencies wanted to see the demonstration of the cost effectiveness and accuracy associated with the use of remote sensing. As a result, CCRS developed project ideas that led to the work on the Crop Information System and that with Statistics Canada described in Sections 6.6.3.5 and 6.6.3.6.

6.6.3.1.4. Introducing the Projects

Over time the work produced in the Applications Division was among the best in the world and won a number of major awards into the 1990s and early 2000s. As described in the introduction to Section 6.6, agricultural work basically ceased in the 2002-2004 time frame, although some land cover mapping continued in as much as it was considered to be related to forestry, climate change and/or water resources – all related to the Minister’s mandate. At that time Ryerson was Director General and McNairn left to join Agriculture Canada.

The following Subsections describe the major suites of projects along with a short description of the US LACIE and AgriSTARS programs to provide some international context. The first two – the Wheat Project and Land Use Mapping – are presented first and they did begin before the others. The next projects detailed in separate sections are Crop Information, Crop Area Mapping with Statistics Canada, and Rangeland Mapping. These were all high profile and highly successful projects.

Section 6.6.3.8 provides project descriptions of a number of projects from what we think of as the early years (or pre-Radar years) of remote sensing. Some of these smaller projects fed into the more important projects and some were simply a response to a request for advice. The overlap in timing between these and the larger projects again underlines the approach taken within CCRS in the early days – one CCRS scientist would often work on four or five projects simultaneously, each with a different user or agency.

6.6.3.2. The Wheat Project

The first major agriculture project at CCRS was undertaken by the late Dr. Fred Peet[187] of CCRS working with the late Drs. Alec Mack and Dr. Lorne Crosson of Agriculture Canada. The project, which began in 1973, was “to estimate total crop production from ERTS signals and supporting data such as soil type, rainfall and historical information.” (Peet, Mack and Crosson, 1974) Multiple dates of data were acquired over eight test sites in western Canada comprising over 1000 fields. Several classifiers were used and even the simplest achieved results that were considered acceptable on a field-by-field basis. Accuracies ranged from 92 to 96% for a combined class of barley and wheat, summer-fallow and rapeseed. These results were also given at the 1973 ***Third ERTS Symposium*** sponsored by NASA. The early success in this project in discriminating rapeseed (which was re-named Canola after new varieties had all but

[187] Dr. Fred Peet was born and raised in Saskatchewan and was himself the owner of a small farm. As a student it happened that he was employed at what became the Prince Albert Satellite Station. After leaving CCRS in the mid-1970s, he later joined the Pacific Forest Research Centre and was not in remote sensing for a time. During this period he was one of the first in the world to develop, under the name of Eidetic Digital Imaging, a PC-based software system for image analysis.

eliminated erucic acid) led to further work on this crop with Statistics Canada, reported here in Sections 6.6.3.6 and as part of the spectroscopic work by CCRS reported on in Section 6.6.3.8,

As part of the same project, ERTS-1 data were assessed for soil and crop type discrimination in the Dark Brown Soil Zone near Delisle, Saskatchewan. (Crosson, Peet and Wacker, 1974) The work was "partially successful" in separating soil types and not very successful in identifying crop types using early June imagery. Not surprisingly, crop separation improved as the growing season progressed. Field classifiers were suggested as a means of improving accuracies.[188]

When assessing satellite data for estimating winter wheat area in Southwestern Ontario, results were said to be less reliable. The area had smaller fields and more numerous confusion crops. One of the conclusions was that aerial photography would be useful to identify field boundaries which in turn would allow better field-by-field discrimination. (Philpotts, Mack and Peet, 1974)

By 1975 it was widely recognized that the real value of improved crop information is found in those countries that did not have (as Canada did and does) a strong statistical crop reporting service. To this end further study of the 1973 satellite data was done to assess crop separability based on reflectance. (Crosson, Peet and Read, 1975) The conclusions reached were not promising: separation of the key crops based on reflectance was not consistent, even when using multiple dates. Crop separability depended on many more factors than the theory had indicated.

By 1977 Dr. Peet had left CCRS and the work continued on through various partnerships established by Dr. Mack, including work with the late Dr. Jane Schubert who had been a senior scientist in the US remote sensing program. (Mack, A. *et al*, 1977) While the Wheat Project was not fully successful it did show some useful points of departure and areas for further investigation for following projects.

The many lessons learned included the knowledge that the theory of "crop signatures" did not always work in practice. Unique crops do not always have unique signatures – at least not in the bands of the spectrum made available in satellite data at that time or, for that matter, in almost all of the systems available since Landsat-1. The value of thorough field work was, however confirmed, as was the importance of understanding the cropping systems that one was investigating. The potential of field classifiers had been shown, as had the variability within and between individual fields. Between and within field variability were to eventually prove quite useful in later studies, including ones not at all related to traditional remote sensing.

In these early projects the seeds were also laid in the minds of those involved in agricultural remote sensing in Canada to use the satellite data in an integrated fashion as part of more traditional statistical surveys, rather than working in a research environment in isolation or competition with traditional approaches used by Statistics Canada, for example. (Brown *et al*, 1981) Perhaps the most important of the lessons learned was simple: producing and handling the hundreds (if not thousands) of Landsat scenes needed to cover western Canada was an operational challenge to which no-one had found a solution. As the Landsat program became more operational and as cost-recovery and commercial entities began to supply data, the challenge became not just greater, but impossible. The cost of supplying the necessary multi-date Landsat scenes at upwards of $3000 each made the data acquisition costs to do just crop estimation in Western Canada far greater than the entire budget for all agricultural production reporting in Canada.

6.6.3.3. Land Use Mapping

6.6.3.3.1. Introduction

Land use and land cover mapping were identified as areas where remote sensing, both airborne and spaceborne, could be usefully applied with significant benefits. Aerial photography had already been

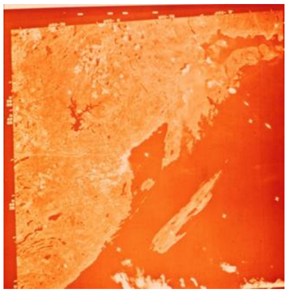
[188] Field classifiers considered all pixels in one field together, rather than assessing individual pixels.

used for many decades to map land use and land cover. Guidelines for accuracies, classification schemes and the like had long been established by Clawson. (Clawson, 1965) The difference between land use and land cover is simple: when mapping land use, one maps what the land is used for. As an example, land may be covered or partially covered by trees (the land cover) and yet used for recreation (such as a park) or for something else (such as a cemetery). Mapping land use requires a more complex set of decisions by the interpreter than general land cover. Of course, as noted in the previous section on forestry, as one delves into the sub-classes in any specific land cover, the complexity also increases.

Mapping land use was one of several areas where satellite technology was oversold in the early-mid-1970s: the capabilities of the early systems available failed to meet expectations. As a result, the uptake of satellite imagery for land use mapping was much slower than was originally anticipated by some proponents. The expertise of the initial Applications Development staff at CCRS – all of whom had published, presented, or been involved in such mapping before joining CCRS – led to a more practical approach that tended to focus on realistic applications. That focus on practical applications and the higher quality imagery produced in the late 1970s (See Section 7.7) in turn led to a slow but steady increase in applications of remote sensing for both land use and land cover mapping in Canada.

Almost Getting in Trouble over Land Use Mapping
Bob Ryerson

At the Canadian Association of Geographers meeting in Vancouver in 1975 I presented a paper on a suggested land use classification. After the presentation I was asked if I thought that Landsat data would have any value in urban planning. During the presentation I had shown some images – one of which was a fuzzy, early image of Thunder Bay. I referred back to the image of Thunder Bay at the right (on which the city of Thunder Bay looked very much like a very large forest clear cut) and said "It would have no value – on the image I showed you can't tell the difference between Thunder Bay and a forest clear cut without a road map." The person posing the question then asked about its use in a larger city like Vancouver. My response was "Sure it would be very useful – if you ever lost the city of Vancouver you could probably find it on Landsat." Unfortunately these quotes made it back to Ottawa where I was asked to explain my "negative attitude." Luckily I was able to do so to the satisfaction of Larry Morley – who once again proved he had a great sense of humour and (usually) a gentle management touch.



6.6.3.3.2. Great Lakes Land Use Mapping

The first major land use/land cover mapping project at CCRS was the Great Lakes Land Use Mapping Project done for Technical Committee B, Great Lakes Pollution from Land Use Activities Reference Group of the International Joint Commission (IJC). The IJC had been asked by the Governments of Canada and the US to conduct a study on pollution of the boundary waters of the Great Lakes system caused by agriculture, forestry and other land use practices.

In August of 1973 CCRS scientists Dave Goodenough and Bob Ryerson were asked to attend a briefing on the IJC's need for the inventory. As Government of Canada scientists they were asked to comment on a proposed approach presented by an American university-based group. As recalled some years later the US group suggested that they could provide highly accurate maps for the entire basin (both Canada and the USA) for under $75,000 using "automatic" digital analysis of ERTS-1 MSS data. Having seen some of the early ERTS data (Goodenough) and having done some mapping with high altitude small scale aerial photography (Ryerson[189]), Goodenough and Ryerson were of the opinion that the US approach would not work and so informed the Government of Canada.

[189] Before joining CCRS, Ryerson used the high altitude aerial photography acquired by CCRS on a contract to map land use in the area of the proposed Pickering Airport

CCRS and the Lands Directorate of Environment Canada were then asked to develop an alternative approach for Canada. The development of this "hybrid" approach was a combined effort of Messrs. Ryerson, Alföldi and Thie of CCRS and Dave Gierman, Bill Switzer and Terry Fisher[190] of the Lands Directorate. All data were to be ingested into the Canada Geographic Information System (CGIS) so that outputs by watershed could be produced. In the areas that were more highly urbanized visual interpretation was done using high altitude normal colour aerial photography acquired by CCRS in 1971. In the agricultural areas the 1971 Census of agriculture was used to determine crop types and insert those values into maps of census tracts, while the Canada Land Inventory (CLI) provided the information on other uses in the southern rural areas. All of this information was assembled by overlaying the different data layers on a watershed map within the CGIS. Older imagery and information were considered adequate inasmuch as the errors were judged to be less than what was anticipated with the digital approach. The northern non-urban and non-agricultural areas were mapped using visual interpretation of Landsat-1[191] data. With all of these data current land use maps could be constructed and estimates of urban growth by watershed could be made based on the existing size of the urban areas and projected future growth. (Gierman and Ryerson, 1975; Gierman *et al*, 1975) This was the world's first large area project where information derived from existing map data, satellite data, airborne data, and census data were incorporated together in a GIS.

As it turned out, the US portion ended up costing far more than was originally anticipated and accuracies were far lower than promised. One of the telling aspects was that one of the land use classes in the US was cloud shadow and another was cloud! And it got worse. When a Washington-based geographer attempted to use the maps to make population projections it turned out that an unexpectedly large population was projected for northern Minnesota. With automated interpretation it happened that the bare rock in open pit mines in the Mesabi Iron Ore Range was classified and mapped as urban – since their signatures were similar to urban areas to the unsophisticated MSS sensor. Cities not much smaller than Minneapolis-St. Paul had popped up in the wilderness. The result re-emphasized the need for adequate ground data <u>and</u> the involvement in the interpretation of geographers or others who understood the local landscape. The mapping had to be re-done on the US side.

6.6.3.3.3. Land Use Mapping: A Canadian Success Story

By 1980 sufficient experience had been gained in a number of projects done by CCRS, or in which CCRS had an advisory role, that a manual was produced on using remote sensing for land use mapping. (Ryerson, 1980) The benefits of using remote sensing were outlined, as were sources of data, suggested procedures, and regional contacts across the country. A detailed table provided information on the suggested (primarily airborne) image scale and type, ground resolvable area, minimum mapping units, optimum time frame, and expected accuracy for some 17 different parameters ranging from general land use to counting cottages and estimating farm type. This summary was used in a number of lectures given in short courses or at conferences aimed at broadening the use of remote sensing for land use mapping. (One such lecture was given by Ryerson at the Fifth Alberta Remote Sensing Course held at the University of Alberta in February 1977.)

As new systems became available other summaries of both the potential of these new systems and work that had been done with them were produced by CCRS scientists working with users. By 1986 remote sensing for land use planning hit the mainstream when Prof. Larry Martin of the School of Planning at the University of Waterloo brought together information on the services of CCRS and the Manitoba Centre for Remote Sensing, and papers on how remote sensing could be used in planning. These appeared in a special issue of ***Plan Canada*** dedicated to remote sensing. (Martin, 1986; Howarth, 1986) The cover of that issue of ***Plan Canada*** was an image of Vancouver produced by WorldSat International, whose products brought satellite data to millions of Canadians. (See Section 3.3.4 above)

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[190] Jean Thie would later join the Lands Directorate and Terry Fisher joined CCRS.

[191] As noted elsewhere, ERTS-1 was renamed Landsat-1.

Several projects were summarized in Seguin and Ryerson (1987) who looked at rural land conversion from forest to agriculture in the Peace River District and changes in agricultural land use in Manitoba. With this experience they proposed optimum methods for using what was at the time the new Landsat TM data. Another example of "getting the message out" was a chapter on monitoring rural land-use change in a book titled "Demands on Rural Lands." The chapter described methods to monitor changes using remote sensing in the context of a rigorous statistical approach tied to both the Census and the National Farm Survey. (Ryerson, *et al*, in Cocklin *et al*, 1987)

More of Canada's work (including some of that by CCRS) was also featured in an invited paper to an Asian-based Journal by Rivard *et al* (1990) that showed how approaches developed in Canada had been applied to map land use for the entire country of Cameroon by Digim/Photsur, a commercial organization based in Montreal. While some other limited land use mapping work was done over the coming years at CCRS, by 1995 attention had begun to shift to radar data and its application. Land cover mapping did become important in terms of climate change, as discussed in Section 6.6.10.

Land Use Mapping, Accuracy and Remote Sensing: Solving a Conundrum

Aerial photography has long used for land use mapping. The problem for remote sensing from satellite and high altitude aerial photography was (and has always been) that the accuracies required for uses such as land use planning or route planning by engineers require accuracies that are over 95% for parcels as small as an acre in size. Quite simply, remote sensing imagery from the early satellites could not deliver the required accuracies. However, in some circumstances (such as in developing countries or for more general-use mapping) less accurate maps may suffice.

One of the solutions has been to adopt land use and land cover classifications that have less stringent accuracy requirements. The first one of these was developed in the US over a period of years by Anderson *et al* (1976).[192] As a result of personal contacts, CCRS had an advanced copy of Anderson's document. A remote sensing compatible land use activity classification for Canada was then developed based on experience gained from 1971-1974. (Ryerson and Gierman, 1975) The system was compatible with the Canada Land Inventory, available aerial photography and Landsat data.

6.6.3.4. Some Lessons from the USA: LACIE and AgriSTARS

The Large Area Crop Inventory Experiment (LACIE) and AgRISTARS (Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing) were major US crop forecasting projects funded and led by the US Government.

LACIE was the first major research-focused endeavor that attempted to apply remote sensing to crop inventory. The impetus was informally said to be the failure of the US to predict and react to a major crop failure in the Ukraine that lost US wheat farmers an opportunity to significantly increase their profits. Less dramatic background is provided in an excellent summary by Erickson (1984) of the rationale for the project, the approaches used, and results. The program included contributions by NASA, NOAA and the USDA – each of which brought unique capabilities and expertise to the program. The first phase developed methods which were then applied to the US and subsequent phases applied the approach to key crop growing areas in the world. Much was made of the ability to predict a failure in the 1977 spring wheat crop in Russia. Accuracies as high as 99% with reference to published statistics were reported, although the target was 90/90 – 90% accuracy 90% of the time.

The program established an evaluation team of international experts, including Dr. David Goodenough of CCRS. There were at least two meetings of this group in 1976 and 1977. A major conference was held in 1978. A number of CCRS scientists and managers were invited to the 1978 conference on LACIE held at

[192] Showing both how inter-related programs were (and the scarcity of expertise) in the 1970s two of the authors of the US paper, Jim Anderson and Ernie Hardy were on Ryerson's PhD examining committee.

the Johnson Space Craft Center near Houston. A comment by Associate Director General Lee Godby made to several of us at the time says a great deal about the program and how the US did things compared to CCRS:

> "They have a greater budget for public relations than we have for our entire scientific program."

Of course, the hidden implication in this statement was that CCRS had to carefully think through a problem. We did not have the financial resources to attack problems without regard to the cost of both the research and its operational application – no matter the projected benefits.

This reality led to the development of a research and development program that was focused on realistic and cost-effective operational uses and operational users rather than on researchers and esoteric applications. If a project looked like it would not lead to a cost effective application, or if accuracies would not meet the real need of the user,[193] it was stopped to cut our losses. For example early research at CCRS on determining acreages of wheat were abandoned when it was realized that the accuracies for an operational program for wheat crop area estimation using satellite data would be no better than those already being achieved by Statistics Canada – and their results were obtained at a much lower cost. Indeed, at the time the cost of one set of Landsat data for western Canada was more than the total budget of the Agriculture Division of Statistics Canada! From then on the focus was on crop condition and/or high value crops in small concentrated areas that could be covered by but a few satellite images.

This operational focus and approach to research led to successful and early applications development work with satellite data in agriculture, forestry, land use mapping, and engineering applications (such as sediment in water related to electricity generation). From the airborne side it led to the use of airborne thermal data for heat-loss mapping and vineyard location and mapping oil on water among others.

6.6.3.5. Crop Information System

The work leading to the Crop Information System represents a classic example of the way in which CCRS approached science in general and applications development more specifically. First there was an apparent need and justification for a crop information system. That was provided by the benefit studies by Clough (1972; 1974 and Clough *et al* 1974), the economic studies that led to the LACIE and AgriSTARS programs in the USA, and so-called "needs studies." (King *et al*, 1977; Ryerson, 1979) Also important was a chance encounter briefly described in the following text box. Second, like much of the important work done by CCRS, it was based on a broad foundation of work by others, good science, and clear thinking. Third, users were engaged to ensure that their needs would be met in a budgetary envelope that made operational sense. (Brown *et al*, 1981)

A Chance Encounter – and Millions of Dollars of Extra Farm Income
Bob Ryerson

In the mid-1970s (I am unsure of the date) I was visiting colleagues in the USDA in Washington who were involved in crop studies. As I had finished up my official meetings I had some time to wait before my flight on a winter Friday afternoon. My colleagues suggested that I should visit a US Government scientist who was working with weather satellite data over the Soviet Ukraine and I did so. He was very excited. As I recall he showed me an image and said "Look, there is no snow over this entire region!!" He went on to say in a very excited voice that he had just merged temperature data over a period of a week or so over the snowless landscape. He then explained "With such low temperatures and no snow for insulation there will be a massive winter wheat crop failure." When I returned home with what proved to be a valuable nugget of information I immediately tried to reach my Director who was away, and then called Larry Morley at home on a Friday evening. He said that he knew someone associated with the

[193] The "real" need of the user was often contentious. In some cases users or potential users wanted to obtain the same sort of information that they always used. And what they always used was conditioned by the data soures available. Remote sensing required a whole new way of looking at the environment and how it appeared from above.

Canadian Wheat Board (CWB) from his days in the Navy and would contact this person with my "news." At the time the CWB had an almost automatic sales or order fulfillment system: orders could be placed at a set price day or night. I was later told that as a result of this information the CWB stopped the automatic selling of wheat for several days. The rest of the world wondered why...and then the news of the crop failure in the USSR came out. And the price jumped. This one piece of information apparently ended up being worth millions of dollars. Larry later told me that the added income to the farmers would nicely cover a good deal of our budget. Another side effect was that US Government Scientists were instructed not to share information with Canadian scientists. That weekend the potential value of remote sensing in Canada moved from theory into reality.

The first substantive work moving towards an operational system was led by the Canadian Wheat Board's Dr. Harvey Glick (CWB). (Glick *et al*, 1983) That work provided the context and early results of efforts to develop a Canadian crop forecasting system. Recognizing the importance of having accurate information on both the supply of and demand for grain in both grain importing and exporting countries world-wide, the CWB established a Weather and Crop Surveillance Section (WACSS) in 1974. It was the head of that Section, Dr. John Benci, who became a member of the CACRS Working Group on Agriculture.[194]

The WACSS was "responsible for monitoring global weather on a daily basis and providing the Board with immediate information on any episodic climatic anomalies such as frost, hurricanes, or floods which may impact production." (Glick *et al*, 1983, p. 333) It also collected ancillary information on crop estimates for weekly reports to the Board. The basis of the weather data were 2000 World Meteorological Organization (WMO) stations from which results were plotted on a daily basis to obtain an overview of crop growth potential for each country of interest. An interesting sidebar was that the location of these stations had to be carefully examined in that some countries placed the stations in locations (such as in forests, on hill tops, in towns, far from agricultural areas, etc.) that would not give a true picture of actual growing conditions. This weather information would be rolled into crop growth models used to predict yields. The problem was that the point sampling density made extrapolation difficult. It was here that remote sensing was first expected to play a role – and it did so in a manner that would "satisfy many of the cost/benefit requirements of an operational forecasting environment." (*op cit*) The implementation was preceded by the recognition and solution of several technical problems detailed in the text box below.

Solving Some Technical Problems on the Way to an Operational Crop Forecasting System[195]

As demonstrated in LACIE (MacDonald and Hall, 1978) Landsat data provided good information on crop condition and proved to be very useful for fields over 5 hectares in size. The potential for success was clearly demonstrated in the LACIE project. Peet *et al* (1974) demonstrated that crop identification was also possible to a certain degree. However, Landsat data were limited by the number of passes over a given location (once every 18 days) and cloud cover often obscured the data of interest. LACIE solved that problem by using a sampling strategy that estimated the situation under the cloud. However, this approach was judged not able to meet the needs of the CWB. The CWB requires data that shows the specific extent of crop damage caused by episodic events so that the yield losses can be quantified and production estimated. Landsat data, given cloud conditions and repeat cycle, was judged to be incapable of meeting the CWB's needs – and this was before one came to the cost and speed with which international data could be delivered.

NOAA-6 and NOAA-7 AVHRR data, however, could be obtained operationally on a daily basis and at low cost. Furthermore these data sets contained data with spectral characteristics that would appear to be amenable to assessing vegetation condition over large areas. The NOAA AVHRR Channels 1 and 2 are similar in spectral

[194] Dr. Glick eventually left the Wheat Board and joined Monsanto and became a senior executive in research with that company.
[195] Information and quotes drawn from Brown et al, 1982a; Brown et al 1982b; Brown and Fedosejevs, 1983, and Glick et al, 1983

characteristics to Bands 5 and 7 of the Landsat MSS, i.e. red and near infrared respectively.

However, unlike Landsat with its $\pm 6^0$ scan angle, NOAA AVHRR data had a scan angle of $\pm 56^0$. This meant that there were "serious geometrical and radiometric distortions to the data which are non-trivial" (Glick *et al*, 1983, p. 334) as one moved further from the nadir view. Atmospheric effects would be much greater on data at the edge of the imagery than was the case with Landsat. In addition the shallower look angle would also result in difficult issues related to distortions caused by differing illumination angles and viewing geometries as one moved to the edges of the imagery. Without correcting these distortions, the data would be virtually useless for any attempt at operational vegetation monitoring. Therefore, before the data could be used, Brown *et al* (1982) developed approaches to correct for the distortions that were both elegant in their simplicity and operationally easy to implement.

The first procedure was designed to correct for radiance variations across the image. This involved measuring the radiances from agricultural areas (i.e. excluding water, forests and cloud), in strips of 20 pixels by 500 lines across an entire image (i.e. 10,000 to 15,000 sq. km.). A second order polynomial fit is made to the data and then used to correct the radiance values of the image across the track. The assumption that generally seemed to hold was that the agricultural areas were similar across the track.

Secondly, image to image comparisons were done by setting radiances of specified (i.e. similar) water bodies to the same level in the two (or more) images. (Brown *et al*, 1982) The result of applying these two procedures was that data could be used at viewing angles from nadir (i.e. right below the sensor) to $\pm 40^0$ and imagery from two or more dates could be compared.

Another issue was the large field of view of the AVHRR sensor – each pixel was 1.1 sq. km. at nadir. This meant that the reflectance values were not from individual fields but from areas comprised of a number of fields – and other features. It was found (Brown 1982a) that there was a strong correlation between the radiances of small grains and radiances of areas 50 x 50 km that included these grain fields (with a coefficient of determination of 0.83).

With data comprised of one band in the area of the chlorophyll absorption band and another in the high infrared reflectance band, this meant that the normalized difference of Channels 1 and 2 ((Ch2-Ch1)/(Ch2+Ch1)) could be used to obtain a measure of crop condition that was similar to the NDVI which had been applied with Landsat, albeit with fewer data points and less precision. When the normalized difference or NDVI was determined and plotted against time for the same area, the result was a Bell curve with the peak at about the time of heading for wheat. Weather conditions at the time of heading are critical. Furthermore it was found that the peak value and the area under the curve were related to crop condition and eventual yield. (Brown and Fedosejevs, 1983) To ensure that comparisons from one year to the next were valid, it was determined that it was important to adjust for the average time of seeding. It was also important to adjust the data based on the local percentage of land in fallow.

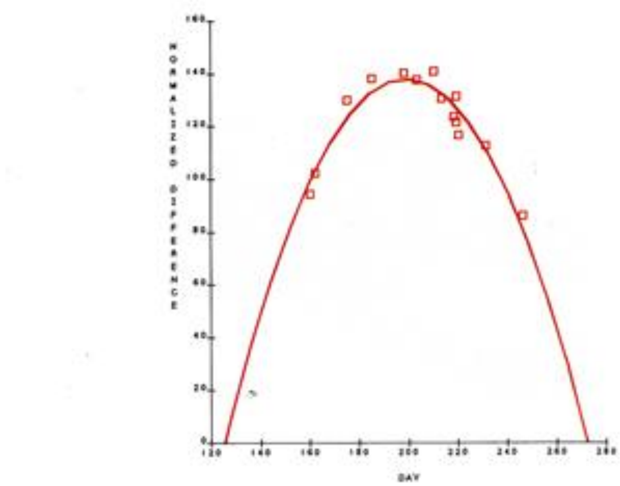


Figure 1: Phenological development curve for an agricultural test area in Saskatchewan Crop Reporting District 6B. Plot of NOAA-7 AVHRR normalized difference, (CH2-CH1)/(CH2+CH1), versus time.

Another application reported by Glick *et al* (1983) was the use of NOAA thermal data to evaluate the extent and intensity of frost damage.

As with other successful projects at CCRS, the Crop Information System (CIS) moved to a first operational stage. (As will be seen, there were several operational stages.) As noted in the material above on the Manitoba Centre for Remote Sensing on October 22, 1987 the CIS was officially launched with a ribbon cutting ceremony. The CIS, a joint venture with CCRS and the Canadian Wheat Board (CWB), was to provide users with a quick and reliable method for obtaining acreage and yield assessments of major crops around the world. In 1988 the CIS commenced in April, and ran through to September. NOAA satellite imagery from the wheat growing areas of Canada and Russia were processed into weekly composites using software developed by CCRS to produce cloud free images. Ten day composites were compiled. The CIS was successfully carried out during the 1989 crop season. There were over 600 satellite images of the Soviet Union, 200 images of Canada and 52 global images processed.

Building on the CIS and other experience Statistics Canada, working with Agriculture and Agri-food Canada (AAFC), started in 2013/2014 to test whether they could use satellite data going back to 1987, as well as historical weather and survey data going back much further, to estimate crop conditions in Canada. In 2015 Statistics Canada released their yield model for 15 crops and then compared them with the September and November survey results from the same year. For the most part, the yield model gave comparative results. The results were robust enough to prompt the agency to replace the September Farm Survey with the model-based Principal Field Crop Estimates. Gordon Reichert was quoted (Currie, 2016) as saying that “The replacement of a statistical survey with a remote sensing model-based approach is a first for any statistical agency worldwide. We can provide a mean value of the relative health of the crop over a seven day period going down to one square kilometer. You can even see the effect of a drought, flood or insect infestation. It is very visual, but more importantly, it is analytical and objective while the results are in virtual real time, that is, about three hours after we receive the satellite imagery we can post the results online.” As is often the case with remote sensing, Reichert noted that “the greatest challenge was convincing others that this method of estimating crop yields was a viable option.” The press release by Statistics Canada noted that it was an incremental approach where the preliminary results provided the support to fund ongoing research, which in turn resulted in full acceptance of the yield model.” For their efforts the team at Statistics Canada and Agriculture Canada received a 2016 Public Service Award of Excellence for Innovation. In the press release (Currie, 2016) Dr. Ron Brown was noted as a visionary whose work led to the current success. As a former scientist involved in the work and as a former Director General of CCRS this author was asked to provide a supporting letter for the project award. That letter stated what most people at CCRS would say about their applications development work: “Simply stated, the Remote Sensing Project represents the culmination of a happy marriage of good science, hard work, and simply dogged determination to do good work for the people of Canada.”

6.6.3.6. Crop Area Estimation with Statistics Canada

The crop area estimation project with Statistics Canada was built in part on the lessons learned in previous Canadian projects (including the Wheat Project and some detailed in Section 6.6.3.8 below), work done in the US (Hanuschak *et al*, 1979), and on a study done within Applications Development that examined the specific needs of Statistics Canada. (Brown *et al*, 1981[196]) The primary end result was a method to use Landsat MSS imagery with a regression estimator to estimate potato acreage in New Brunswick, with a subsidiary project aimed as estimating Canola in the Peace River district. The work received a great deal of international attention and visibility. (Ryerson *et al*, 1981; Ryerson *et al*, 1983; Ryerson, Dobbins and Thibault, 1985; Ryerson, Tambay and Plourde, 1982)

The first consideration from previous lessons learned was associated with crop separability: the crop of interest must be separable from the other crops grown in the same area. Secondly, the crop of interest must be distributed over a limited geographic area to minimize the cost of satellite data – covering all of western Canada, for example, was not economically feasible with Landsat. Third, the crop must be of sufficient importance to warrant the expenditure of funds and effort spent on developing and then operationalizing the crop area estimation procedure. Fourth, incorporation of ground information and use of a statistical approach is needed to remove errors associated with misidentification, field size, and limits of classification methods. Fifth, there must be a user with the willingness to embrace remote sensing and

[196] An appendix in the report suggested a proposed project with Statistics Canada that was accepted by that agency.

commitment to implement a remote-sensing based approach if it works. Developing an approach to estimate the area of potatoes in New Brunswick with Statistics Canada met these requirements – and many more.

Following work done by CCRS with the Departments of Agriculture in both PEI and New Brunswick, CCRS approached the Agricultural Statistics Division of Statistics Canada with a suggestion to test remote sensing as a means to estimate the acreage of potatoes in New Brunswick. There were, from Statistics Canada's point of view, both strategic and operational reasons for becoming involved.

Strategically there were three issues. First, making accurate estimates of potato acreage in New Brunswick and Prince Edward Island had long been an issue at Statistics Canada with significant political implications: potatoes dominate the economies of both provinces. It was suspected that farmers tended to under-report acreages to Statistics Canada staff for the simple reason that a low mid-growing season estimate of acres planted tended to lead to higher prices. Variations between initial estimates made in mid-summer and the final crop production figures in the autumn could be as much as 10% or more. Second, when there was a discussion that the province might work with CCRS to produce an estimate, Statistics Canada wanted to be involved – they did not want what they considered to be a "competing" estimate to their estimate – and the ensuing discussion about which one might be correct. Thirdly, it was assumed that publicizing the fact that satellite data were being used might lead farmers to more accurately report their acreage planted to potatoes since a satellite would be able to get the correct estimate anyway.

The initial operational reasons for Statistics Canada involvement in the use of satellite technology over conventional data collection systems included: (1) reducing respondent burden; (2) improving the accuracy of estimates generated from on-going surveys; (3) increasing the reliability of estimates for small geographic sub-regions; (4) contributing to the generation of change statistics from one year to the next; (5) contributing to better stratifications, larger sample sizes and hence higher accuracies; (6) the possibility of calculating estimates for intra-census years; and (7) providing estimates throughout the growing season. (Dobbins, Ryerson and LeBlanc-Cooke, 1983)

The initial plan was to have CCRS staff do the estimation in one year with the Statistics Canada staff observing, followed by a second year where the Statistics Canada staff did the work supported by CCRS staff with the project being taken over by Statistics Canada in the third year. This approach to ensuring that the users were ready to take over a project was the standard practice in Applications Development. In fact, the methods worked so well that Statistics Canada took over more responsibility than expected in the first year and basically ran the project in the second year. The several reports on the project explained the many logistical and technical issues that were overcome, ranging from project planning and integrating field data to satellite acquisition and agreeing on methods to assess accuracy. The planning and technical problems solved are briefly outlined in the Table at the end of this Subsection. (Dobbins *et al*, 1983; Ryerson *et al*, 1983)

The potato area estimate derived from Landsat data and a regression estimator in September 1981 was 53,827 acres. The published estimate using conventional approaches was 53,000 acres, which was later revised upwards after the Census was released. The Census of Agriculture estimate eventually released in June of 1982 was 53,793 acres. The project team was ecstatic – the Landsat estimate produced in ten days using the approach developed was just 34 acres off what the Census had enumerated, and was done much faster than comparable methods elsewhere. Since only two Landsat scenes were required, the cost of data was limited. A comparison of the approaches used in the US and Canada was the subject of a cooperative paper by USDA and CCRS. (Ryerson, Sigman and Brown, 1981) Much as this project used some of the ideas from the US (Hanuschak *et al*, 1979) some of the new approaches developed in this project were later adopted by the USDA and also formed the basis for a number of other crop estimation projects in Canada.

At the end of this project Ryerson was seconded to Statistics Canada for 18 months to develop that agency's remote sensing program under the leadership of Barry Proud head of the Crops Section and George Andrusiak the Director of the Agriculture Division.

Planning and Technical Problems Solved in CCRS/Statistics Canada Crop Estimation Projects

Problems Solved:

Planning

- Designed an approach that removes the on-going need for senior remote sensing expertise and specialized statistical knowledge;
- Assembled a project team of mathematical statisticians, remote sensing experts, economists, and field personnel.
- Planned, managed, and coordinated the activities, training, and budget of the project team;
- Ensured all roles and responsibilities of all project staff were understood;
- Organized and delivered aerial photographs of sample sites for the Agricultural Enumerative Survey (AES) field staff;
- Conducted AES fieldwork accurately, consistently, and in a timely manner;
- Checked field work;
- Brought together at the right time the right field information, satellite data, analysis capability (people and equipment) to assess the result and meet the release date of the statistic
- Reached agreement on an independent approach to assessing accuracy achieved using aerial photographs and field visits (Some at Statistics Canada originally suggested using their estimate as "accurate." Jean-Louis Tambay, the Senior Statistician on the project noted that StatCan's number was also an estimate.)

Technical

- Worked with one satellite image date – unlike LACIE and AgriSTARS, the project did not have multi-date Landsat data, but it did have accurate ground data;
- Because of the background in environmental sciences, Landsat data were regarded as images from which information could be interpreted and then statistics calculated – unlike the US where the Landsat data were seen as numbers from which statistics could be calculated using sophisticated special-purpose software;
- Worked with low-cost off-the shelf hardware and software;
- Early problems (such as ground data collection training, ground data consistency and accuracy) had to be solved quickly before they became important;
- All problems at the critical stage (such as delays in satellite data delivery, bad weather, loss of field notes by a courier) are important and must be dealt with immediately;
- Field work had to deal with two major crops in New Brunswick – and twelve in the Peace River District - where the target crop (Canola) was not dominant;
- Some of the aerial photography used for field work showed older or different field boundaries;
- Some respondents refused to cooperate – so PR materials were created and made available;
- Landsat data overlap from adjacent scenes had to be removed;
- Keeping track of imagery, field notes, areas processed vs areas not yet processed was a challenge;
- Complex classifiers did not yield good results in a timely fashion so a simple classifier was used;
- Where calibration or field data collection was under cloud cover (or cloud shadow, or smoke from forest fires) allowances had to be made in how the statistical analysis was performed;
- Crop area had to be estimated under the limited cloud cover (or cloud shadow, or smoke from forest fires) encountered;
- Areas of haze had to be dealt with – and where possible this was done in a subjective fashion rather than using complex correction algorithms;
- The crop of interest may or may not be important in the design of the sampling frame. In PEI and New Brunswick potatoes do drive the creation of the sampling frame, in the Peace River District, canola doesn't

Planning problems were derived primarily from: Dobbins *et al*, 1983. Technical problems are primarily from Ryerson *et al*, 1983 and Ryerson *et al* 1985.

6.6.3.7. Rangeland Mapping
Frank Ahern (with Bob Ryerson)

Rangeland is a highly visible and important resource in western Canada. McQuillan and Strome (1979) estimated that the value of a satellite-based rangeland monitoring program would be conservatively estimated at $3 million per year.[197] As noted in the text box below, there was also political interest in the topic. The end result of this project was an operational application of remote sensing that was both scientifically sound and elegant in its simplicity. The work won kudos for the scientists and field experts involved.

It was well known that Landsat MSS data could be very useful in crop and vegetation monitoring in that the amount of healthy growing "green" vegetation could be estimated. This was proven in the LACIE and AgriSTARS programs discussed above, as well as in a number of other studies with both satellite data and airborne imagery. The problem with rangeland was two-fold. First, as Tucker noted (1977) at a certain point the amount of green biomass can be so high as to be saturated and not, therefore, measurable. Second, as the summer progresses, green vegetation dries out and turns brown – but is still usable as pasture. A monitoring program had to be able to estimate both green vegetation and standing brown biomass throughout the season. Brown biomass was as high as 60% of the biomass in the field studies associated with this work. (Thomson *et al*, 1980)

Extensive field work, spectroscopic and airborne data led to a better understanding of the relationship between the Landsat spectral signatures and the many components of the rangeland vegetation canopy, including green and standing brown biomass. This led to the development of an approach to a contrast enhancement to provide both qualitative and quantitative assessments of rangeland for operational decision making. (Ahern *et al*, 1981) The project was one of those featured in the Canadian COSPAR Report. (Thompson *et al* 1982) Of particular note, the final report for the project (Brown *et al*, 1983) received the award from the ASPRS for the best paper on image interpretation in the English language for the year in which it was published.

Rangeland and Politics
Bob Ryerson

Rangeland was one of the few resources that attracted the direct attention of the political level. Kenneth Schellenberger, Member of Parliament for Wetaskiwin, Alberta and an Agrologist saw some write-ups in the media on remote sensing and contacted CCRS to ask about the use of remote sensing for rangeland management. As an Agrologist, he sought out an Agrologist at CCRS – me. Once contact was made he came to visit CCRS at the Belfast Road location to ask his questions. This episode created a minor storm at the time in that Mr. Schellenberger was not only an MP, but a member of the opposition.

6.6.3.8. Other Early Agriculture and Land Use Projects
Over a period of years up to the mid-1980s a number of other agriculture and land-use related projects were undertaken in addition to those discussed in the previous Subsections. Considerable detail is presented here to illustrate the amount of effort and range of projects undertaken at the start of Applications Development work in agriculture. The same level of effort would be seen for the several other applications areas on which CCRS focused in the early years. While most of these agriculture and land use projects used satellite imagery, some used airborne sensing and were built on the work of people outside CCRS. Each project is briefly discussed in a separate paragraph, although several (potatoes in New Brunswick, Beans in Ontario and Bare Ground in PEI) were reported on together in the literature to outline how a number of project planning, field work and image analysis and output issues were solved.

[197] In 2016 $ this would be about $12 million.

(Ryerson, Mosher and Wallen, 1979) The work reported in this Subsection added to the understanding brought to other projects carried out by CCRS and others in Canada. In most cases only those projects for which there is a written record are mentioned, unless there are clear recollections. Each project is discussed under a separate heading, but they do not warrant a separate section.

Detect Frost Prone Areas in the Niagara Region. This early project used CCRS thermal imagery to map frost pockets in the Niagara Region. The work was done in association with Dr. John Wiebe of the Vineland Experimental Station. Previous to this work it was assumed that cold air drained off the Niagara Escarpment and areas close to the Escarpment were unsuitable for growing high quality wine grapes. The thermal imagery showed that on one of the coldest nights there were many areas previously thought to be unsuitable that did not suffer severe frost. These included the so-called benches which are now home to some of the finest wineries in North America. The resulting maps produced by Dr. John Wiebe (and subsequently updated by Dr. Helen Fisher) contributed to the development of the $600 million wine industry in Ontario.

Livestock Locations Near Stream Courses. Technical Committee B of the Pollution from Land Use Activities Reference Group of the IJC wanted to identify livestock concentrations near streams and rivers in the Great Lakes Basin. Statistics Canada's census information was not considered adequate in that the livestock numbers for each farm were assigned to the location of the farm headquarters – not their actual location. By 1973 a method to determine livestock numbers using aerial photography had been developed as part of Ryerson's PhD thesis. (Ryerson, 1975) A photographic key[198] was developed for the IJC work and applied by two interpreters to 1:15,840 black and white aerial photographs that covered all of Ontario that drained into the basin. The locations with livestock numbers were subsequently loaded into the CGIS.

PEI Crop Mapping and Bare Ground Susceptible to Erosion. Work began in 1974 to evaluate airborne and Landsat for crop mapping with Norbert Stewart of the PEI Department of Agriculture and Forestry. One key data set was the location of bare ground in the spring. Land bare in the spring was at greater risk of being eroded and the Department was encouraging farmers to leave a winter cover to hold the soil. It was determined that general crop maps could be made with high altitude airborne imagery, but a combination of small field sizes and cloud in mid-summer limited the usefulness of satellite data for crop mapping. However, the satellite data proved 95% accurate for mapping the bare ground in the spring. The maps were very useful for planning the Department's visits by extension workers so that they only visited those farms where bare ground appeared to be an issue.

White Beans in Ontario. The white bean crop, with a value of $50 million per year in the mid-1970s, was an important regional specialty crop.[199] It had been the subject of extensive research using CCRS's early colour IR airborne imagery to demonstrate the importance of using certified seed to reduce the devastating impact of bean blight, which threatened to destroy the crop in the province. (Wallen and Philpotts, 1971) The 1976 "White Bean Project" was aimed at developing methods to determine the acreage of white and red kidney beans for the Ontario White and Yellow Eye Bean Producers Marketing Board. The Board needed timely estimates that were 90% accurate 95% of the time. Interestingly, airborne colour imagery interpreted by inexperienced staff did not meet the accuracies required, but digital analysis of satellite data proved to be from 91-96% accurate in the test areas used by Wallen in his previous work. With the satellite data there was some confusion with other crops, and area estimates were consistently lower than was actually the case. (Ryerson *et al*, 1979) Field Sizes played a role – especially in those small isolated fields in which seed is grown. (Ryerson and Wallen, 1977) In hindsight, a regression estimator as used later in the potato work with Statistics Canada would likely have brought the accuracies to near 100%.

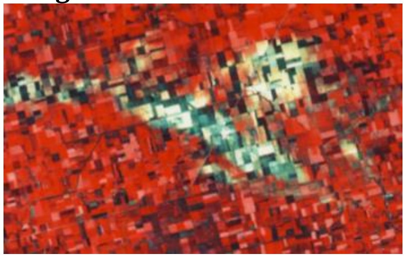
[198] Of interest is that the term "photographic key" was an early form of what came to be called an "expert system."
[199] White beans are used to make what are often called Boston baked beans.

New Brunswick Potato Acreage Inventory Project. This project began in 1974 with Dr. Peter Mosher of the New Brunswick Department of Agriculture to determine the feasibility of using mid-August high altitude colour aerial photography and Landsat to determine the acreage of the province's potato crop. Accuracy required was said to be 80-85%. Potatoes represented over 30% of all farm cash receipts for the province at that time, and New Brunswick's production was 1/5 of Canada's total. A test site contained 818 hectares of potatoes was verified using low altitude imagery and field work. Accuracies of 95% were achieved with 1:112,000 aerial photography by four interpreters. Accuracies achieved with digital analysis of Landsat data were in the vicinity of 90%. A pilot test was then developed for 1975 using test sites containing 3560 hectares of potatoes. The area of each field was measured and verified with field work. In the widely dispersed test sites accuracies in 1975 varied from 85 to 97%. Interestingly enough, the province wide accuracy was just 84.5% compared to the official estimate. It may well be that the official estimate was incorrect or our Landsat analysis missed some minor areas of production. The question of how to measure accuracy played into how accuracies were assessed in the later work with Statistics Canada. The estimated 1975 cost of the Landsat work was $2000 including data and travel of New Brunswick staff to Ottawa, while the aerial photography cost was $12,000 to $15,000. (Ryerson, Mosher, Wallen and Stewart, 1979; Mosher and Ryerson, 1977) The work was regarded as sufficiently successful at the time that a step-by-step manual was produced showing how to the estimate was derived. (Ryerson, Mosher and Harvie, 1980) While this work was supplanted by the work with Statistics Canada, it did provide a basis for the latter work.

Alberta Corn Project. This cooperative project focused on mapping corn and potatoes in the irrigated areas of southern Alberta. The Alberta Center for Remote Sensing provided the imagery from mid-August of both 1977 and 1978, while field work was carried out by the Plant Industry Branch of Alberta Agriculture. Corn could be separated from potatoes, but there was confusion in the presence of sugar beets, a significant crop in the irrigated areas of southern Alberta. This confusion existed with both simple and more complex classifiers. The report, which discussed a number of problems including reasons why there were bare spots in the midst of fields classified as corn, concluded that mapping corn was not feasible. (Ryerson and Shaw, 1981)

Rapeseed Monitoring Project. The rapid growth in importance and value of rapeseed and early success in differentiating it from other crops in Western Canada led to a concerted effort in the late 1970s to establish the parameters for operational monitoring of the crop. CCRS brought three levels of data over a test site in Melfort, Saskatchewan to the problem: ground-based spectroscopy, airborne MSS, and Landsat data. It was determined that Rapeseed (later called Canola) could be differentiated from other field crops provided the rapeseed (or Canola) was in bloom or when field peas and grains were ripening and beginning to turn yellow. This finding, confirmed with all three data sets, led to a surprisingly large window of 45 days out of 60 days in the middle of the growing season during which the probability of correct classification was between 85 and 94%. (Brown *et al*, 1980) This project led directly into the work by Statistics Canada noted above.

Assessment of Forage Condition During a Drought and Assessment of Crop Damage from a Tornado. In the drought case the PRFA wanted to assess the condition of forage within drought-stricken western Manitoba. The assessment would lead to identifying areas where support was needed to maintain herds. A simple approach was developed using a 1:250,000 enlargement of colour IR Landsat data acquired for field work within two days of the satellite acquisition date. Fields larger than 5 hectares could be reliably categorized at an estimated 95% accuracy by both experienced and inexperienced interpreters into three classes of forage condition: poor, medium and acceptable. Approximately 1 day of field work per image was estimated as being required for a full operational application. (Ryerson and Arnason, 1981) The second case was an enhanced Landsat colour IR image shown here where shades of red indicate vegetation and the white and green areas show the damage caused by a tornado (the swath-like



bare areas) and associated intense rainfall (circular area to the upper right). The value of these two uses of Landsat data is twofold. First they do provide useful information for extension workers. Secondly, knowing that such imagery is being used is assumed to result in fewer false claims for assistance or insurance payouts.

Crop Area in Manitoba. This pilot project, done within the context of the CCRS Technology Enhancement Program, was a natural outgrowth of work done previously. It built on previous experience within Statistics Canada, CCRS experience with wheat, summer fallow, rapeseed/canola, and the experience of the Manitoba Centre for Remote Sensing. Crop areas were estimated for Manitoba Crop Districts 1, 2, and 3. Reliable estimates could be determined with Landsat for spring-sown grains, summer fallow, and Canola/rapeseed using the regression approach developed in the Statistics Canada work describe above. (Horn *et al*, 1984) The true success of the work can be seen from the fact that Statistics Canada and the Manitoba Centre for Remote Sensing carried out a province-wide application over the next three years with no CCRS involvement. (Poktant and Magahay, 1986) Pokrant and Magahay[200] concluded that "the remote sensing crop area estimation is capable of producing accurate and timely estimates for canola/rapeseed, spring-sown grains and summer fallow." (op cit p 89) They also noted that cloud cover could frustrate acquisition of Landsat data at the required time of year. Lack of data was one of several reasons why remote sensing was at the time judged to be incapable of providing a stand-alone approach to estimation. They concluded that it is but one of a number of tools that could improve the estimates while reducing costs.

Marijuana. The mapping of elicit crops has long been of interest to a variety of agencies in the US and Canada. One well known group in the USA had a contract to develop special filter systems to differentiate marijuana from all other crops. ERIM then had a contract to use this filter system to map marijuana in Mexico. Several detachments of the RCMP approached CCRS at various times for technical assistance in how to identify marijuana in the context of there being surrounding legitimate crops or vegetation. Eventually imagery was used to identify marijuana being grown in forest clearings or in the midst of legitimate crops – usually corn.

6.6.3.9. The Introduction of Radar Data to the Agricultural Tool Box
Heather McNairn

6.6.3.9.1. Introduction
Satellite monitoring of crops and soils quickly falls apart if clouds obscure the crops of interest at the optimum time(s) of year. Pioneers in agricultural remote sensing with radar, Drs. Brown (CCRS), Brisco (working with CCRS) and Boisvert (Agriculture and Agri-Food Canada or AAFC) believed that SAR had to be part of the solution and dedicated themselves to some of the earliest ground-breaking research in radar and agriculture. (Boisvert *et al* 1995; Touré *et al*, 1994; Major *et al*, 1994; Major *et al*, 1993; Brisco *et al*, 1992; Brisco *et al*, 1991; and Brisco *et al*, 1990) But those with knowledge of radar understand its complexity. With its two-way scattering and variances in backscatter as a function of many target and system characteristics, understanding what SAR is trying to tell the observer is akin to peeling an onion. It took a forging of SAR applications specialists from CCRS with soil and agronomy scientists at AAFC to systematically peel off one layer after another.

[200] Lynda Kemp (nee Magahay) is another of those who was touched by CCRS early in her career. She began as a summer student working for Ryerson in the newly formed Remote Sensing Section at Statistics Canada. Hired by Statistics Canada on her graduation from the University of Guelph, she retired in 2017 as Assistant Director of the Agriclutual Statistics Division.

6.6.3.9.2. The Road to Success: Co-operation in the Field with Agriculture and Agri-Food Canada (AAFC)

In the late 1980s through the 1990s application scientists (including Dr. Ron Brown, Dr. Brian Brisco, Dr. Francois Charbonneau, Jean-Claude Deguise, Dr. Heather McNairn, Dr. Karl Staenz and Dr. Joost van der Sanden) provided extensive knowledge in hyperspectral and SAR data acquisition, calibration, processing and modeling. Yet "grounding" these scientists with their often lofty aspirations of what remote technology would bring to Canadian agriculture, was handled easily by their AAFC counterparts. AAFC scientists brought to the table a depth of understanding of Canadian soils (Dr. Johanne Boisvert, Dr. Eric van Bochove, Dr. Michel Nolin, Dr. Clarke Topp, and Dr. Nicolas Tremblay), annual crops and rangelands (Dr. Guy Lafond, Dr. Dave Major, Dr. Elizabeth Pattey, and Dr. Anne Smith) and land use (Dr. Ted Huffman). These AAFC scientists were pivotal in CCRS's continuing success in advancing space to map and monitor agricultural landscapes.

Beginning in the early 1990s, CCRS led large collaborative research campaigns over a series of Canadian super sites. AAFC scientists contributed to each campaign, as did leading researchers at Canadian universities (Guelph, Laval, Lethbridge, McGill, Manitoba, Saskatchewan, Sherbrooke, Waterloo and others). Pre-satellite, knowledge was gained and methods developed using radar data collected using the CCRS truck-mounted scatterometer (McNairn *et al* 2001; McNairn at al 1996; Smith and Major, 1996; Boisvert *et al* 1995; Touré *et al* 1994; Major *et al*, 1994; Major *et al*, 1993; Brisco *et al*, 1992; Brisco *et al*, 1991; and Brisco *et al*, 1990) and the CV-580. (Smith *et al*, 2006; McNairn *et al*, 2004; Sokol *et al*, 2004; and McNairn *et al*, 2002) Airborne data quality was assured under the steady watch of CCRS leading experts in SAR processing and image calibration. (Dr. Robert Hawkins, Tom Lukowski, Kevin Murnaghan and Dr. Rihda Touzi) Dr. Touzi's unwavering belief in the potential of polarimetry is particularly noteworthy. His enthusiasm was contagious and today some of the most promising methods in agriculture exploit this advanced technology as described in detail in Section 6.7.2.4.

Typically these large CCRS-AAFC led field campaigns budgeted upwards of one hour to collect soil and/or crop measures to characterize conditions in each agricultural field. Sampling days were long and work conditions less than ideal. At times conditions were frigid and wet with crews quite literally dragging their soil-encased boots through the fields during early dawn SAR acquisitions. (1994 SIR-C campaign – Sokol *et al*, 2004 and McNairn *et al*, 2002) During other campaigns crews were exhausted after dragging what seemed like their weight in corn samples under sweltering 3 meter high corn canopies. (1999 Clinton campaign – McNairn *et al*, 2004) Teams battled mosquitos that rose in thick swarms from early-morning dew-drenched crops and grasshoppers that stripped every leaf of wheat, sending crews scurrying through fields. (1997 Carman campaign – McNairn, *et al*, 2002a; Wood *et al*, 2002 and Brisco *et al*, 1998) And some unfortunate teams were sent ducking for cover as cowboys yelled to stay clear as they herded buffalo that had broken free and were charging through our sample field (2002 Indian Head campaign). It has taken an army of dedicated Canadian researchers to collect and analyze these data.

Research into developing remote sensing methods for agriculture, whether based on multi-spectral, hyperspectral or radar, always involved massive field experiments with significant collaboration. Soils and cropping practices vary across this country and as such, field campaigns were initiated in various regions. Pre-2003 CCRS most often led these massive super site campaigns, with experiments (scatterometer, airborne, satellite) conducted almost every year. In some years, such as 1994, multiple campaigns were delivered (1994 SIR-C/X-SAR and Lethbridge scatterometer experiments). (Sokol *et al*, 2004; McNairn *et al*, 2002; McNairn at al 1996; and Smith and Major, 1996) Post-

The CCRS Truck Mounted Scatterometer=>

2003,[201] the lead for agriculture research shifted to AAFC where this approach to super site based research and government-university-industry collaboration continued.

Research led by scientists at CCRS and AAFC was visionary and inspirational. Many of these early results from agriculture remote sensing experiments were captured in a 1990 issue of the ***Canadian Journal of Remote Sensing*** (volume 16, issue 3). Boisvert *et al* (1996) followed with a review of SAR for soil moisture estimation, summarizing what we had learned from the OXSOME, ERSOME and SIR-C experiments. McNairn and Brisco (2004) updated what we knew about the potential of polarimetric SAR for soils and crops, leading up to the launch of RADARSAT-2. (McNairn and Brisco, 2004)

Southern Manitoba, particularly the region south and west of Winnipeg, has long been targeted as a super site for hyperspectral and SAR research. The attraction here is many-fold. The crop mix in this region is diverse and within a short geographical distance, soil texture changes dramatically. As such CCRS scientists were interested in setting up a super site in the region given that one relatively short CV-580 flight, for example, could traverse many soil zones and capture significant changes in soil moisture. For AAFC, the attraction held, not only for these reasons but also because this is a rich agricultural region prone to flooding due to its topographic flatness and heavy textured soils. It remains a super site to this day. AAFC has set up a permanent in situ soil moisture network for microwave research here, and the Carmen-Elm Creek area hosted both the 2012 and 2016 SMAP Validation Calibration Experiments (SMAPVEX-12 and SMAPVEX-16). (McNairn *et al*, 2015)

The following table documents the legacy of super site experiments led by CCRS from the early 1990s.

The Legacy of Super Site Experiments Led by CCRS from the Early 1990s
Heather McNairn

Campaign	**Dates (Lead)**	**Purpose**	**Remote Sensing Data and Reference**
Oxford County Soil Moisture Experiment (OXSOME) Oxford County, On	May & July 1990 (Dr. Ron Brown)	Determine if SAR can be used to estimate surface soil moisture	CV-580 airborne
ERS-1 Soil Moisture Experiment (ERSOME) Oxford County, On	May to November 1992 (Dr. Ron Brown)	Investigate SAR for soil moisture estimation and crop type determination	CV-580 airborne ERS-1 satellite
Altona 1993 Altona, Manitoba	August 1993 (Dr. Ron Brown)	Investigate crop type discrimination using SAR	JPL AIRSAR airborne ERS-1 satellite
Spaceborne Imaging Radar-C (SIR-C)/X-SAR Altona, Manitoba	April and October 1994 (Dr. Ron Brown and Terry Pultz)	Further develop methods to estimate soil moisture using SAR Early examination of polarimetry for soils and crops	CV-580 airborne JPL AIRSAR airborne ERS-1 satellite McNairn *et al*, 2002 and Sokol *et al*, 2004

[201] Editor's Note: This was after Dr. McNairn joined AAFC when CCRS essentially abandoned research in agricultural remote sensing.

Lethbridge Scatterometer Tillage Experiment Lethbridge, Alberta	June and July 1994 (Dr. Heather McNairn, Dr. Anne Smith, Dr. Dave Majors)	Evaluate C- and L-band for mapping tillage and residue	CCRS Scatterometer McNairn at al, 1996 And Smith and Major, 1996.
Ottawa Scatterometer Experiments Ottawa, Ontario	April, September, October, November 1996 (Dr. Johanne Boisvert and Dr. Heather McNairn)	Investigate C- and L-band SAR to estimate residue characteristics (amount and type)	CCRS Scatterometer McNairn *et al* 2001
Altona 1996 Altona, Manitoba	October 1996 (Dr. Heather McNairn)	Determine use of SAR for tillage change detection	RADARSAT-1 satellite McNairn *et al* 1998
Carman 1997 Carman, Manitoba	June, July, August 1997 (Dr. Heather McNairn, Dr. Joost van der Sanden, Dr. Karl Staenz, J.C. Deguise)	Investigate C-band SAR for classifying crops Develop hyperspectral applications for precision farming	RADARSAT-1 satellite Compact Airborne Spectrographic Imager (*casi*) airborne hyperspectral McNairn, *et al*, 2002a And Wood *et al*, 2002 Brisco *et al* 1998
AgriSAR 1998 Ottawa, Ontario	June and July 1998 (Dr. Joost van der Sanden and Dr. Heather McNairn)	Develop methods to use polarimetric C-band SAR for crop classification	CV-580 airborne RADARSAT-1 satellite
Clinton 1999 Clinton, Ontario	June and July 1999 (Dr. Heather McNairn, Dr. Karl Staenz, J.C. Deguise)	Investigate polarimetric C-band SAR for classifying crops and determining crop condition Develop hyperspectral applications for precision farming	CV-580 airborne RADARSAT-1 satellite Probe-1 airborne hyperspectral McNairn *et al*, 2004
Ottawa 2001 Ottawa, Ontario	June and July 2001 (Dr. Elizabeth Pattey, Dr. Anne Smith, Dr. Heather McNairn)	Investigate polarimetric SAR for within field zonal delineation for precision farming	CV-580 airborne *casi* airborne hyperspectral Smith *et al*, 2006
Sask2000 Indian Head, Saskatchewan	June and July 2000 (Dr. Heather McNairn, Dr. Karl Staenz and J.C. Deguise)	Investigate polarimetric C-band SAR for classifying crops and determining crop condition Develop hyperspectral applications for precision farming	CV-580 airborne RADARSAT-1 satellite Probe-1 airborne hyperspectral
Sask2002 Indian Head, Saskatchewan	June and July 2002 (Dr. Heather McNairn, Dr. Karl Staenz and J.C. Deguise)	Investigate polarimetric C-band SAR for classifying crops and determining crop condition Develop hyperspectral applications for precision farming	RADARSAT-1 satellite Envisat ASAR satellite Hyperion hyperspectral satellite

6.6.3.9.4. The Result

The ground and remotely sensed data discussed in the previous Subsection have supported many a graduate thesis and advanced many a career. But something much more remarkable transpired by the dogged dedication of this community. After years of mentoring by Drs. Brown, Brisco and Boisvert, Dr. McNairn left CCRS in 2003 to lead applications development at AAFC. She took with her the collective wisdom accumulated by these dedicated CCRS-AAFC-university collaborators. Peeling the onion, to understand what SAR is telling us and to develop robust methods with repeatable results, has most certainly yielded dividends.

How to Peel the Onion: Some Technical Details
Heather McNairn

As Canada contemplated space-based radar, applications scientists contemplated how to ready the user community for the inevitable access to these data. The CV-580 and the 1994 SIR-C/X-SAR mission were important sources of data for agriculture. So too was the CCRS ground-based scatterometer. The scatterometer was mounted on a hydraulic boom supported on the flat bed of a 5-ton truck. The instrument operated in 3 frequencies (L, C, and Ku-band), 4 polarizations (HH, HV, VV, VH) and was typically operated at incident angles of 20 to 50 degrees. (Sofko *et al*, 1989) The instrument was acquired by CCRS in 1985, with the components assembled, calibrated and tested with the help of the University of Saskatchewan (1986-1989). Early experiments on crop discrimination were carried out in Saskatchewan by Drs. Ron Brown and Brian Brisco, in collaboration with the university. The system was then deployed for use in controlled experiments at the AAFC research station in Lethbridge (1992-1995) under the watchful eye of Drs. Major, Smith, Boisvert, McNairn and Brown. It was then shipped to AAFC's Ottawa research station (1995-2003) where it was put to full use by Drs. Boisvert and McNairn.

This non-imaging instrument was very well suited to study soils and crops. A scatterometer is ideal for generating dense temporal data sets (daily or even hourly) at relatively low cost, and affords the collection of very detailed ground measurements albeit over spatially limited plots. AAFC and CCRS ran numerous experiments whereby treatments were applied to plots and backscatter was diligently measured in different radar configurations (different frequencies, varying incident angles and look directions). Plot treatments included planting different crops, measuring backscatter diurnally and following crop growth from planting to harvest, irrigating to vary soil moisture, and tilling with different plough implements to vary roughness and crop residue.

These experiments carefully deconstructed SAR for these agricultural scientists. Criticisms regarding the applicability of such spatially limited measures to data from satellite platforms were put to bed when the late Dr. Ferdinand Bonn (University of Sherbrooke) made a request to Dr. McNairn (CCRS). Would she review the bulk of scatterometer results and present a perspective of their contribution at the Advanced SAR workshop (Montreal, 2003)? The studies were numerous, yet despite the challenge of collating these results the outcome was rewarding. The conclusions reached in these scatterometer experiments were repeatedly confirmed by results reported from subsequent airborne, RADARSAT-1 and RADARSAT-2 research. The breadth of confirmation included results on crop discrimination (Brisco *et al*, 1992), rangelands (Major *et a*, 1994), soil moisture (Boisvert *et al*, 1995 and McNairn *et al*, 1996), and tillage. (McNairn *et al,* 2001; Major *et al,* 1993; McNairn *et al,* 1996; Smith and Major, 1996; and Brisco *et al*, 1991) The importance of these early scatterometer experiments could not be overstated. These early experiments inspired scientists to delve further into SAR for agriculture, assisted in planning of airborne campaigns, and in defining optimal SAR configurations for future satellite missions. The marriage of early scatterometer experiments with airborne sorties and satellite-based experiments led to confidence in the application user community and the conclusion that indeed, radar had an awful lot to contribute.

Today, AAFC delivers an operational crop inventory based exclusively on an integration of SAR and optical imagery. These annual products identify every crop in every field across Canada, and are provided free of charge to the public. AAFC is now working to transfer these methods to partners around the globe. Soil moisture products from SAR are pre-operational and research at AAFC is closing in on SAR-based estimation of crop biomass with an eye on mapping Canada with these methods and using data from the RADARSAT-Constellation Mission. In the midst of a field on the Canadian prairies at 6 AM in the morning with a soil moisture probe in hand, it might have seemed like we would never get here. Much is yet to be accomplished, but CCRS's contribution to Canadian agriculture is measurable and remarkable.

6.6.4. Engineering[202]
Bob Ryerson

From the very beginning of the Applications Division, Engineering was given a place of prominence with the appointment of Tom Alföldi as one of the first scientists hired. Alföldi had a Master's degree in civil engineering and remote sensing from the University of Toronto, including the Interuniversity Course on Integrated Aerial Surveys. He produced early work on landslides (Alföldi, 1973), mapping sediment in water using chromaticity and Landsat data as well as some land cover mapping. (Alföldi 1975) He was also the scientist in charge of the optical interpretation equipment that CCRS procured in the early to mid-1970s. (See Section 3.1.5) Alföldi later went on to work in technology transfer and was the force behind the early and successful web presence of CCRS.

6.6.5. Ice[203]
Bob Ryerson

As a result of the planned development of off-shore oil fields in the Beaufort Sea, a great deal of early airborne remote sensing work was done on ice monitoring and mapping. While the early work was done in Data Acquisition Division, some work was done in Applications Development and the RADARSAT Project Office in the 1990s. In the words of Bob O'Neil who was first a scientist and then Head of the Sensor Development Section: "I would argue that the single most important/significant data collected by CCRS was the Ku-band scatterometer profiles collected and analyzed by Laurence Gray from the AJIDEX mission as this data demonstrated that 1st year sea ice could be distinguished from multi-year ice. The historical context is important: there was a lot of interest in oil deposits in the Beaufort Sea (recall too, the interests of Intera). Unfortunately this interest had pretty much evaporated by the late 70s because of the Berger Inquiry (1974) and the construction of the Alaska Pipeline. Even so, there was sufficient interest in navigation through Arctic ice, and sovereignty, that RADARSAT was able to proceed."[204]

Over time the interest in ice grew as did the amount of work CCRS did on ice as the concept of a radar satellite to monitor Canada's sovereignty in the north developed into RADARSAT-1. (See discussion on microwave applications to ice in Section 6.7.2.3. With the shift in CCRS priorities in the early 2000's several key people left and the Canadian Ice Service added some research capability to its already well developed operational ice monitoring activity.

6.6.6. Geological Remote Sensing at CCRS 1970s-2018[205]
Vern Singhroy

Geological remote sensing in Canada started with Drs. Larry Morley and Alan Gregory who were geophysicists employed by the Geological Survey of Canada (GSC). In the early 70's both Morley and Gregory provided geological information from the visual interpretation of ERTS-1 (later called Landsat-1) imagery. Most of the interpretation at that time used large hard-copy prints of ERTS-1 images with the interpretation drawn on transparent Mylar sheets overlain on the imagery. In the 1975-1990 period Roy Slaney of the GSC was seconded to CCRS. He continued to develop uses of Landsat and airborne radar images provided over Canada by the CCRS Convair 580 program. His compilation "Landsat images of Canada: A Geological Appraisal" in 1981 showed how Landsat images could provide both lithological and structural information to geologists.

[202] This is one of several application areas where it has proven difficult to find authors. This short summary is meant to identify this as one of the areas where CCRS did applications development.
[203] This is one of several application areas where it has proven difficult to find authors. This short summary is meant to identify this as one of the areas where CCRS did applications development.
[204] Personal Communication from Dr. Bob O'Neil, October 8, 2018.
[205] Editor's Note: Vern Singhroy received the Canadian Remote Sensing Society's 2011 Gold Medal Award for his contribution to Canadian and International Geological Remote Sensing programs and training.

Bill Bruce, a geomorphologist at CCRS, also contributed to the early development of geological remote sensing in Canada. He focused on the technology transfer of geological remote sensing to the provinces with some notable successes in Nova Scotia. Bruce and Vern Singhroy from the Manitoba Dept. of Mines (and later with the Ontario Centre for Remote Sensing - OCRS) provided significant case studies on terrain mapping and surficial geology being used by the provincial geological surveys.

The MEIS (Multidetector Electro-optical Imaging Sensor) sensor developed at CCRS was instrumental in developing geobotanical techniques for mineral exploration in the early 1980's. The geobotanical mineral exploration program was led by Singhroy at OCRS. In those early days, the recommendations from the Geological Working Group of the Canadian Advisory Committee of Remote Sensing (CACRS), chaired sequentially over ten years by Alan Gregory, Roy Slaney and Vern Singhroy, were important in shaping geological remote sensing programs. The Working Group's activities contributed to the increased use of geological remote sensing by universities, provincial geological surveys, mining companies and consultants. Prof. Philip Howarth, originally in the Department of Geography at McMaster University (later at Waterloo) and Prof Wooil Moon, Earth Sciences Department at University of Manitoba were the first to offer programs in geological remote sensing at the graduate and undergraduate levels.

Dr. Vern Singhroy joined CCRS in 1990 to succeed Roy Slaney. He was the first to integrate airborne SAR with aeromagnetic and radiometric geophysical images and SAR images fused with Landsat images to assist in geological mapping and mineral exploration. These image fusion techniques are still being used by mineral exploration companies. In the mid 90's, Singhroy conducted radar geological training in several GlobeSAR participating countries, notably Peru, Columbia, Chile, and Jordan. One significant outcome was in eastern Jordan. Singhroy's interpretation of CCRS airborne SAR imagery led to the discovery of additional sources of groundwater. The current Syrian refugee camps in eastern Jordan currently rely on this discovery.

RADARSAT-1 and 2 images continue to provide additional exploration and mapping tools for various national and international geological programs. MacDonald, Dettwiler and Associates (MDA) used CCRS expertise to provide training to countries with significant mineral exploration programs such as Brazil, Australia and Chile with the goal of increasing their sales of RADARSAT images.

The data fusion and polarimetric SAR techniques developed at CCRS are widely used by geologists. These results were published in the 1991, 1994 and 1999 in the ***Canadian Journal of Remote Sensing*** (CJRS) Geological Remote Sensing special issues, edited by Singhroy. Canadian spin offs of the RADARSAT-2 and Landsat image fusion techniques include the regional surficial geological mapping of all of northern Ontario conducted by CCRS (Singhroy) and the Geological Survey of Ontario. In addition, Jeff Harris at the Geological Survey of Canada and CCRS used enhanced Landsat images for geological mapping of Arctic Canada. Harris was the recipient of the Canadian Remote Sensing Society's 2017 Val Shaw Award for practical and career-long contributions to the field of natural resource remote sensing.

Since 2008 Singhroy and his team at CCRS have focused on using RADARSAT-2 interferometry to monitor steam assisted gravity (SAGD) mining techniques in the oil sands. These techniques provided the guidelines for the Alberta Energy Regulator to monitor the mining operations in the oil sands. InSAR techniques have also been used to monitor landslides and subsidence processes affecting Canada's strategic energy and transportation corridors (pipelines, railways and highways). Internationally, CCRS used RADARSAT-2 InSAR techniques to monitor areas affected by earthquakes such as those in Haiti, Nepal, and Chile. As Chief scientist of the RADARSAT Constellation Mission (RCM), Singhroy edited a 2016 CJRS special issue on the potential capabilities of RCM. From a geological perspective RCM will provide the high-resolution rapid revisit images needed to monitor active geohazard areas as reported in this special issue.

6.6.7. Hydrology[206]
A small program in hydrology was started when Jean-Claude Henein was Director of the Applications Division. The program was headed by Terry Pultz.

6.6.8. Mapping
Dianne Richardson and Thierry Toutin[207]

6.6.8.1. Introduction
The first applications development work at CCRS that was truly associated with what one might think of as traditional mapping took place in the mid-late1980s, before the creation of the Mapping Section. This work was undertaken by Thierry Toutin under the Director of Appications Division, Jean-Claude Henein,

At this time there was a strong mapping collaboration between CCRS and the Canada Centre for Geomatics (CCG) – the future CTIS, Sherbrooke). The focus was on internally developing a 3-D mapping system with SPOT-1/Landsat. Toutin spent 18 months with CCG scientists (including nine months located at Sherbrooke) to develop a precise 3D orto-rectification system with DEM of high-resolution satellite SPOT/Landsat data. This precise modelling integrated sensor technology, satellite orbitography, geodesy and mapping science. The geometric correction and and DEM multi-sensor generation algorithms and systems were ported into operational software déveloped in collaboration with Centre of Sherbrooke (1989-90). Somewhat later the same software was incorporated into the stereo workstation with Sherbrooke and Laval University in 1991.

This early work by Toutin (Toutin and Carbonneau, 1992), along with other R&D at CCRS (notably by Drs. Bert Guidon and Jack Gibson), provided the base to start the Mapping Section few years later. The previously developed software was used to process the geometrically ortho-corrected Landsat imagery with DEMs for Doug O'Brien. O'Brien combined geometrically corrected satellite data with basic topographic map data as a demonstration of the potential contribution that some of the higher resolution data might make to traditional map products. These widely distributed experimental maps of the Peterborough area were visually appealing but did not catch on with the mapping community. It was some years later that a more coordinated effort was made. This section describes that effort and some of the results.

6.6.8.2. Satellite Mapping Development Section: Overview of Mapping R & D
Dianne Richardson

6.6.8.2.1. Background and Introduction
In early 1993, Dr. Dianne Richardson came to CCRS after completing post graduate studies with the International Institute for Geo-Information Science and Earth Observation, and the Wageningen University and Research, both in the Netherlands. In her estimation there were a lot of activities within the Centre that could be relevant to make contributions to more traditionally based mapping programs such as the emerging electronic digital vector based presentation of topographic and thematic maps.

Around 1993, the Centre for Topographic Mapping and the Geographical Services Division had recently eliminated their mapping research and development group. Dr. Richardson considered this to be short sighted for the longer term welfare of the Sector, and thus developed a proposal to the Director General of CCRS, Dr. Leo Sayn-Wittgenstein. A Mapping Research and Development Section within CCRS was proposed in a detailed memorandum of some eight pages.

[206] Editor's Note: We have been unable to find an author with the appropriate background willing to write about this topic.
[207] Dr. Toutin wrote Section 6.6.8.3 on 3D topographic mapping development, as well as contributions to the introduction to this section. .

The objective was to bridge the research talents of CCRS scientists with those of some of the fundamental needs in topographic and thematic mapping. This was especially relevant since digital mapping was evolving rapidly and the likelihood of using satellite imagery as a more effective resource for map updating was an obvious progression from aerial photography. At the time, topographic and thematic mapping were undertaken elsewhere in the Sector where, as noted above, little research capacity was available. During those early years, topographic and thematic mapping were largely developed and/or updated using conventional manual techniques and undertaken by traditional cartographers.

It was Richardson's opinion that a mapping research and development section in CCRS should focus on elements or features that were relevant to every map, be it topographic or thematic. (Richardson, 1993; Richardson, 1997)

Elements that provide spatial context to which topographic or thematic content is related involve what was (and still is) referred to as 'base map elements.' These are generally hydrographic, transportation and boundary-type features or objects. From the remote sensing standpoint, CCRS could augment or facilitate the mapping programs that were being undertaken elsewhere in the sector. This could be done by developing effective algorithms for map updating that involved the extraction of detail related to hydrographic and transportation networks from a range of remotely captured imagery. This would allow other parts of the Sector to sidestep the more labour intensive process of map revision based on photogrammetrically extracted object detail from aerial photography. It was especially relevant at the time since higher resolution remote sensing imagery was becoming available and thus CCRS was in a position to spearhead specific types of object recognition that would benefit a larger audience. (Richardson, 1994)

Dr. Richardson's proposal to Dr. Sayn Wittgenstein was considered throughout the broader managerial makeup of CCRS as well as with the Director General of the Topographic Mapping Agency. It was given the go-ahead, and thus the first Mapping Section within CCRS had its beginning.

6.6.8.2.2. Objectives of the New Mapping Section

The newly formed section was named the Satellite Mapping Development Section and was to research, develop and deliver methodologies that addressed fundamental (front end) processes that would both support and help derive information necessary for mapping (e.g. DEM generation, feature recognition and extraction). Since a number of different types of methodologies were involved and different types of mapping were apparent, the three expected overarching outcomes of the activity were crafted as follows:

- **Contributions to Mapping Activities:** Research, development, and demonstration of the capabilities of remotely sensed data to support mapping activities in environments such as federal and provincial agencies, environmental, urban/municipal; in so doing to seek collaborative research initiatives with agencies such as the Canada Centre for Topographic Information;
- **Development of Industrial Partnerships:** Development of an industrial capability to use high-resolution space borne imagery and RADARSAT data to meet selected information needs of users (e.g. topographic, environmental, and municipal mapping information); and
- **Contribute to the Use of Remote Sensing Techniques in an Internet Environment:** When applicable provide direction to GeoCan and Industry for establishing access to remote sensing and mapping techniques from an Internet environment.

6.6.8.2.3. Refocusing the Science

In early 1993 or thereabouts, the newly formed Section was comprised of a number of scientists, notably Drs. Bert Guindon, Jack Gibson, Laurence Gray, Thierry Toutin, Karl Staenz and Dr. Richardson as the Section Head. A year later, Drs. Bob Hawkins and Ridha Touzi were added to the scientific staff.[208] CCRS had considerable relevant expertise within the Centre, but many aspects needed to be realigned or let go if the new Mapping Program was to focus on delivering the objectives set out to senior management. Simply stated, if work was being done within the newly developed and refocussed mapping program that was no longer germane to its objectives, it had to stop or be put into a more relevant section. The transition from ongoing work to new challenges required a re-orientation of the science in a number of areas including radiometric correction, development of automated ground control points, digital elevation models, use of RADARSAT in mapping, and planimetric feature extraction.

Radiometric Correction: CCRS had an important role in the area of data validation such as radiometric performance/assessment. Only peripheral emphasis, however, was now to be placed on radiometric correction as related to the work of the mapping section. Although it was essential in presenting appropriately mosaicked images, techniques and expertise were available both through universities and in Canadian industry thereby diminishing the need for the Mapping Section's continued participation.

Support for Mapping from Geocoded Imagery, the Need for Ground Control Points: Precision corrected satellite image products required auxiliary input, in particular precise positions for a selected set of features (ground control points or GCPs) visible on the imagery. High level processing throughput could only be achieved if GCP marking was accomplished in an automated fashion using GCP image chips. GCP databases in use for satellite data were not readily available to users nor were they suitable for the correction of high resolution (1-3 meter) satellite imagery. In the early 1990s, a pilot program was launched in support of the CEODesk Project, to assess the feasibility of employing GCPs extracted from the federal Aerial Survey Data Base (ASDB) of aerial photography (north of 50 degrees Latitude) and provincial mapping data of southern areas of the country. Initial investigations of digitized ASDB photography, processed with the GEOCOR software indicated that it would be possible to generate one meter resolution image chips with sub pixel positioning accuracy. This was an impressive improvement at the time. The pilot program involved the generation and assessment of approximately 4000 GCPs. Some support was provided from the new Satellite Mapping Development Section by Dr. Jack Gibson as the need arose. As things progressed, however, this activity was not considered leading edge research, so guidance and advice was provided only on request. (Investigations were designed to assess coupling the GEOCOR software with CEODesk so that resources could go online.)

DEM Generation (Optical Imagery): Digital elevation data were and are required at many different scales and for applications as varied as supporting corrections to satellite data, communications, and engineering projects. CCRS had a strong capability in DEM generation using high and medium resolution airborne and satellite electro-optical data, as well as both airborne and space borne stereo and interferometric SAR. In the early 1990s continuing an active R&D portfolio was necessary to ensure that technology transfer to Canadian industry was a success. Strategic alliances between CCRS and some of the commercial vendors of high-resolution satellite imagery were actively and successfully pursued. At the time, consideration of an industrial service for the delivery of DEM generation via an Internet environment offered a potential area within which CCRS could support the underlying delivery of methodologies. In this context, industry was to provide a new service tool for the DEM generation, along with rapid product delivery.

[208] Some of the work of these scientists is described in other Sections. There is work on microwave applications development by Dr. Laurence Gray, on polarimetry by Dr. RidhaTouzi, SAR data by Dr. Bob Hawkins, and the work on hyperspectral data by Dr. Karl Staenz. This section focusses more on the research applied to what may be considered more traditional mapping.

Thematic Mapping; RADARSAT: SAR image exploitation, especially stereo and interferometric SAR (InSAR) was continued to support the provision of information relating to terrain height extraction and terrain movement discussed in the next several paragraphs.

Terrain height extraction appeared to be a potentially important use of radar data. Market opportunities for international sales of large area (low resolution) DEMs remained uncertain, however, the potential Shuttle Radar Topographic Mission (SRTM) in 1999 or 2000 would likely require the development of refined capabilities of radar techniques. MacDonald Dettwiler and Associates had already identified the mapping market as one of their two important business areas behind the investment in and development of RADARSAT 2. There was also the potential for combined datasets from RADARSAT 2 with RADARSAT 1 to provide both increased accuracy and an enhanced resolution DEM for more marketable products. It was thought that the Satellite Mapping Development Section could work with both UBC (Prof. Cumming) and MDA to explore the best options for DTM generation with combinations of RADARSAT data. SMDS had a successful Announcement of Opportunity project approved by DLR, Germany, to work with the SRTM X-band DTM data. This work was done with the Centre for Topographic Information.

Terrain movement was important for several application areas. Using SAR and interferometric SAR would contribute to data sources and knowledge for monitoring global warming. Terrain movement was an outcome in part of methodologies developed by Dr. Laurence Gray for glacial ice movement and discharge (related to global climate change and sea level rise), measuring small terrain movement (e.g. related to seismic activity), and terrain feature change (e.g. ice fields, permafrost, ground ice, and rock slides).

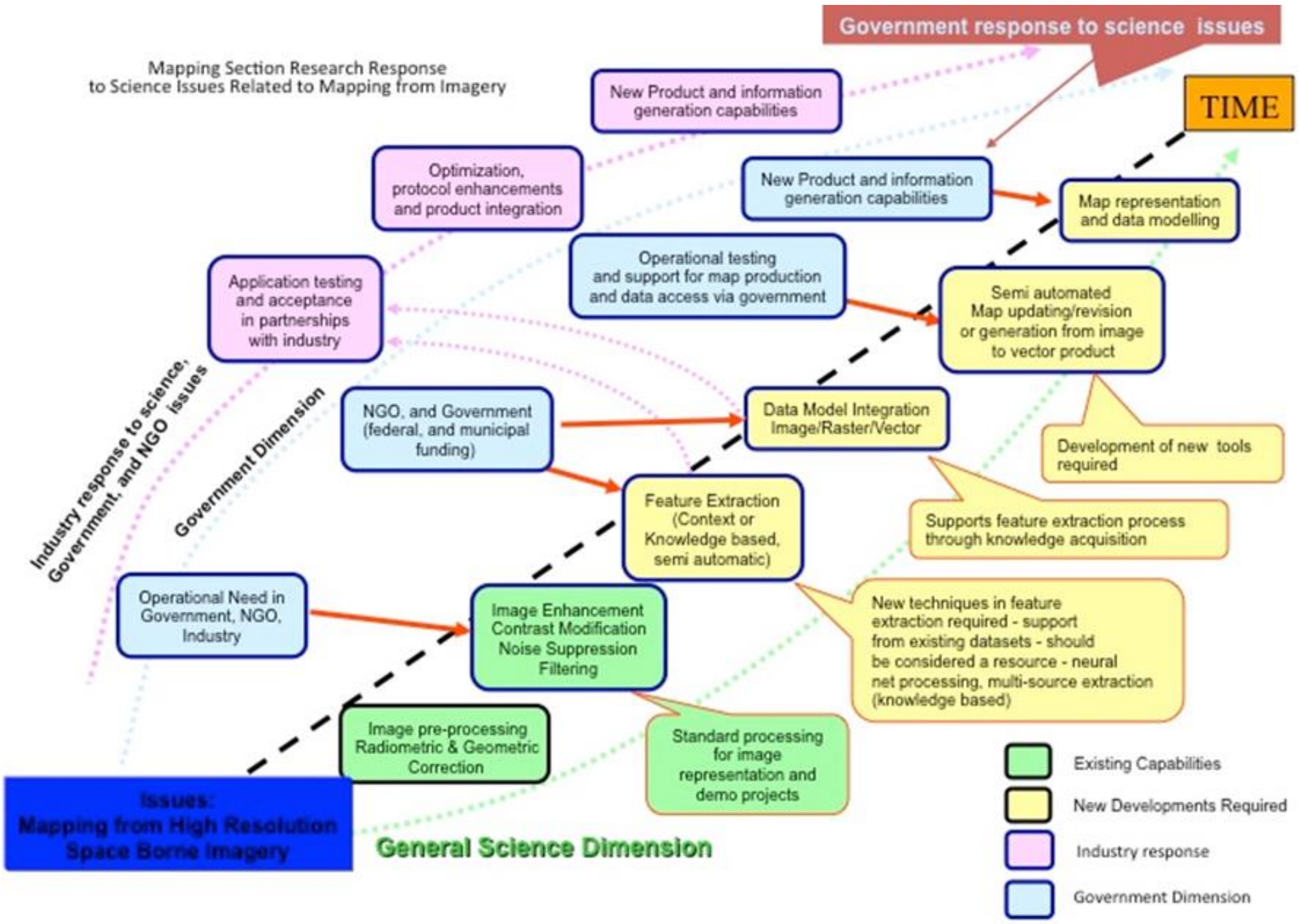
Both the terrain height extraction and terrain feature movement were contributions to the Disaster Information Centre (DICE) at the University of Manitoba, Winnipeg. Terrain height contributed to their flood risk assessment and prediction research, while terrain movement was important in ice and sea ice characterization and temporal change research. Terrain movement with differential InSAR was also one of the foci of the 'Natural Hazards and Disaster Monitoring' GEOIDE proposal in which CCRS and Atlantis became working partners.

Planimetric feature extraction: Planimetric feature extraction methodologies using stereoscopic data would contribute to knowledge for mapping man-made structures and was an appropriate area of application of RADARSAT data. Road feature extraction had proven successful and the results were evaluated for use with vector form map data.

6.6.8.2.4. New Challenges in Thematic and Topographic Mapping from Imagery

6.6.8.2.4.1. Introduction

The Satellite Mapping Development Section needed a clear path – in so far as that might be possible – in an effort to move the science along a temporal trajectory that allowed the CCRS to lead the parade in technology development rather than follow along behind. In the 1990s and early 2000s Internet technology, advances in data capture, database processing among many other aspects were changing rapidly and in unexpected ways. A simple plan was crafted that loosely explored the relationships among industry, government science, academe and research to provide some focus. The following figure provides an overview of these relationships between industry, government and science initiatives relevant to the SMDS ~ 1997-2001.



An understanding of these relationships allowed the SMDS to crystalize plans to move forward and set the research agenda for the next few years. Three technical topics provided the focus of these plans: feature extraction and classification, data integration, and generalization. Each of these is explained in turn in the following Subsections.[209]

6.6.8.2.4.2. Feature Extraction and Classification

Among many other aspects, two basic issues were important for feature extraction and classification of high-resolution imagery for the development of methodologies applicable to, but not limited to, mapping.

First, development of recognition capabilities based on both spatial and contextual information was and are applicable to enhance feature extraction processes from high-resolution space borne imagery. These processes were to be designed to support the application of advanced concepts and tools necessary to generate automatic and semi-automatic classifications suitable for application specific tasks and to support mapping activities.

Second, feature extraction and classification using high-resolution space-borne data would require additional spatial information for high-level tasks. Traditional image analysis tools were inappropriate for high spatial resolution data or panchromatic imagery. Thus, more direct and effective links had to be

[209] Editor's Note: While some of the technical detail provided here may be difficult for the lay reader, it has largely been left intact to maintain the technical thread for the more technically inclined reader.

established between the results/output from the application of image understanding research and its subsequent use and inclusion with vector domain GIS environments. The above two areas embraced the development of methodologies in feature recognition and extraction, image enhancement, and generalization, spatial and ancillary data integration. At a later stage these aspects were to be linked with appropriate integration processes involving image/vector translation at the data model level. (Richardson, 1996)

6.6.8.2.4.3. Data Integration

Data integration was considered very important if imagery was to effectively contribute to 'mapping'. However, most efforts in data integration at the time had been undertaken at the geometric level. Usually, geometric integration was explored and resolved within a single model domain, i.e. vector/vector, or raster/raster.

More advanced research in this area was addressed for the creation of techniques involving both geometric and semantic data integration across a selected number of resolutions, and scales. These were to be limited to high resolution space borne optical imagery, and relatively detailed vector based data ~ 1:20 000. With testing, high-resolution data were explored in efforts to supplement existing lower resolution data. As a result, an image or map could be produced with variable resolution and variable certainty. Products of this nature were to play an important role in map revision, and disaster monitoring, where lower resolution data sufficed for the less significant topographic area while the higher resolution data could be integrated for increased detail and visualization. The direct impact of this research was in map generation and map revision.

Research into data generalization, followed by development of methods for geometric, semantic, and data model integration, offered the potential of techniques suitable for environmental, ecological, and land use monitoring, urban planning, census and demographic and topographic mapping. This was an area with limited expertise in CCRS. As such, universities were contacted and a preliminary project developed under the GEOIDE program. Additionally, consulting work was initiated with the Topographic Engineering Center for the U.S. Army and involved three industrial partners, Mercator Systems, Cubewerx and Intergraph.

6.6.8.2.4.4. Generalization

At detailed scales or high resolutions such as 1 - 3 meters, the spatially heterogeneous nature of the data restricts the transformation of information from one scale to another. In image data, generalization could take place before analysis by pixel resampling, or grouping after analysis to produce a minimum map unit. Where homogeneous data predominated, problems related to multiple scaling in spatial phenomena may not occur. Generalization of measurements on observable heterogeneous phenomena captured at a large geographic scale generally could not be invoked directly to produce medium scale or regional estimates. This suggested that increasing the level of heterogeneity of the phenomena under observation also increased the difficulty of extrapolating information across scales.

Generalization was an area of research that addressed issues in data integration, data abstractions, and representation. These processes allowed the automatic derivation of spatial and semantic information to less dense and complex presentations both at the representation level as well as database. This research, in conjunction with feature extraction and data integration, offered potential for mapping from high-resolution imagery, with subsequent representation in map form. Smaller scale derivations for automatic density reductions had already been developed and tested at CCRS. Thus, the 'back end' processing was in place, and the 'front-end' data input processes needed to be enhanced. Thus, the feature extraction and integration issues were the higher priorities. (Richardson, 1994b; Thomson and Richardson, 1996; Richardson and Mackaness, 1998)

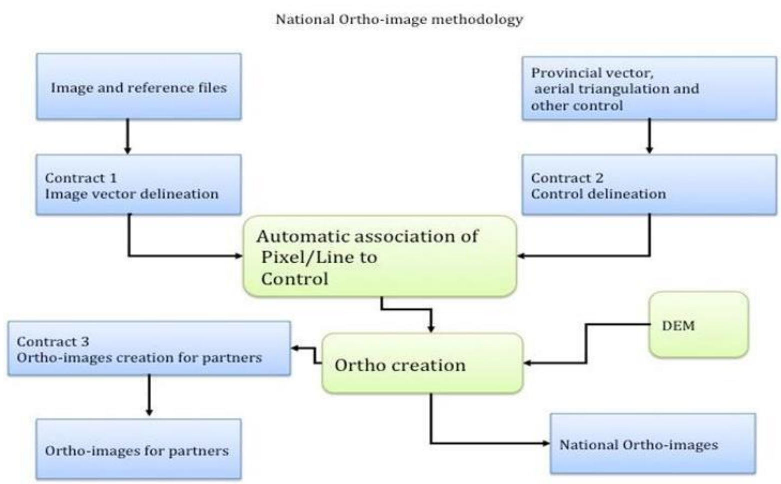
6.6.8.2.5. Map Revision

An important step in the research associated with map revisions was to focus on higher resolution optical imagery for vector-based mapping. These data could be extremely useful for updating topographic maps. Landsat-7 was also a target for facilitating the enhancement for a 'national adjustment.' Multi resolution feature extraction became a focus largely for the hydrography and transportation network recognition among other objects and features. At the same time, regional land cover mapping for environmental assessments was also considered.

Landsat-7 was an easy target for, between the two Sectors, CCRS talent and Mapping Services' needs were well aligned for the initiative. The objective in using Landsat-7 was to produce a complete set of cloud free ortho-images covering the Canadian landmass. Landsat-7 data of the Canadian landmass was routinely acquired and archived by CCRS. The focus for coverage included summer imagery for the years 1999 to 2005. The data were processed to level 1G (geometrically corrected) and ortho-rectified for the Centre for Topographic Information (CTI) in Sherbrooke. The Internet delivery mechanism exploited the GeoGratis environment.

Funding approval was given in February 2000, for a $175,000 project. A formal agreement was established between CCRS and CTI, which outlined each partner's contribution. The partnership largely involved the collection, processing, and delivery of Landsat 7 data with free access via the web portal GeoGratis.

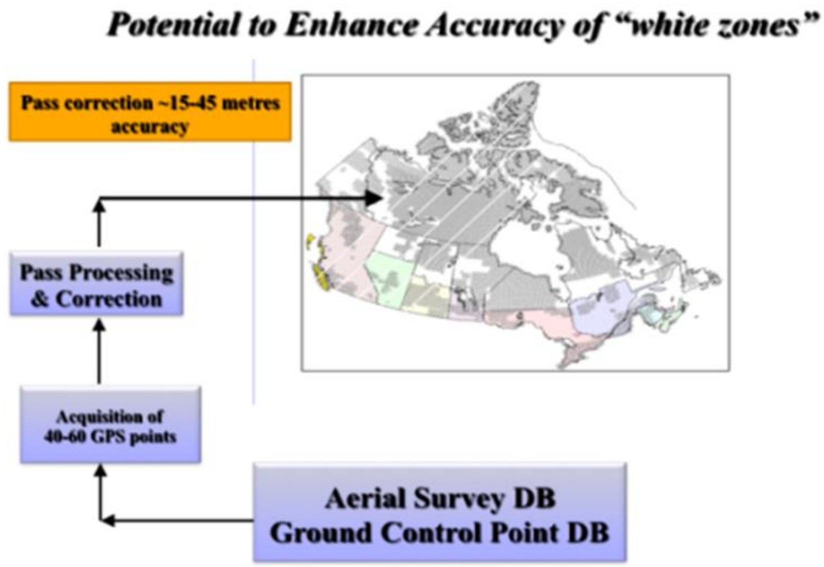
The detailed objectives involved using the best geometric control available for image correction and the use of provincial data when possible. The entire Canadian landmass was to be covered with the ortho images and CCRS would evaluate the accuracy of the ortho images. A three-way partnership was established among the CCRS, CTI [Sherbrook] and the provinces. The provinces provided selected detail for control. An image acquisition plan for the summers of 1999 through 2001 was developed to obtain cloud-free data.



With access to provincial data for ground control the estimated accuracy improved. In the southern part of Canada, accuracy of 30 metres or better was achieved. At that time accuracies of 150 metres or better were expected for the northern part of Canada. A new project was initiated to improve the accuracy of the northern areas and, by so doing, improve our overall mapping accuracy. The process involved to create the national ortho-images was quite straightforward and is shown in the accompanying figure.

There were numerous benefits in pursuing the ortho-image initiative. A better framework of topographic features would result with the better ground control. The ortho images would fit provincial data and further, consistent imagery of roughly the same time stamp and accuracy would be available for the entire Canadian landmass. Provincial agencies would be in a better position to update their own topographic maps. Another very important aspect was that 'vertical integration' or in other words, integration of data through multiple layers would achieve improved geometric harmony.

CCRS went on to resolve outstanding challenges with the ortho-image mapping that logically were the result of an absence of ground control points. While partnerships with the provinces facilitated the initial ortho-map project, there were still areas in the country for which adequate ground control was an issue. In an effort to keep moving forward a new initiative was launched and referred to as the 'National Adjustment'. It focused on establishing the right information 'tapestry' for base mapping the objective of which was to achieve the best accuracy possible, given the resolution and size of the Canadian landmass, This was done in an attempt to bridge areas in the country for which acceptable ground control was not available. As such, 'pass corrections' were established that would render accuracies of 15 – 45 metres and would bridge 'white zones' or those zones lacking GCPs, as shown in the accompanying figure



The National Adjustment initiative provided a unified imagery base for seamless nation-wide image mosaics. The error in the adjustment could be uniformly distributed and secondary derived control would be available anywhere. Multiple data layers could then be easily co-ordinated with the imager, thereby facilitating better quality thematic mapping.

Improved Accuracy of Ortho-images as a Result of Different Sources of Ground Control						
	Accuracy in Meters					
Source of Control	15m	20m	30m	40m	50m	150m
Provincial	X	X	X			
ASDB			X	X	X	
1:250,000						X
GCDB			X	X		
National Adjustment				~X		
ASDB=Aerial Survey Data Base; and GCDB = Ground Control Point Data Base						

6.6.8.2.6. Further Advances through Partnering with Canadian Industry, U.S. Military, and Canadian Universities

As mentioned above, the new CCRS Satellite Mapping Development Section arrived on the scene just as high-resolution satellite data from a number of new sensors became available. There was broad interest in these new data sources. Partnerships were readily available through the Canadian and U.S. Military, Canadian Universities and with other government departments. Much interest was expressed in the development of what is called object extraction for applications in transportation network mapping, hydrographic network mapping along with land-use and land-cover mapping.

One of the first steps in exploring these new data sources was to examine the likelihood of automatic techniques for object extraction – road network, hydrographic network, etc. Once again, recognizing that certain objects are fundamental to most types of mapping, work was purposely focussed on transportation networks. These provide a sense of direction and relationship to the landscape to almost every map viewer and they serve as a fundamental reference. Historically, these objects had been extracted from aerial photography, a fairly labour and time consuming effort. If we could exploit digital image processing, we would move the mapping process forward and reduce the overhead in creating this essential information for map revision.

A multistep process was initiated that involved both CCRS staff as well as the larger university community. Dr. Richardson initiated a project within CCRS that directly exploited software development techniques for automatic object extraction and at the same time launched a university partnership project with the University of Victoria and the University of Quebec at Hull, Quebec. As well, a number of Canadian high tech companies expressed enthusiasm for partnering and both Cubewerx and Mercator Systems joined the initiative.

Efforts to advance using multiple layers of geospatial data at different resolutions for feature extraction required involvement from many sectors. In the late 90's, Richardson developed co-operative research and development for processes referred to as 'path analyses and multi-resolution vector based processing' which was funded through Canadian industry and by the Topographic Engineering Centre of the U.S. Army, (TEC). A large collaborative science program for the development of analytical methods for processing of high-resolution optical imagery was conceived, designed and assembled. This work was funded by various agencies to a total of about $730k/year. With in-kind support these efforts were funded to around $1.3 million/year.

Additionally, advances were made with software development that allowed industry uptake through PCI Carto. Licensing agreements for software generated over a number of years were transferred to PCI in the field of automatic database generalization.

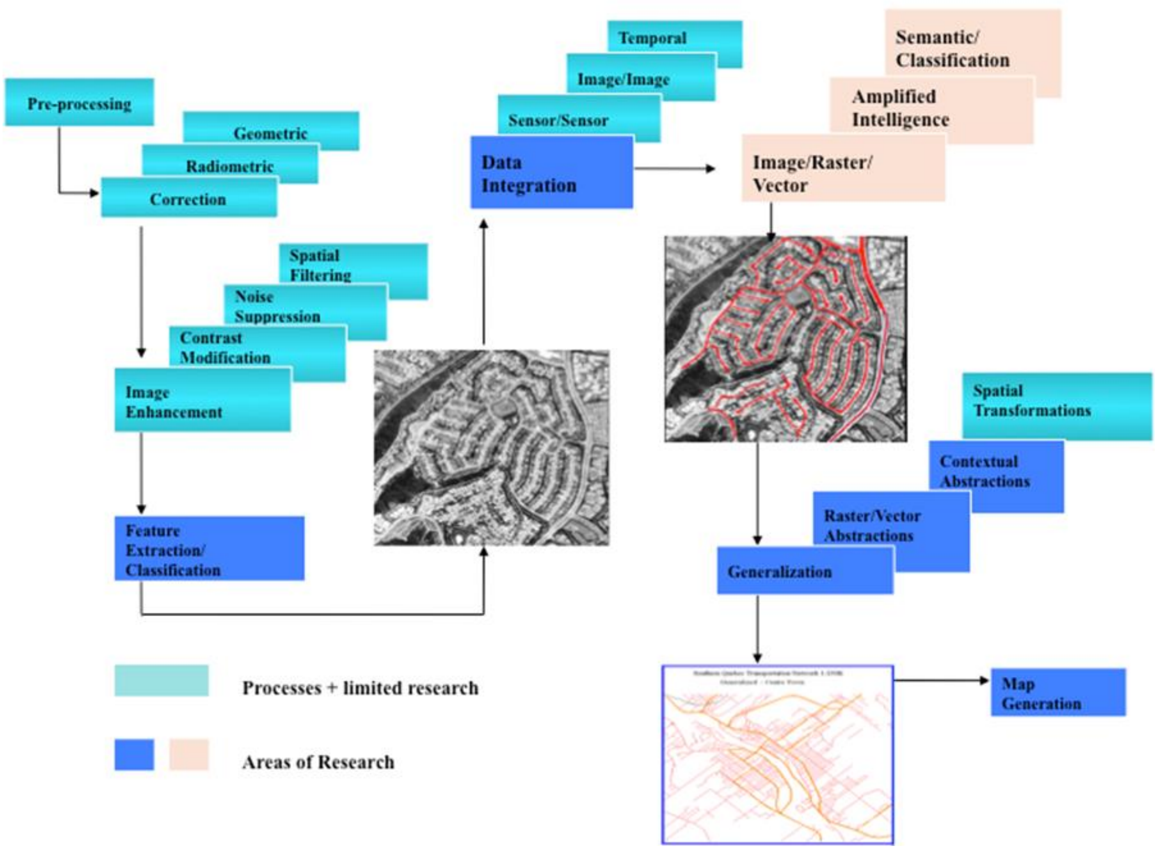
A number of Canadian companies worked closely with Richardson and her team, namely Swiftsure Spatial Systems Inc. (formerly Mercator Systems Ltd.), Cubewerx Inc., and Holonics Data Management Group. In late 1999 Non-Disclosure agreements were established and subsequently detailed technical documentation necessary for software development purposes was transferred. The three companies developed new Internet mapping services, in part based on technology conceived and tested by Richardson and her team. To this end, these companies consulted regularly with the CCRS team through the revolving fund.

In the late 1990s a great deal of work was underway using multiple source geospatial data. The National Image and Mapping Agency, U.S. Department of Defense, (NIMA) invited Richardson to develop a new methodology for the development of multi-resolution object querying. In the late 90's, the only technology development of this sort was experimental work done by Intergraph Corporation. Since results from Intergraph processing only rendered about a 65-70% level of accuracy, NIMA had asked Richardson and her team to develop a more sophisticated technique based on object-to-object correlation. The Topographic Engineering Corps (TEC) of the U.S. Army requested that this work be pursued in an attempt to create something more successful. The impact of this technology rested in the benefits gained through partitioning data activities necessary for automatic map revision and map querying. The partitioning is rendered possible since multiple source data could be queried and applied to determine the 'best map'. It also meant that the "best answer" could be delivered by exploiting information at many different levels of detail, classification, and accuracy. The experimentation for NIMA focused on shoreline data, whereas with TEC it involved multi-source transportation networks.

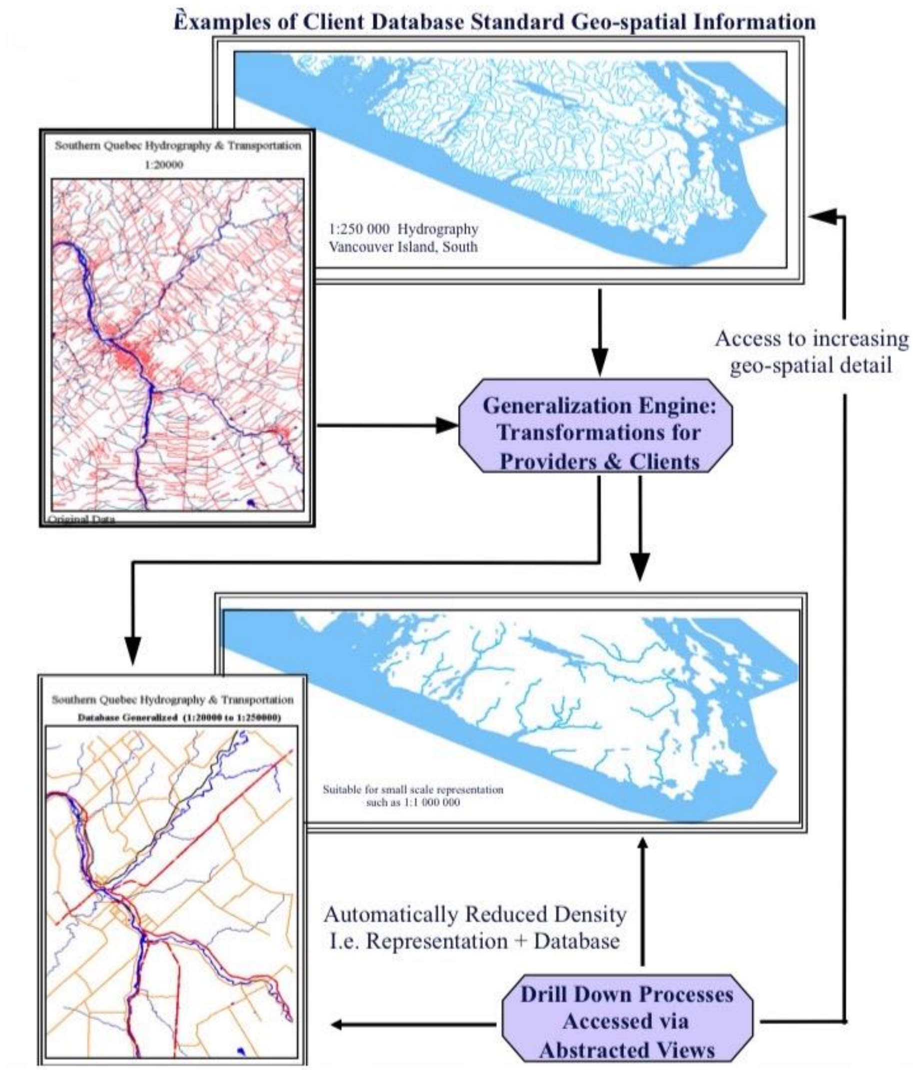
Another development that moved the mapping agenda along was referred to as "path analyses processes" (Shortest Path Spanning Trees or SPST), which were transferred to the U.S. Military. The SPST could rapidly sift through multiple sources of vector-based data and derive transportation networks based on temporally, spatially, and semantically heterogeneous data. By offering this capability, it meant that fewer map revisions needed to be made and that maps could be contrived in emergency situations if needed. To acquire these techniques, among others, the U.S. Military awarded over $1million in contracts to Canadian companies who were involved in this work with CCRS. (Richardson 1994c and Thomson and Richardson, 1995)

Other companies were intrigued by this type of software performance and licensing agreements with PCI were established for the acquisition of the software techniques in data pre-processing, enrichment, generalization, and thresholding. PCI was awarded ~$680k from IRAP and provided 30% additional funding to make the techniques workable.

The processes and research areas necessary to achieve automatic object extraction from high-resolution optical imagery are outlined in the following figure.



The Mapping Section was also involved with providing advice and software to the National Atlas of Canada staff in data pre-processing and generalization. As a result, the National Atlas replaced their older base map material with more accurate DND data. This put them in a position to map far more rapidly and with scale independence. Examples of pre-generalized map data and the results following rule-based generalization is shown in the figure below. These newly (at the time) developed and experimental operations could potentially save weeks to months of work for a cartographer. Rupert Brooks and Robert Thomson assisted in moving the software from the Canada Centre of Remote Sensing to a National Atlas of Canada platform.



Along the way a number of non-disclosure agreements were established to allow others to obtain access to the software, detailed documentation, and engineering specifications that were developed. One was with Holonics Data Management Group and another with Swiftsure Ltd. The objective was to build new technologies and package the techniques as a series of software services for Internet applications in geo-spatial processing.

Richardson brought together academic research teams from three universities, industry and government partners in a proposal for a multi-university Network Centre of Excellence project under the umbrella of GEOIDE. It was entitled "Development of Automated Techniques to Extract, Generalize, and Access Geospatial Information from Hyperspatial Remotely Sensed Data." This project would substantially advance the research work at CCRS and influence university and industry programs.

The following tables outline a number of the projects under the Satellite Mapping Development Section and both industry and agency partners.

Satellite Mapping Development Section Projects
High Resolution Space Borne Imagery Projects • DEM generation from high res satellite data using GEOCOR software was tested and explored with a delivery tool via the Internet; (Simulated data were successfully tested); • Assessment of high res products for remote sensing applications development in forestry, mapping, and environmental monitoring, among others: simulated datasets were also explored;

- Feature extraction of planimetric features in urban areas (simulated high res datasets);
- Continued R&D guidance for the establishment of the GCP database; and
- Investigated the merit of a high res mosaic of the Canadian ecumene and determined its potential for object linking to vector based (provincial) datasets.

Multi-Resolution R&D Projects

- Explored tool development for spatial data manipulation such as automatic generalization and multi-resolution feature linking; and
- Established and undertook collaboration with CubeWerx, Mercator Systems, Intergraph and the U.S. Army for dynamic multi-source, multi-resolution feature linking and application development.

RADARSAT R&D Projects

- Finalized RADARSAT stereo extraction processes;
- Started planimetric feature extraction from stereo RADARSAT;
- Applied stereo methods to ENVISAT data as well as evaluated polarimetric data as a mechanism to extrapolate algorithmic requirements for RADARSAT 2;
- Used InSAR and stereo techniques for planimetric, altimetric and terrain displacement R&D; and
- Finalized the RADARSAT Training Tool Kit on CD-Rom and on the web.

Industry and Agency Partners – Satellite Mapping Development Section

Industry Partners

- Multiple scene bundle adjustment (with PCI);
- DEM extraction from spaceborne and airborne SAR (with Atlantis and PCI; Texaco as client);
- Korean Satellite geometric processing (with PCI and Datron, US); and
- Collaboration with PCI, Universal Systems, CubeWerx, for automatic generalization of spatial data.

Agency Partners

- DEM product evaluation. (co-operation with Centre for Topographic Information [CTI] Ottawa, Forestry Canada, Atlantis, GeoCan, and J2 Geomatics);
- High Res satellite imagery feature extraction collaboration with CTI;
- Integration and generalization of spatial datasets in collaboration with CTI;
- Differential InSAR for glacial ice motion with NASA Goddard Space Flight Center, JPL, Ohio-State University (Byrd Polar Research Center), Japan (NASDA, JAMSTEC and Kochi U.), Australia (U Tasmania), and GSC Glaciology;
- Continued cooperation with DND, NIMA, and the Topographic Engineering Centre of the U.S. Army, Mercator Alliance, USL, Intergraph, HydraSpace, Cubewerx and PCI for high level tools for automatic generalization;
- Collaborated with University of Alberta and the Geological Survey of Canada using fused datasets for geological and geomorphologic mapping applications, Moose Mountains, GEOIDE;
- Collaborated with the University of Victoria, Laval, and Universite du Hull on high-resolution feature extraction (space borne imagery) and integration with vector based data sets for map revision (GEOIDE); and
- R&D to exploit differential satellite InSAR for terrain movement in particular for the discrimination of tectonic movement and earthquakes (GEOIDE).

6.6.8.3. 3D Topographic Mapping

Thierry Toutin

At the end of the 1980s, with the launch of the new French SPOT satellite with high-resolution VIR stereo-sensors it was important to take full advantage of this new source of Earth Observation (EO) stereo data for Energy Mines and Resources to meet its 3D topographic mapping mandate. In response, CCRS scientists developed a new 3D mathematical model and algorithms fully adapted to the special characteristics of the SPOT satellite stereo sensors to accurately ortho-rectify the image data with sub-pixel accuracy. (Toutin and Carbonneau, 1989) This mathematical model integrated knowledge of satellite orbitography, sensor technology, photo-/radar-grammetry, geodesy, stereoscopy and mapping. Later on, in collaboration with Laval University, these models and algorithms were ported into a PC stereo-workstation, to on-line process stereo data for 3D topographic mapping. (Toutin and Beaudoin, 1995) Both systems were customised to fit the Department's map production process.

Over three decades, these algorithms were harmonized to match the characteristics of each new space- and air-borne platform and sensor in the visible and microwave spectrum from medium to very high resolution, such as Landsat-5/7, ASTER, SPOT-1/5, EROS-A/B, IKONOS, QuickBird, ERS, JERS, TerraSAR-X, Radarsat-1/2,Terra-SAR, COSMO-SkyMed, RCM, the airborne Convair-580 SAR and others. (Toutin, 1989, 1999; 2004; Toutin and Omari, 2011; Toutin *et al*., 2014)

Due to their versatility, effectiveness, accuracy and ease-of-use the systems were licensed with regular upgrades for more than 25 years to different Canadian system/service companies with royalties to the Department. They were used for many different applications (3D mapping, geology, forestry, hydrology, glaciology, etc.) within national and international CCRS programs (GlobeSAR, SAREX-92, Radarsat-1/2, RCM…). In addition, research with ortho-rectification of Radarsat-2 SAR data demonstrated its capability to perform 3D topographic mapping, and other thematic applications, without any terrain survey. (Toutin and Omari, 2011) More than 20 maps not previously produced at latitudes over 80° were made for the first time using stereo high-resolution Radarsat-2 SAR data with no need to acquire ground control points. The Department saved tens of thousands dollars and was then able to finalize the 1:50 000 topographic map program in the North, fulfilling its mandate on time.

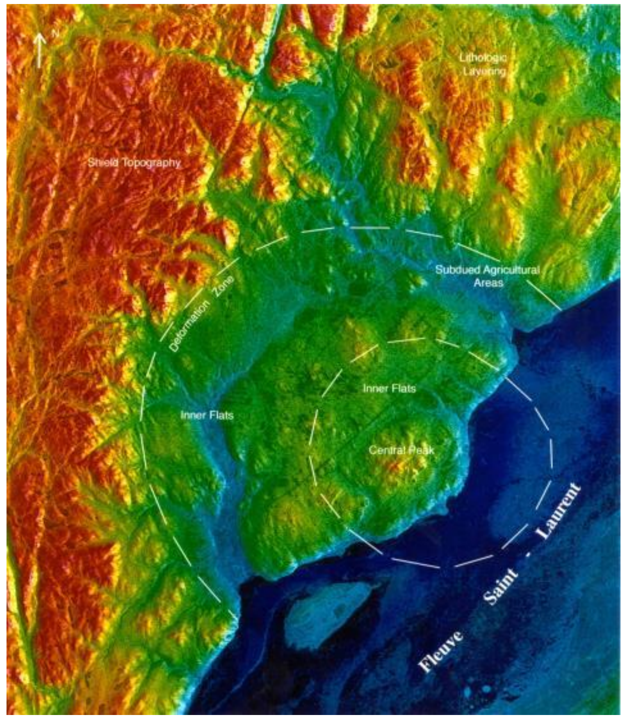
These tools were also used and are still being used in Canada and worldwide by research centres, universities, service companies and international organizations. This wide use increased the international visibility of CCRS. As an example, the new millennium brought the advent of a new generation of VIR sensors with very high resolution (0.6-2.0 m), mainly in the USA (Ikonos, QuickBird, WorldView) but also in France (SPOT5) and Israel (EROS-B) to improve mapping applications. While most of the relevant information related to the satellite and its sensor were not always available, CCRS scientists were able to overcome this lack of data to adapt previous mathematical models and algorithms to these sources of data. (Toutin, 2004) Using Radarsat-2 data, CCRS scientists improved the 3D mathematical model and algorithms to process these very high resolution data without any ground control (Toutin and Omari, 2011) increasing the versatility and use of the CCRS-developed model. One of the most recent and largest impacts for CCRS and the Department were:

- The creation of the pan-Canadian coverage with thousands of ortho-images from SPOT4/5 HRV/HRG; and
- The planimetric update of 306 map sheets at 1:50,000 and creation of DTMs in the North using 105 stereoscopic couples of SPOT5-HRS.

The client would not have been able to finalize this SPOT pan-Canadian coverage and the 306 maps without the support of the research that had produced the models and algorithms.

By the mid 1990's, a new 3D method, the chromo-stereoscopy, was developed at CCRS to be applied for 3D applications mapping. (Toutin, 1995) This new 3D tool is based on a phenomenon named chromostereopsis, in which coplanar coloured stimuli are perceived as differences in apparent depth. Chromostereopsis is due to the transversal chromatic dispersion and the asymetrical relation of the visual and optical axes. The resulting chromatic dispersions for both eyes generate transversal parallaxes, which are a function of the wavelength and can thus be enhanced with special ChromaDepth™ glasses: the red colour appears higher than the blue colour with the other visible colours in between.

The method developed transforms a quantitative field (elevation, magnetic, gravity…) into blue-to-red colours and integrates it with an ortho-rectified remote sensing image. Within certain regions of the spectrum, subtle distinctions between two chromaticity's, as small as 5-10 Å, may be appreciated, and with extended practice, humans can discriminate 120 or more chromaticity's when intensity and saturation are constant, but many more if intensity and saturation vary. The brain then combines this 3D chromaticity cue with the 2-D picture to produce judgements about the relationship of objects in space. Consequently, the interpretation of the cartographic and remote sensing data can be easily and better performed by themselves (Figure 1) but more efficiently with the ChromaDepth™ glasses since they strongly increase the chromostereopsis and colour parallaxes. The figure to the right is a Chromo-stereoscopic image with Radarsat-1 fine mode SAR image and the combined elevation-bathymetric fields. (See Toutin and Rivard, 1997 for a higher quality rendition)



6.6.9. Oceans[210]

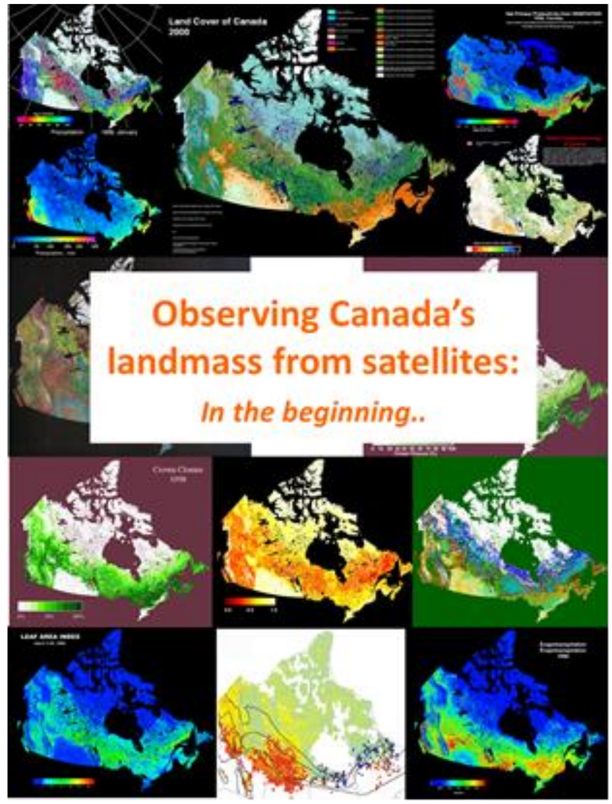
While there was significant work in Data Acquisition Division and in the RADARSAT Project Office on Oceans, the Applications Development work began when Jean-Claude Henein was Director of the Applications Division. The first person to be devoted to oceans applications was Dr. Marie-Catharine Mouchot. Dr. Mouchot did some excellent work at CCRS before returning to her native France. Over the years she maintained close ties with several former colleagues at CCRS. Eventually Cathryn Bjerkelund took on the responsibility for applications development work in oceans. She eventually left CCRS.

[210] Editor's Note: We have been unable to find an author with the appropriate background willing to write about this topic so a short summary has been prepared.

6.6.10. Canada- Wide Mapping and Monitoring for Global Change and Environmental Applications

Josef Cihlar

6.6.10.1. Introduction



Observing Canada's Landmass from Satellites (Cihlar, 2018, See Title Page to the right) is a monograph that reviews various aspects of monitoring activities at CCRS between about 1988 and 2004. It summarizes the initial motivation and purpose; the scientific and policy drivers; technology developments; the quest for resources to undertake the work; the establishment of a research team; program development and major projects undertaken; research challenges and solutions; results and information products (satellite or satellite + process models) obtained during this period; and a brief update to 2018. The report also shows that in addition to the CCRS research team, many other individuals made specific contributions, some of which were critical to the evolution of this program. These include CCRS managers; other CCRS scientists, engineers and IT specialists; and managers and scientists from other government departments as well as from other countries. In other words, it follows on the path of cooperation that was a hallmark of how CCRS operated.[211] Finally, it illustrates policy-science linkages within the federal government and the supportive role government science can – and should – play in helping the development of policy options.

The monograph title might appear somewhat pretentious – after all, were not all CCRS activities about monitoring Canada? Perhaps yes in a sense that prior to the existence of this program satellite data could be obtained anywhere in Canada provided one was patient (or lucky) because of cloud cover limitations and the initial complete reliance on Landsat platforms. But not so if one required a reliable source, capable of producing quality results. This is the genesis of the 'DOCLS' program (Daily Observations of Canada's Landmass from Satellites) described in the monograph.

6.6.10.2. The Setting

Applications Development Section (ADS) staff members were acutely aware of the coverage and reliability limitations of Landsat data. For some applications, these limitations were not serious; this was the case for geologic mapping but also for other themes where alternative data collection methods were infrequent (or non-existent). The situation changed dramatically when scientists and policy makers became concerned about 'global change.'

The search for more robust alternatives in the early 1980s included an effort to put a wide-swath, moderate resolution optical sensor on the first RADARSAT platform. A suitable sensor was defined (Cihlar *et al*., 1984), and technical discussions between the RADARSAT Project Office and NASA Goddard Space Flight Center engineers (Barnes[212] and co-workers) indicated such a sensor could be built. Eventually, the available budget eliminated this option and RADARSAT became a single-sensor platform.

[211] Editor's note: This section also highlights another aspect of how CCRS operated: Dr. Cihlar is very careful to name and give credit to those who contributed to the success of the work.
[212] A list of those named here by surname and their affiliations is given in a text box at the end of this section.

Concerns about the pervasive and growing impact of humans on the environment first reached the global level in 1972 when the United Nations resolved to establish the UN Environment Program. As scientific evidence of the impacts and environmental changes accumulated, it became evident that we do not really understand many aspects of the Earth's environment, the consequences of human actions, and what remedies would be most effective. This realization led to the creation of the International Geosphere-Biosphere Program (IGBP) by the International Council of Scientific Unions in 1986. IGBP defined a global research program but also spawned many National Committees and their programs. In Canada, the leadership in program development was taken on by the Royal Society of Canada.

The scientific community realized that global change research is impossible without satellite observations playing a key critical role. Thus, at an International Space Year planning conference, IGBP representative Thomas Malone stated:

> "We stand on the threshold of a renaissance in the sciences concerned with the Planet Earth, including its flora, fauna, and the humans who call it home. This renaissance has its origins – in no small part – in the powerful observational capability provided by space technology. Its fulfillment is conditioned – in no small measure – on the initiative, imagination, and active involvement of the international community of space agencies. This involvement is more than merely supplying the promising new technology of 'remote sensing'. It will require intensive participation in the birth of a sweeping new science, one that promises to illuminate over the next few decades the intimate interaction of the geosphere and biosphere and the role of human activity in inducing global change. . ." (Meyerson, 1988, p. 31)

With NASA initiative, the International Space Year (1992) provided the initial impetus for the development of space programs in many countries to support global change-type applications. In the US, this took the form of the Mission To Planet Earth, a planned ten year program involving new satellite missions, sensors, information technologies, information products and scientific investigations. In Canada, two 'terrestrial' ISY projects were undertaken (Global Change Encyclopedia and Land Cover, see below); and the momentum created carried on through other programs during the 1990s and beyond.

CCRS involvement in global change activities began plainly enough: in December 1986 Cihlar (as Head of the Applications Development Section) attended a meeting on the IGBP organized by the Royal Society of Canada in Ottawa. He realized that earth observation was an essential and indispensable tool in global change applications, and therefore this area was of key importance to CCRS mission. CCRS management at the time (Sayn-Wittgenstein as Director General and Henein as Director of the Applications Division) clearly understood the relevance, and with the support of other Directors and Hugh O'Donnell (Assistant Deputy Minister at the time) embarked upon the development of a supporting program at CCRS. This included cooperation with the Royal Society. Among others, Cihlar helped found and co-chaired (with LeDrew) the Remote Sensing Technical Group (RSTG); O'Donnell and Sayn-Wittgenstein participated in the planning of the Canadian Global Change Program (CGCP), and contributed to the formation of the Resource Group on Data and Information Systems; and the Sector co-published two important reports: '***Contribution of satellite observations to the Canadian Global Change program'*** written by the RSTG (Cihlar *et al*., 1988) and a BOREAS planning workshop report. (Cihlar, 1990)

In 1988, NASA issued an announcement of opportunity for scientific participation in the "Mission to Planet Earth." Science teams from other countries were not eligible for funding but would receive free data and access to other relevant US facilities. Sayn-Wittgenstein endorsed a proposal for the 'Northern Biosphere Observation and Modeling Experiment' (NBIOME) with Cihlar as Principal Investigator and a team including Ahern, Brown, Teillet, Fisher and external co- investigators. NBIOME overlapped with the ISY Land Cover project, and so the ISY resources could be used more effectively.

6.6.10.3. Challenges

In the late 1980s, the most promising source of satellite data for large- area applications was the Advanced Very High Resolution Radiometer (AVHRR) carried onboard US National Oceanic and Atmospheric Administration (NOAA) satellites. AVHRR obtains full global coverage twice a day. These data, intended for meteorological applications, were not paid any attention by the Canadian terrestrial remote sensing community, primarily because of the relatively poor spatial resolution (1.1 km at nadir), the lack of data reception capabilities,[213] and the strong focus on Landsat.[214]

As a step in establishing the new program, CCRS resolved to 'upgrade' the Canada- wide AVHRR data reception and archiving system. The decision was based on a proposal presented by Cihlar and Fisher on February 11, 1988. A new AVHRR reception and archiving system was established at the Prince Albert Satellite Station. Eastern Canada coverage was initially provided from Shoe Cove, and later through various arrangements with AES, Fisheries and Oceans, etc. The implementation and operation of this new capability was led by the Data Acquisition Division (for reception and archiving: Irwin, Anderson) and Data Processing Division (signal processing, data archiving and retrieval; Fisher, Guertin). Starting in 1993, full growing season daytime AVHRR data (whole passes within the station mask) were acquired and archived.[215]

AVHRR data processing and information extraction were the other major challenges. While in the case of Landsat the signal processing and product generation enjoyed the attention and funding of a large community in Canada and elsewhere: AVHRR was less than a 'poor cousin'. Experience with AVHRR data was mostly limited to the atmospheric community, although NOAA did generate one terrestrial product (vegetation index). At the time, the most advanced group in this respect was led by Tucker at NASA Goddard Space Flight Center.[216] They conducted various global and regional studies using seasonal Global Area Coverage (GAC) data and demonstrated the value of multitemporal imaging for monitoring vegetation dynamics.

NOAA's and Tucker's experience made it clear that in working with daily AVHRR data rigorous – and as refined as possible – AVHRR data processing is the key to success, with a number of preprocessing steps required before data analysis could be undertaken. When addressing the scientific and implementation questions involved in such data processing, CCRS benefited greatly from the involvement in international activities, particularly the IGBP-ISY global 1 km land cover mapping project based on AVHRR data. As a member of the IGBP Data and Information System Panel, Cihlar contributed to the definition of that project and of Canada's contribution. The project was formally proposed by IGBP (IGBP, 1989), accepted as part of the ISY portfolio, and an international team was established to oversee the implementation. Teillet and Cihlar were members of the team and contributed to the definition of data processing methods.[217] The IGBP-ISY Land Cover project and its Canadian component (the latter funded by the Canadian Space Agency (CSA) and CCRS) employed the data manipulation procedures worked out by the IGBP Panel.

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[213] The data were received by the Atmospheric Environment Service (AES) in Downsview and Edmonton for its programmatic needs but not archived or distributed to other users.

[214] CCRS did receive some AVHRR data, primarily due to the initiative of Arthur (Art) Collins, but not systematically and without archiving or distribution capability.

[215] This activity continued uninterrupted since that time, and was later enhanced by retrieving (online) other historical AVHRR data from the US.

[216] As part of developing initial CCRS capabilities, we obtained some seasonal GAC data from Tucker. While the best available for Canada, the GAC data had a resolution of only ~5km and no location consistency because of the resampling algorithm used.

[217] CCRS contributions included a special meeting in Ottawa on March 12-14, 1990 on AVHRR pre-processing methodologies. At that meeting, D'Iorio (PDF at CCRS at the time) also presented results of our work later reflected in the consensus approach.

AVHRR generates a large amount of data even by today's standards, but the amount of data was very large in the early 1990s.[218] Processing the data was therefore impossible without specialized systems. Through the NBIOME project, a team (D'Iorio, Fisher, Guindon, and Cihlar) identified characteristics of a system optimized for AVHRR processing. It appeared that such system could be based on MOSAICS, an existing product marketed by MacDonald Detwiller & Associates. "On February 16, 1990, Cihlar presented to CCRS management a case for a new AVHRR processing system with two objectives: "to develop and demonstrate a methodology for monitoring land cover change using AVHRR data; and to produce land cover data base for Canada as a contribution to the ISY". The system would be capable of: reception and quicklook processing of all AVHRR daytime orbits (about 1000 passes per year), precision processing to location accuracy of 0.8 km, and compositing into a 1 km- resolution data base covering Canada's landmass. The deliverables would be the computer system and a database with six composites obtained during 1991. CCRS approved the proposal, issued a contract to MDA for building the system (1990/08), and appointed Erickson as the contract authority. Fisher, Teillet, Guindon, Brown, and Ahern contributed substantially to detailed specifications, progress reviews, and performance testing. (Cihlar, 2018, p. 71)[219]

It is important to point out that global change-type applications were not the only motivation for CCRS to receive AVHRR. Those applications were considered 'research' and 'science,' while CCRS management was always interested in immediate practical uses. From that perspective, the Canadian Wheat Board initially became the principal user of AVHRR-derived information. As noted previously one of the Wheat Board's objectives was to track the development of crops (primarily wheat) and predict the harvest levels well in advance so that favourable prices could be negotiated. The Wheat Board was interested in western Canada as well as in production by major competitors and potential buyers of Canadian wheat. For the prairies, it developed a procedure to translate satellite-derived information into potential yield, and to gradually refine this estimate as the season progressed and the crop condition (revealed in the satellite data) changed. Interest in this application was shared by both CCRS and the Manitoba Remote Sensing Centre (MRSC) in Winnipeg as is detailed in Sections 3.1.2. The main proponents were Henein and Brown at CCRS, and Best and Pokrant at MRSC. A cooperative arrangement was eventually implemented, with MRSC receiving the 'prairie' AVHRR pass each day and processing it using the GeoComp system. During the growing season, this processing received a priority; data processing for all of Canada and creation of nominally cloud-free composites was carried out during the rest of the year. Hurlburt, Dixon, Busch and Lux operated the GeoComp at MRSC. Statistics Canada also became a user of the AVHRR- derived information as part of its agricultural statistics program; their use continued uninterrupted after the Wheat Board was dissolved by the federal government in 2015.

Funding is the lifeblood of a research program. Even with the willing support of the new initiative by CCRS management, DOCLS would not have been possible without significant new funding. This became a reality when Canada decided to participate in the ISY. An interdepartmental committee led by the Ministry of State for Science and Technology and chaired by Dr. David Low accepted two CCRS proposals for ISY participation: Global Change Encyclopedia (later renamed GEOSCOPE, see below) and Land Cover of Canada (the latter as part of the IGBP project). With the support of Low, Ghent-Mallett and other CSA staff the proposals were endorsed by Kerwin[220] and funded for execution. ISY funding supported the GEOSCOPE project, parts of the technology development for AVHRR processing,

[218] Editor's Note: There is great interest today in "big data." Remote sensing has been at the forefront of both the use and understanding of big data since the 1970s. The image data with which we work has always taxed the computer systems with which we have worked. It should not be surprising that those in remote sensing are among the leaders in dealing with big data.

[219] The first GeoComp used specialized hardware to achieve the processing speeds; unfortunately, that also meant it could not be efficiently modified as the hardware technology improved, and the second GeoComp was therefore produced differently.

[220] Dr. Larkin Kerwin, 1st CSA President; the CSA was being formed at this time.

and initial research and algorithm development for AVHRR; however, it was 'sunset' funding with no promise of continuity.

The concerns about global impacts of human activities also reached the political levels. They led to the 1992 Earth Summit in Rio de Janeiro where Canada played an active role. Prime Minister Mulroney committed Canada to action by signing the 1992 Rio Declaration on Environment and Development. Subsequently, the federal government undertook the preparation of the Green Plan, a coherent, comprehensive national effort to deal with the challenges of human impacts on the environment. (Government of Canada, 1990)[221] As part of the planning process, Energy, Mines and Resources (now Natural Resources Canada, NRCan) undertook planning for additional research activities; a departmental Task Force was appointed by Deputy Minister Bruce Howe and led by Sayn-Wittgenstein. "Among nine proposals selected within EMR for the Green Plan, number two was the CCRS proposal drafted by Cihlar titled '***Monitoring Canadian landmass from space***.'[222] The project would "develop a system for the monitoring of the Canadian territory which will emphasize (i) the role of the Canadian landmass in the global carbon cycle and (ii) provision of up-to-date information on the environment." (Cihlar, 2018, p. 20) Eventually, this proposal was supported by Dawson and Environment Canada as part of a Cabinet submission for Green Plan funding. The initial approval was for a seven year program, but during government-wide Program Review in the mid-1990s the decision was made to include the funds in the A-Base. Although the Green Plan funds were reduced several times after initial approval, overall they provided a reliable and continuing source of support.

Another source of funds became available through the CSA's Long-Term Space Plans (LTSP). LTSP II was less relevant because the CSA priority was on the success of the first RADARSAT mission. CCRS received funds for six initiatives, all focused on increasing the use of RADARSAT data. As a result, the only funding for DOCLS-type work was allocated to the 'Earth Observation Data Sets Program' (EODS) that supported generation of radar data sets. Proposals for DOCLS support were more successful in LTSP III. Based on the progress in NBIOME, RS/LAI, and other projects Environmental Monitoring Section (EMS)[223] staff submitted for the LTSP III a research proposal 'Climate Change and Ecosystem Impact' (CCEI) with a goal to "support the government priorities related to sustainable development, knowledge infrastructure and climate change." At that stage, work on biophysical products derived from satellite data and models employing these products progressed sufficiently to propose a more ambitious goal than CANVAS (Canadian Vegetation Assessment System) – namely the routine production of a range of environmental information." (Cihlar, 2018, p.23) Although the approved funding was substantially less than proposed, it effectively supplemented other sources and allowed further progress in DOCLS R&D, development and validation of information products, and development and application of process- based models capable of using satellite inputs.

Organizational arrangement and team building presented another major challenge. ADS staff did the initial work: Ahern, Brown, Simard, Cihlar, and other participants in the GEOSCOPE project. With the ISY projects progressing CCRS also accepted a role in the BOREAS project, and the volume of work grew. Thus in 1992 CCRS management decided to form a new Section, Global Monitoring (GMS). Initial staff consisted of Cihlar (Head), Simard (also the GEOSCOPE project leader), Deblonde, and contract support. GMS was later renamed Environmental Monitoring Section (EMS) but its terms of reference did not change until at least 2004. The next two team additions proved a 'stroke of luck' in both timing and the talents gained. Dr. Zhanqing Li was just finishing a PDF with AES and was hired in 1992 after presenting an excellent seminar at CCRS. Dr. Jing Chen, a PDF at the University of British Columbia, joined in 1993 when EMS needed continuity for its work on the BOREAS project. Although both young,

[221] In retrospect, in the opinion of the author (Cihlar) the Conservative Mulroney Government has been the most progressive, pro-active and decisive federal government to date regarding the environmental challenge we face.
[222] Later renamed Northern Biosphere Observation and Modeling Experiment (NBIOME).
[223] Cihlar was head of the EMS from 1995-2002.

they had the educational backgrounds and research experience necessary to make them highly effective in producing and validating new satellite products and process-based models: furthermore, numerous research papers resulted. Another important asset was their ability to find and attract similarly talented young researchers: Fraser, Leblanc, Trishchenko, Fernandes and others. The new staff salaries were covered mostly by the external funds. Over the years, the team size increased through both government employees and contract staff. For example, the CCRS telephone list from 2001/04 shows EMS staff of 32 (both DOCLS and local applications,[224] government employees and contractors). EMS productivity increased similarly, with many papers in leading international journals reporting on new algorithms, analysis procedures, models, satellite products, etc.

Data processing, analysis and supporting tools made up the third major component required to make DOCLS a reality. In this respect, staff of the Digital Methods Division made a significant contribution in several respects. Fisher developed the concept, led the implementation of GCNet and provided guidance on the specification of hardware and software for image and GIS analysis. Erickson and Adair managed contracts to develop the first and second versions of GeoComp, respectively. Prindiville, Lavergne, Velarde, Graves and others supported acquisitions and maintenance of data processing hardware and software, in later years mostly as PC networks.

In addition to CCRS employees, many other individuals contributed (in various ways) to the DOCLS effort; Cihlar's (2018) review listed 361 individuals from NRCan, government departments, Canadian universities, and other countries or international organizations.

6.6.10.4. Projects

DOCLS projects were proposed, approved and executed within the CCRS framework defined by the Project Selection and Review Committee. The various projects completed over the years fall into four areas, as briefly described below.

GEOSCOPE: Originally titled Global Change Encyclopedia, this is one of the two projects proposed by ADS/CCRS and funded by the CSA as part of Canada's contribution to the International Space Year.[225] Its essence was not new research or new information; rather, the objective was to assemble the best existing remote sensing data and analytical tools, and make these widely available in a compact and organized format to the global community – schools, the public, researchers, universities etc. The project was initially led by Cihlar and then by Simard until its completion. Manore, Baker, Fisher and Cihlar were the main team members during the execution phase, but other Applications Division staff (Brown, Prévost, Mouchot, Leconte) as well as scientists from other government agencies and universities contributed to the development of scenarios for using the data sets (satellite, GIS, socio-economic, etc.). Simard led the team and contractors (LMSoft) through the challenging period of obtaining data sets from many international contributors, defining software capabilities and ensuring their development, developing and implementing example scenarios to demonstrate effective use of satellite data, and preparing the final package for distribution.

When released in 1992 as part of ISY celebrations, GEOSCOPE became a star attraction at international conferences, and among others earned a congratulatory letter from the French Minister of Research and Technology to our Minister of State for Science and Technology (to whom the CSA reported at the time). The success of GEOSCOPE led the CSA to establish a GEOSCOPE Division for coordinating distribution and marketing of the product. "By early 1994, GEOSCOPE product consisting of two CD-ROMs . . . was completed, commercialization licence with LMSOFT was signed, and revenue targets for CSA and CCRS were discussed. The packaged product contained the world's first database of images

[224] The LEAP Program was developed within EMS (in parallel with DOCLS) to focus on local environmental applications; it was led by Fung.
[225] From the ISY perspective, CSA was the sponsor of the project (and its representative at the international level), and CCRS was responsible for product development.

from 10 satellites, 240 socioeconomic variables from 140 countries, hundreds of maps of environmental variables, and a sophisticated querying and data manipulation software package." (Cihlar, 2018: p. 82)

BOREAS: The Boreal Ecosystem-Atmosphere Study (BOREAS) was the largest land experiment ever conducted in Canada – in terms of the experimental area size, the number of agencies, research teams and individual researchers involved, the overall cost, and the scientific yield. It was conceived by NASA and the North American scientific community as a step towards obtaining a better understanding of the energy, CO_2/ greenhouse gases, and water exchange between the boreal forest (including wetlands) and the atmosphere. The main issues were the impact of this vast ecosystem on weather and climate, and the consequences of changing climate on the boreal ecosystem.

As the main initial sponsor, NASA worked with the scientific community to define the project plan and ensure its execution. Sellers and Hall were the NASA project managers. There being no suitable representative boreal forest area in the U.S., NASA resolved to carry out the project in Canada and to work with Canadian government agencies and universities to ensure successful results. Since CCRS was NASA's Canadian counterpart, SMRS was approached to participate in the preparations for BOREAS.

Sayn-Wittgenstein took the lead and solicited involvement of other departments and managers in coordinating Canada's involvement. He also approved the establishment of the Canadian BOREAS Secretariat in the Applications Division of CCRS with the task of ensuring coordination and completion of tasks at the working level. Cihlar was appointed as the Canadian BOREAS Coordinator. CCRS contributions also included pre-processed satellite data (Landsat, AVHRR, SPOT), airborne (CV-580) radar data, participation of researchers (Chen, Li, Cihlar), and a great deal of time of senior managers (Sayn-Wittgenstein, Henein, Guertin) to help the project succeed. CCRS was also responsible for spending NASA money on field infrastructure, and the many contracts were also handled by the Secretariat and CCRS Finance (Rochon, Emmerson, Barnes, and Laity). The project started in 1989 with a planning phase and continued until the late 1990s. The last field campaign took place in 1996. The scientific yield obtained by the participating 200+ scientists was very high: among others, they produced three special issues of the Journal of Geophysical Research and 354 other peer reviewed papers. The entire data base (field observations, in situ and remote sensor records, etc.) remains accessible at the US Oak Ridge National Laboratory. Canadians have already benefited from improved weather forecasts resulting from a better understanding of the energy exchange over the vast boreal ecosystem. Hall (2001) discusses other aspects of BOREAS' achievements.

NBIOME: The Northern Biosphere Observation and Modeling Experiment was initially proposed in the late 1980s as a component of the 10-year Mission To Planet Earth (MTPE) program. The kernel of the proposed project was the impact of global change on Canada's terrestrial ecosystems. Because of Canada's size, only satellites could provide information on the seasonal and inter-annual dynamics of the forests, agroecosystems, wetlands and tundra. Furthermore, frequently acquired wide area AVHRR-type data had to be the backbone of any workable satellite-based monitoring. MTPE planners were well aware of the need for DOCLS-type data, and the first platforms included AVHRR- like sensors but with much improved characteristics, both spectrally and spatially (with the highest resolution of 250m). NBIOME provided the setting for the development of procedures to 'clean up' AVHRR data by removing or minimizing effects of clouds (full pixels or subpixel), smoke, haze, bidirectional reflectance, snow, etc. The improvements were gradual, and took place over most of the 1990s. As better data sets became available, the development of information extraction algorithms and biophysical products could begin, and this too was a gradual process building on preprocessing improvements.

While NBIOME continued to focus on AVHRR preprocessing and land cover type information, other EMS projects designed within the NBIOME framework addressed different biophysical properties: forest fire dynamics, leaf area index, primary productivity, etc. The development and validation of the appropriate algorithms was challenging and often tedious work requiring field data, repeated testing, inter-comparisons, AVHRR data reprocessing, etc.

With data products of acceptable quality available, the next challenge was the identification of spatially explicit process models that could employ the satellite products. Originally, NBIOME assumed that existing biophysical models (or those to be developed in the meantime) could be used but this turned out to not be the case. The reason seems to be that prior to the availability of satellite products, model developers could not propose modeling strategies for which input data were not available, thus existing models were not suitable for use with satellite data: a 'catch 22.' However, by the time EMS produced quality biophysical products, EMS staff included four experienced process modellers – J. Chen, W. Chen, S. Wang and Y. Zhang. They developed peer-reviewed models for carbon (short- and long- term), water, and permafrost dynamics that were specifically suited for use with AVHRR-derived satellite products. The models also required other biophysical products that in some cases involved GIS- type combinations of individual biophysical properties. Cihlar's 2018 review includes 22 different input and output products, most of them covering all of Canada (see Title Page above).

EMS plans at the time called for using these models and outputs in support of Canada's international reporting obligations and national environmental reporting in the form of sustainable development indicators. The need for such indicators was identified by the federal government in the Budget Speech, and the specifics were developed by the National Round Table on the Environment and Economy. Prototypes of several environmental indicators (forest cover indicator, climatic water budget indicator, and other candidate measures) were developed but these applications were not pursued systematically because of a 2002 program reorganization at the Sector level under Itzkovitch, the ADM at the time. (See Section 4.7.)

Radiation Budget: DOCLS work at CCRS included work on the radiation budget because of its importance to climate modeling and because some satellite sensors were well suited to ascertaining the magnitude and trends of the various components of the surface and atmospheric radiation budgets. Although all of Canada was covered in these studies, the overall extent was global due to the nature of the sensors and missions involved. Li and his team conducted most of these studies. This area was somewhat unfamiliar to CCRS; in fact, the value of these projects was questioned at one point by the Project Selection and Review Committee and required a special presentation and justification prior to project approval – which was provided then, and amplified during a 1998 external Peer Review of EMS activities organized by CCRS management. (Cihlar, 2018) The U.S Department of Energy funded most of the radiation budget work, through competitive grants awarded to Li over the years. The CCRS team collaborated closely with AES scientists in Canada and with several institutions in the US. It also produced the only EMS paper published in the prestigious journal Nature. (Li *et al*., 1995) Although this area represented Li's main interests, he also led the development of the highly successful forest fire detection and mapping,[226] and he developed two products relevant to ecosystem studies – absorbed photosynthetically active radiation, and ultraviolet radiation UV-B. (Cihlar, 2018)

The importance and achievement of CCRS's DOCLS work began to be appreciated in the late 1990s, both within the Sector and beyond. In addition to the two awards for forest fire work, EMS scientists received at least seven Sector or Departmental awards, the Alouette Award by the Canadian Aeronautics and Space Institute, the Gold Medal by the Canadian Remote Sensing Society, and the Distinction Bronze Award by the President of the Treasury Board. Two EMS scientists (Cihlar, J. Chen) were inducted into the Royal Society of Canada.[227]

6.6.10.5. Beyond 2002
In 2002 Cihlar left the EMS after accepting a Program Manager position for the ESS Climate Change program. W. Chen was the first acting Head, followed by others.

Four other EMS team members departed, drawn by irresistible offers from universities: U. Toronto (J. Chen, Liu), University of Maryland (Li), and University of Ottawa (Kerr). All have had excellent careers

[226] This work received the Head of Public Service award and the Agatha Bystram award.
[227] As of this writing, the only RSC Fellows inducted for their accomplishments in Earth Observation.

with many contributions that have been recognized by the scientific community in various ways. It is gratifying to see that their thematic pursuits logically followed from the work they carried out while at CCRS, albeit much beyond the initial steps we took together.

Nevertheless, of the 2002-period membership, 7 scientists continue working at CCRS. The Section is now titled Optical Methods and Applications Section, led by Janzen. CCRS is a Division of Canada Centre for Mapping and Earth Observation (CCMEO) within the Strategic Policy and Results Sector of NRCan. In spite of the many changes in the government setting (three different governments, six Deputy Ministers, several reorganizations above or within CCRS) the team maintained steadfast focus on DOCLS issues. A cursory review of the post-2002 outputs shows an impressive record of achievements – new methods, data products and many research papers and applications, including numerous 'firsts' in Canada. Generally, in quality, level of detail, and answers to questions regarding environmental changes they are far beyond those of 2002, all this in spite of distinctly unfriendly actions of the Harper governments (2006-2015) towards environment and science.[228]

Among the various accomplishments, the maintenance of long-term satellite data records deserves special mention. It is the best record of Canada's landmass and arguably the best in the world of any country because of its quality, consistency and duration. It provides the foundation for all subsequent research and biophysical product generation, and is available to all Canadians through the NRCan website. Much of the credit belongs to Latifovic and colleagues who developed, implemented and maintained the system now covering 29 years (AVHRR) and 16 years (MODIS) of analysis-ready data for all Canada.

The level and quality of CCRS DOCLS accomplishments became evident in 2017 through a contract-based assessment of Canada's preparedness to monitor the impacts of climate change within the framework of the Global Climate Observing System. (Cihlar, 2017) "For the landmass of Canada, systematic observations of 18 ECVs and about 50 specific products are required; CCRS DOCLS- related activities to date have resulted in 24 specific products for 12 ECVs (Cihlar, 2017) . . . the contributions to DOCLS applications continue to accumulate; and as or more important, the scientific rigour of the methodologies and the quality of resulting products continue to grow." (Cihlar, 2018, p. 131)

People and Affiliations Named in 6.6.10	
Adair, Mr. Michael (Mike), Digital Methods Division, CCRS Anderson, Mr. William (Bill), Data Acquisition Division, CCRS Ahern, Dr. Francis (Frank), Applications Division, CCRS Baker, Mr. Ralph, CCRS Barnes, Mr. George, Finance, CCRS Barnes, Mr. William (Bill), NASA, U.S.A. Brown, Dr. Ronald (Ron), Applications Division, CCRS Busch, Mr. David (Dave), Manitoba Remote Sensing Centre Chen, Dr. Jing, Applications Division, CCRS/ University of Toronto Chen, Dr. Wenjun, Applications Division, CCRS Cihlar, Dr. Josef, Applications Division, CCRS Collins, Mr. Arthur (Art), CCRS Dawson, Dr. Kirk, Environment Canada	Kerwin, Dr. Larkin, President, Canadian Space Agency Laity, Ms. Kathy, Finance, CCRS Latifovic, Dr. Rasim, Applications Division, CCRS Lavergne, Mr. James (Jim), Digital Methods Division, CCRS Leblanc, Mr. Sylvain, Applications Division, CCRS Leconte, Dr. Robert, Applications Division, CCRS LeDrew, Prof. Ellsworth, University of Waterloo Li, Dr. Zhanqing, Applications Division, CCRS/ University of Maryland, U.S.A. Liu, Ms. Jane, Applications Division, CCRS/ University of Toronto Low, Dr. David, Ministry of State for Science and Technology Lux, Mr. Gerry, Manitoba Remote Sensing Centre

[228] Editor's Note: This document is meant to be an apolitical of showcase good policy that leads to a better Canada and a more competitive Canadian industry. While one Conservative government has been critized, another has been praised in this section.

D'Iorio, Dr. Marc, Applications Division, CCRS Deblonde, Dr. Godelieve, Applications Division, CCRS Dixon, Mr. Roy, Manitoba Remote Sensing Centre Emmerson, Ms. Monik, Finance, CCRS Erickson, Mr. Arvon, Digital Methods Division, CCRS Fernandes, Dr. Richard, Applications Division, CCRS Fisher, Mr. Terry, Digital Methods Division, CCRS Fraser, Dr. Robert (Rob), Applications Division, CCRS Fung, Dr. Ko, Applications Division, CCRS Ghent-Malett, Dr. Jocelyne, Canadian Space Agency Graves, Mr. Robert (Rob), Digital Methods Division, CCRS Guertin, Mr. Florian, Director, CCRS Guindon, Dr. Bert, Applications Division, CCRS Hall, Dr. Forrest, NASA, U.S.A. Harper, Mr. Steven, Prime Minister, Government of Canada Henein, Mr. Jean-Claude, Director, Applications Division, CCRS Howe, ___Bruce, Deputy Minister, NRCan Hurlburt, Ms. Patricia (Pat), Manitoba Remote Sensing Centre Irwin, Mr. Roy, Data Acquisition Division, CCRS Itzkovitch, Dr. Irwin, Assistant Deputy Minister, ESS Janzen, Mr. Darren, CCRS/ CCMEO, ESS Kerr, Dr. Jeremy, Applications Division, CCRS/ University of Ottawa	Malone, Prof. Thomas, International Geosphere-Biosphere Programme Manore, Mr. Michael (Mike), Applications Division, CCRS Mouchot, Ms. Marie-Catherine, Applications Division, CCRS Mulroney, Mr. Brian, Prime Minister of Canada O'Donnell, Mr. Hugh, Assistant Deputy Minister, Surveys, Mapping and Remote Sensing Sector Prévost, Mr. Christian, Applications Division, CCRS Prindiville, Mr. Michael (Mike), Digital Methods Division, CCRS Rochon, Ms. Jeanne, Finance, CCRS Sayn-Wittgenstein, Dr. Leo, Director General, CCRS Sellers, Dr. Piers, NASA, U.S.A. Simard, Dr. Rejean, Applications Division, CCRS Teillet, Dr. Phillipe, Applications Division, CCRS Trishchenko, Dr. Alexander (Alex), Applications Division, CCRS Tucker, Dr. Compton (Jim), NASA, U.S.A. Velarde, Mr. Cesar, Digital Methods Division, CCRS Wang, Dr. Shusen, Applications Division, CCRS Zhang, Dr. Yu, Applications Division, CCRS

6.7. Sensor Development

6.7.1. Optical Sensors[229]

Bob Ryerson

Optical sensors are logically listed first here inasmuch as much of the first sensor work at CCRS was in optical sensors. While there was a significant amount of early work at CCRS developing optical sensors including LiDAR and push-broom scanners (e.g. MEIS), the main emphasis shifted to radar with the interest in a radar satellite. With the budget cuts of the mid-1990s the entire sensor development program was cut. It should be noted that a great deal of early hyperspectral sensor development was done in industry, notably by Itres Research of Calgary which is still selling sensors. Several of the scientists involved in the CCRS optical work have been approached to contribute but declined to do so, leaving one of the interesting aspects of early CCRS work untold as of this writing.

6.7.2. Microwave Development

6.7.2.1. Introduction

The microwave airborne sensor development began with the acquisition of the ERIM SAR and the Convair 580, and as mentioned elsewhere the sensor development basically ceased when the Convair-580 facility was turned over to Environment Canada. The sensor development activity and the development of applications were linked – it was some of the Sensor Section scientists who were most closely tied to the development of applications and new approaches to SAR data analysis to extract useful information.

[229] It has proven difficult to find authors to write about optical sensor development and thus this is an area where that is not well covered here. Other sections do address the development of systems to process optical data for a variety of applications.

6.7.2.2. The Development of Canadian Remote Sensing SAR systems: a Brief History

Chuck Livingstone[230]

6.7.2.2.1. The Context

As noted elsewhere, CCRS was created under Director General Larry Morley with a mandate to develop remote sensing technology in Canada, become world leaders in the field, and promote the development of a Canadian remote sensing industry. The mind-set of the day was that innovation was good, government would shoulder high-cost, high risk developments, industry and government would collaborate with minimal barriers and industry would rent the use of government equipment to explore possible markets.

By 1974 CCRS had acquired three aircraft that had been modified to support optical remote sensing R&D, had purchased a retired long-range CV-580 executive aircraft (originally operated for Johnson & Johnson), and had contracted modifications of its airframe, navigation system and power system to create a radar remote sensing R&D aircraft.

6.7.2.2.2. Satellites and Sovereignty

In 1975 the report "Satellites and Sovereignty" was presented to Cabinet and Cabinet liked it! In parallel CCRS was developing a radar remote sensing aircraft (the CV-580) but had no radar. At the same time the Environmental Institute of Michigan (ERIM) had developed a state of the art remote sensing SAR but had no aircraft. A "deal" was reached. CCRS would fly the ERIM SAR in exchange for access and support in its use and ERIM would support the radar in exchange for flight hours and aircraft support for their projects.

In response to the Cabinet's approval of the "Satellites and Sovereignty" report the Surveillance Satellite project (SurSat) was started in 1977 with a mandate to explore the application of SAR to natural resource measurement and monitoring. It was also to investigate a role for space-based SAR using the soon-to-be launched (1978) SEASAT-A as an example and airborne (CV-580) SAR as a surrogate test system.

In 1977 the SAR 580 system was commissioned and began work for SurSat with Innotech Aviation operating the aircraft and ERIM technologists operating and maintaining the radar. Intera won the contract for sensor operation in 1978 while CCRS scientists helped define SurSat test projects.

SEASAT-A was launched in 1978 and lived for 106 days before a massive power system failure killed it. But before long, space-based SAR was established as a remote sensing tool for oceans and ice and digital processing was demonstrated as being feasible, as is discussed in Section 5.

6.7.2.2.3. CV-580 CCRS-ERIM Experimental SAR in 1977

At the outset, in 1977, the CCRS CV580 was configured with:

- A Ku band scatterometer (this was a Teledyne prototype for the lunar lander radar);
- 13.4 GHz, fan beam;
- A PRT 5 thermal profiler;
- A flight data recording and photo annotation system ADAS; and
- 2 RC10 mapping cameras with modified annotation blocks.

[230] Editor's Note: This Section has been taken from the PowerPoint presentation given by Dr. Livingstone (2017). Minor edits have been made to convert material from slides into text: otherwise the material remains the same. A complete timeline on Radar development is given in Appendix B.

The ERIM/CCRS SAR 1977		
	X band	**L band**
Frequency	9.35 GHz	1.245 GHz
Bandwidth	89 MHz	60 MHz
Pulse length	2.7 μs	1.8 μs
Peak Power	2 kW	5 kW
Resolution	3 m x 3 m	3 m x 3m
Swath	5.4 km/ch, 2 channels	5.4 km/ch, 2 channels

- Signal data recording used offset Fresnel zone plate codes captured on moving 70mm film that was illuminated by a custom, slit aperture CRT;
- Signal data were processed to film images or on a granite bench optical processor at ERIM;
- Image product noise floors were dominated by back-end film grain noise;
- Calibration pulses could be analogue-generated and captured on film for intensity scaling to engineering parameters; and
- The antenna steering had a single axis (azimuth). Elevation pointing was adjusted by removing the radome loosening some set screws and tapping the angle adjustment until a best elevation angle was achieved

The radar was designed and built in the early 1970s analogue world as an experimental SAR.
The first single chip computer (4 bit calculator chip became available in 1974) heralded the start of the digital age.

6.7.2.2.4. The Early Learning Experience to 1981

The very first thing learned was that the radar and its platform are an integrated sensor system. An integrated science, technology, flight planning, sensor operator, flight crew and aircraft maintenance team was required to make it work. The computer operators on board the aircraft sat in three chairs, read indicators, and ran the instrument. Operator knowledge and skills were critical to minimizing the human error component. We built a system that persisted in form and function until the CV-580 was retired in 2010.

In the beginning SAR data analysis was basically the same as visual photographic interpretation. SAR scattering theory was in its infancy and ground-based microwave scattering studies were just starting. With access to the ERIM X/L band SAR, CCRS, Intera and Innotech learned how to plan and execute SAR missions. An integrated government-industry team was developed for SAR data acquisition work. SAR data sets were acquired for: agriculture, forestry, hydrology, sea ice, geology, and oceanography. Canadian scientists began to learn how to interpret and use SAR data across a range of applications.

In 1980, after the end of SurSat, the RADARSAT Project Office began to plan a Canadian SAR satellite The RADARSAT project office became the main client for the airborne SAR system. RADARSAT's space-related activities latter moved to the newly formed CSA in 1989. By 1981 the radar system documentation set had been built and CCRS and Intera took it apart and developed a complete schematic set. There was two-axis radar antenna steering, an ERIM-built digital SAR recording system and an MDA built (limited swath and resolution) real-time processing system had been added. ERIM added a signal digitizer to its optical SAR processor and MDA had expanded its SEASAT-A processor. This processor was the great grandfather of today's GSAR processor: it could process a 5 km X 5 km SAR scene in 67 minutes. By 1981 a C-band channel had also been added to the CV-580 radar.

6.7.2.2.5. The European SAR campaign 1981: A Defining Event

In 1981, Intera negotiated a CV-580 SAR campaign with the European Joint Research Center to provide digital SAR data needed to develop European remote sensing SAR capability. The broad objective of the work was to determine the future roles of SAR remote sensing as an observation tool in a European context. Remote sensing applications included cartography, soil survey, hydrology, geology, geomorphology, seasonal snow cover on glaciers, agriculture, forestry, and land use. SAR calibration was part of the exercise. At this time quantitative SAR was still in the future.

The campaign had mixed success. Radar system failures impacted the execution of the campaign, although these issues were corrected in the field. Other problems included inconsistent radar calibration, as well as instrument and operation stabilities. Coordination of ground-based and airborne activities was inconsistent and data delivery was slow. Even with the various issues, many European organizations and agencies started their development of significant SAR remote sensing capabilities with this program and the data acquired were used for many years. Another positive outcome was that CCRS and Intera learned how to conduct major remote sensing programs far from Canada's shores. Several 1980s SAR remote sensing campaigns used planning and execution lessons learned from the European Campaign. These included the NASDA SAR campaign "Japan 1983" and the MIZEX 1984 Greenland marginal ice zone campaign.

The spin-offs from the European SAR campaign were many and important. European and Canadian quantitative microwave remote sensing scientists continued to push back the limits. By the end of 1982 MDA had expanded its SEASAT-A processor to include airborne data processing. This was the great grandfather of today's GSAR processor. It could process a 5 km X 5 km SAR scene in 67 minutes. This was the tool that supported the European SAR campaign data analysis.

Other outcomes included Germany's start in long term work on SAR processing at DFVLR,[231] including information extraction and, later on, airborne experimental SAR development. Both activities continue to this day. CCRS contracted ComDev to develop a new C-band SAR antenna that corrected many of the limitations of the earlier version and replaced the CV-580 ancillary data recording system to provide more complete flight and sensor setting documentation. Airborne SAR systems limitations and the rapidly expanding digital technology prompted CCRS to start the specification of a digital SAR system for the late 1980s. Following the European campaign Intera contracted with ERIM to build the STAR-1 airborne radar that was commissioned in 1983. The work on digital image generation was later used to build Canada's ice reconnaissance capability. (See Section 3.3.3)

6.7.2.2.6. The Birth of Quantitative SAR Remote Sensing in Canada

Early work with SEASAT-A showed that space-based SAR was feasible, and that SAR data could be calibrated for consistent measurements of the earth surface. Qualitative analysis of airborne SAR data and intense ground based work on the microwave properties of natural targets showed that quantitatively calibratable image products were possible and were highly desirable. To that end CCRS embarked on a series of contracted studies in 1982 that looked at the rapidly developing digital signal processing technology to specify and build C and X band airborne SAR systems that could reliably provide quantitative SAR measurements. The CCRS C-band SAR was commissioned in 1986 and the CCRS X-band SAR was commissioned in 1987. They replaced the ERIM SAR which was removed in 1985.

In 1985 Energy Mines and Resources formally proposed the development of a Canadian Space-based SAR system – the initial cost estimate of $ 770M was believed to be too high. This effort triggered 10 years of effort that resulted in RADARSAT-1. In 1985 the CCRS-ERIM SAR was decommissioned and the radar was returned to ERIM.

[231] Now DLR.

In 1986 CCRS started its Radar Data Development Program – known by its initials "RDDP." The four goals were to:

- Develop SAR applications science;
- Develop SAR processing and information extraction technologies to prepare for future SAR satellites (ERS-1 and RADARSAT-1);
- Acquire quantitative SAR data and coordinated surface data at many Canadian sites; and
- Promote and foster international campaigns to build expertise and markets.

CCRS C and X band SARs: Instrument Structure and Properties

Instrument Structure

- These radars were built as research and development tools that had finely configurable operating parameters and could be modified to include initially unforeseen operating modes. The builders were MDA, Canadian Astronautics Ltd., and Knudsen Engineering;
- The planned design life was 10 years (The C-band SAR was retired after 24 years);
- The radars were implemented using mid 1980s digital technology (discrete components, Z80, 8086 and 8087 microprocessors and operating software was delivered from EPROM ICs that contained assembler code. Each radar consisted of a control module, a real-time processor module, and exciter-receiver unit and a transmitter;
- Low-rate control data processing used microprocessors; high-speed signal management used hard-wired logic;
- Motion compensation calculations were performed on an early array processor (one 8086 controlling a three 8087 stack that processed inertial navigation and radar been direction feedback data;
- The real-time processor was implemented in a 7 look transversal filter that implemented time-domain convolution processing;
- The main operator interface consisted of text display and control module that could access 30 nested command and display screens (most of these were parameter pre-set adjustments), a signal display oscilloscope, display signal selector, transmitter control and an antenna control module; and
- The secondary operator interface consisted of the real-time signal display control, the signal recorder interface, the auxiliary data recorder and interface, the real-time data recorder and interface and an ARINC 429 bus display.

Airborne SAR Properties

- Range resolution and sampling;
    - High resolution: sampling 4 m, resolution 6.0 m, swath 16.4 km slant range; and
    - Low resolution: sampling 16 m, resolution 20 m, swath 64 km slant range;
- Range coding and compression SAW delay line chirp generator, compressor;
- Azimuth signal: sampling rate (2.32 VA (m/s) or 2.57 VA (m/s)), resolution 0.6 m C-band, 0.7 m X band
- Incidence angle range at 6 km altitude:
    - High resolution: 0° (nadir) to 76° (nadir mode (starts at nadir) and narrow swath mode starts at 45°: and
    - Low resolution 45° to 85°;
- Signal conditioning: selected sensitivity-time control;
- Signal recording: 4096 range samples, (6 bit I, 6bit Q), range compressed data:
    - Range compressed pulse width: C, 49 ns and 120 ns; X 32 ns and 134 ns;
    - Radar settings and navigation data are in the headers for each sample; and
    - Dual polarization recording;
- Auxiliary data recording: Radar setting and navigation data at 45 ms intervals;
- Real-time processing: 7 look high resolution 10 look low resolution;
- Transmitter radiated power: C-band 34 kW, X band 3.28 kW; and
- X-band SNR (Signal to Noise) problems at far range.

6.7.2.2.7. A Chronology for a Period of Rapid SAR Development: 1986 to 1992

- 1986 to 1990 intensive SAR calibration studies provided the calibration constants needed for quantitative SAR applications;
- 1987 the Intera STAR-2 radar was commissioned for ice reconnaissance;
- 1987 the MDA designed radar used modules developed for CCRS with software to support Intera's imaging business;
- 1990 Airborne repeat-pass SAR interferometry was demonstrated by CCRS;
- 1991 C-band along-track and across track SAR interferometer modes were commissioned;
- 1991 ERS-1 SAR launched and commissioned;
- CV-580, ERS-1 cross calibration experiment;
- 1991 RADARSAT-1 contract let to SPAR Aerospace;
- 1992 ESA-funded SAREX mission to Central and South America to develop South American expertise in SAR remote sensing;
- 1992 CV580 SAR polarimeter commissioned.

6.7.2.2.8. Chronology of the Migration Towards Space-based SAR Remote Sensing

- 1992 J-ERS-1 L-band SAR R&D satellite launched by Japan. HH polarized, 15 MHz bandwidth with CCRS Gatineau station a receiving site;
- 1993 GlobeSAR 1 airborne SAR campaign to develop international SAR remote sensing. capability in preparation for RADARSAT-1 with test sites in 10 countries in Asia, Africa and the Middle East;
- 1993 CV-580 SAR polarimeter calibration in preparation for mode application demonstrations;
- 1994 CV-580 SAR under flights for SIR C coverage of the Altona agricultural test site;
- 1995 CV-580 tests SAR polarimetry for marine targets and demonstrated ship detection possibilities;
- 1995 ERS-2 launched (Gatineau station reception);
- 1995 RADARSAT-1 launched and commercial space-based SAR remote sensing begins.

6.7.2.2.9. A Time of Tumultuous Change: 1995-1997

One major event dominated 1995 – CCRS shut down much of its airborne program as a response to the 40% budget reduction imposed in the 1995 Federal Budget. With the budget cuts there was also an apparent shift from what we call an innovation focus to a management focus as tolerance to risk largely disappeared. Airborne SAR instrument development activity did continue in France, Germany and USA. SAR R&D effort in Canada shifted to satellite data analysis and exploitation tool development largely under the increased Earth Observation budget[232] envelope of the Canadian Space Agency.

Another significant set of events occurred in industry. In 1995 the Intera STAR-2 system was decommissioned and Intera moved its headquarters to the USA and became Intermap.

In 1996 the CV-580 system was transferred to Environment Canada ending the CCRS operation of airborne platforms. At this time the CCRS Limebank road facility used for sensor development was closed. The CV-580 system did continue to be used to support various development areas but no major system improvements were made. Successive attempts to have the radar redesigned as a next generation research tool failed to get support. 1996 also marked the development of polarimetric SAR processing and information extraction tools with the objective of building a SAR polarimetry market.

[232] Editor's Note: The budget for Earth Observation at the CSA increased in the 1994 budget. The space budget was increased by $800M over ten years, much of that for EO. As noted elsewhere it was the only significant increase in any area in the 1994 budget.

1997 saw GlobeSAR-2 projects in South America with CV-580 and RADARSAT-1 data collection at the same time. The intent, as was the case for the first GlobeSAR Program, was to develop SAR remote sensing capabilities and markets for RADARSAT-1 data. In the same year the Intermap STAR 3i Precision across-track interferometer was commissioned using design concepts and lessons learned from 1990 to 1994 CCRS InSAR work.

6.7.2.2.10. From the RADARSAT-2 to the RADARSAT Constellation Mission

The MDA RADARSAT-2 development contract began in 1998. It was a major industrial innovation that was to retain all of the RADARSAT-1 modes and add to them a number of additional features to make it the most advanced civilian SAR satellite of its time. There was a dual polarized, dual aperture active-array antenna along with pulse-interleaved polarimetry (in response to earlier CCRS SAR polarimetry R&D). A “Spotlight” mode resulted in better resolution and more detail while the ScanSAR, or lower resolution mode, was calibratable. Solid state data recorders were also added.

Exports continued of both data and technology. In 2002 the Raytheon-MDA SIVAM SAR system (3 aircraft plus ground processing) was commissioned in Brazil.

In this period the Department of National Defence innovation by the current author (Livingstone, 2017) was the Ground Moving Target Indicator (GMTI) experimental mode. The SAR-GMTI theory and practice using the CV-580 along-Track interferometer mode was developed in 1991 and demonstrated in 1993 and 1994. A number of airborne SAR-GMTI experiments 1998 to 2012 focusing on land and marine moving targets. The emphasis was placed on radar properties of cultural or man-made targets. The RADARSAT-2 GMTI preprocessor was delivered to DRDC in 2007. In 2009 the CV-580 disk recorder was commissioned for use in GMTI studies and in 2011 an operational SAR GMTI processor for RADARSAT-2 was delivered. The RADARSAT-2 high-resolution wide swath mode was demonstrated in 2014 using the RADARSAT-2 multi-aperture design developed for the experimental GMTI modes

In 2004 there were polarimetric data acquisitions by the CV-580 to support RADARSAT-2 polarimetric SAR applications research and development. That same year work was started on the design of a disk recording system to replace the CV-580 Helical- scan recorder for SAR signal data.

In 2008 RADARSAT-2 was launched and that same year the CV-580 was used as a test bed for the DND CMO Aurora SAR. Only a year after the launch of RADARSAT-2, the requirements for the next satellite pointed towards a co-planar SAR constellation of “small” SAR satellites – the RADARSAT Constellation Mission. The first RCM satellite pre-launch testing was carried out in 2016.

In 2010 support for the CV-580 by Environment Canada ended. Canada no longer has an airborne SAR development and test system. The aircraft was parked in a field near the Ottawa International Airport where it sat forlornly for several years, no longer looking like the world class research facility it once was. As noted in the text box and photograph in Section 6.5.6 in 2015 it was flown for the last time when the CV-580 aircraft and radars were delivered to the Canadian Aviation and Space Museum, watched by some fifty former CCRS and contractor employees.

6.7.2.2.11. Some Observations and Conclusions

The building of an industry capability took from five to as many as seventeen years, as is shown in the table following the discussion in the next paragraph.

Over time, and perhaps related to budget cut-backs, there appears to have been a change in how the government approached risk. From 1970 to 1995 there was an innovative risk-tolerant environment in the Government of Canada. There was extensive government-industry collaboration that featured a visionary approach to achieving long-term objectives. Basically the Government assumed front-end development risk and the resulting research was quickly exploited by industry. Capability development took as little as three years and market development less than four years. From 1995 to the end of the period covered in this document, the Government became management-focused and risk intolerant. Activities were severely cost-constrained with less interaction between the research community in Government and industry. At the same time the scope of R&D in government was reduced. This has led to a decrease in the international impact of Canadian public investment as measured in industry sales in key niches. A corollary is that industrial exploitation time has increased, leading to yet another negative factor in the Canadian remote sensing industry's competitiveness.

Canadian Involvement in SAR System Development

• First CV-580 R&D SAR to European SAR campaign (1976 to 1981)	5 years
• First CV-580 R&D SAR to STAR-1 (1976 to 1983) (GoC risk reduction)	7 years
• European SAR Campaign to first GoC digital R&D SAR: (1981 to 1986)	5 years
• European SAR campaign to STAR-2 (1981 to 1987) (GoC risk reduction)	6 years
• First digital R&D SAR to RADARSAT-1 (1987 to 1995)	8 years
• SAR interferometer development to STAR 3i (1991 to 1995)	4 years
• SAR polarimeter development to RADARSAT-2 use (1992 to 2008)	16 years
• SAR ATI development to RADARSAT-2 GMTI (1991 to 2008)	17 years

Source: Livingstone, 2017.

6.7.2.3. Microwave Applications Development

Laurence Gray

The development of applications of microwave remote sensing at CCRS included a number of "firsts" that led to significant programs both in Canada and internationally. The following provides a short description of some of the contributions made by the airborne radar programme in the Data Acquisition Division of CCRS.

CCRS participated in the 1975 Arctic Ice Dynamics Experiment (AIDJEX) in the Beaufort Sea and showed that appropriate radar look angles allowed unique backscatter signatures for different sea ice types. (Gray *et al*, 1977) These findings were illustrated with the SAR 580 some years later and played a significant role in the justification for the development of RADARSAT.

In preparation for its first radar satellite, ESA funded participation of the CV580 in a study of ocean backscatter as a function of wind speed and direction at both C- and Ku-bands. This unique contribution provided a key input to the ESA satellite wind scatterometer development. (Attema, *et al* 1986)

CCRS scientists performed the first demonstration of repeat-pass interferometry with an airborne SAR. (Gray and Farris-Manning, 1993) This provided proof that relative movement within a SAR scene could be recovered at a fraction of the radar wavelength. By comparing the phase from two complex SAR images one can extract small relative movement (changes in the radar range of a few millimeters to centimeters) from one scene to another. Subsequent work with satellite radars showed that it is possible to map terrain movement due to earthquakes, landslides, resource extraction, or the movement of glacial ice. This is now a significant application of satellite SAR.

CCRS work demonstrated the value of airborne cross-track interferometric SAR (InSAR) to create digital elevation models, or DEMs. (Gray *et al*, 1992) Eventually Canadian industry adopted this technology and Intera marketed an airborne cross-track InSAR for mapping. Another application that was demonstrated at

CCRS was the use of the airborne along-track InSAR for moving target identification. This work helped justify the extra moving target mode on RADARSAT-2.

An interesting and highly visible activity led by CCRS was the mapping of Antarctica with RADARSAT-1. The satellite was rotated to look south and produce the first high resolution map of Antarctica. Using repeated tracks CCRS helped produce the first map of the moving ice streams in West Antarctica. (Gray *et al*, 1992a; Joughin *et al*, 1999) One of the previously unknown ice streams was subsequently named after the first Canadian scientist to over winter in Antarctica (the Blackwall Ice Stream named after Hugh Blackwall Evans https://en.wikipedia.org/wiki/Blackwall_Ice_Stream). The ice stream mapping work used a new technique, now known as 'speckle tracking,' which produced two-dimensional displacements in both range and azimuth. (Gray *et al*, 1992b; Gray *et al*, 2001) Speckle tracking is now the standard technique for mapping glacial ice motion. CCRS scientists later used a new algorithm based on interferometry and speckle tracking to produce vertical ice displacement in the presence of horizontal motion. This provided the first demonstration of the movement of sub-glacial water underneath the Antarctic ice streams.

CCRS also provided the first definitive demonstration of the influence of the ionosphere on satellite SAR. (Gray *et al*, 2000) This was key in explaining some previously unknown artifacts in satellite InSAR work.

6.7.2.4. Polarimetry
Ridha Touzi and Chuck Livingstone

6.7.2.4.1. Introduction[233]
The highly technical material in this section provides the background to the science that was done in polarimetry at CCRS over a period of years. The primary take-away for the non-scientific reader is that this work by a small team at CCRS was the basis upon which the next generation radar satellites following RADARSAT-1 were designed. **An estimated ten billion dollars have been spent or committed by Canada, Japan and other countries on satellites related to this work and the CCRS Convair 580 SAR.**[234] For the interested reader the text box in the next Subsection provides the sequence of events, details of the science and some of the implications of what was achieved. The remainder of this introduction begins to explain the concepts and science involved in polarimetry.

We are familiar with polarization in sunglasses, which are used to minimize reflected glare. The electromagnetic plane waves from the sun have electric fields that vary perpendicular to the direction of their travel, and can have components in the horizontal (H) and vertical (V) directions. Polarizers can be used to limit the transmission of one of these components, hence decreasing the amount of radiation that reaches our eyes.

Similarly, in the microwave part of the electromagnetic spectrum, it is possible to choose antennas that transmit and receive either or both of these types of electromagnetic waves.

In such a radar system, it is possible to have four transmit-receive combinations: HH, HV, VH, and VV (where the first letter refers to the transmitted wave and the second to the received one).

Knowledge of the relative energy of each of these four transmit-receive combinations and the phases between them can be used in the field of polarimetry to synthetize target radar backscattering for any

[233] Editor's Note: Polarimetry is a complex topic. The sub-topic of decomposition is perhaps the most complex and challenging topic in remote sensing to explain to the non-scientist. The importance of CCRS's work in polarimetry has led us to provide what we hope is an accessible explanation for the non-scientist of the concepts and the importance of the work in the introduction and Appendix E, written by Lori White.
[234] The $10 billion is based on the reported costs of Canada's three RADARSAT programs, Japan's ALOS series and ESA's ERS-1, 2 and Envisat. See the following text box for further details.

combination of transmitting-receiving antenna polarization. This permits the derivation of important information about the scattering of the electromagnetic waves from the ground. Important information on scattering mechanisms that occur at the target can be provided for enhanced target structure characterization and biophysical parameter measurements.

6.7.2.4.2. The CCRS Role in the Calibration of Polarimetric Satellite and Airborne SAR and Influence on the Design of Polarimetric Satellite SAR Missions

Ridha Touzi and Chuck Livingstone

An Explanation of the CCRS Role in the Calibration of Polarimetric Satellite and Airborne SAR and Influence on the Design of Polarimetric Satellite SAR Missions
Ridha Touzi and Chuck Livingstone

The CCRS Convair-580 C- and X-band SAR was modified to add a scattering-matrix based polarimetric capability in 1988. (Livingstone *et al*. 1989) At that time, conventional fully polarimetric (FP) airborne SAR (such as the Jet Propulsion Laboratory (JPL) AIRSAR) used an implementation strategy with a receiver dedicated to the HH-HV (Horizontal transmit Horizontal receive-horizontal transmit, Vertical receive) polarization, and a second receiver that captured the VV-VH polarizations. CCRS (Dr. C.E. Livingstone) was the first to introduce a unique and innovative implementation strategy for fully polarimetric (FP) SAR that permits separate amplification of the cross- and like-polarized signal for optimum measurement of cross-polarization (HV and VH) backscatter [Livingstone *et al*. 1989, Livingstone *et al*. 1995]. This unique polarimetric architecture implemented in the Convair 580, improves radar channel balancing and signal-to-noise performance and resulted in CCRS influencing the design of several polarimetric SAR missions, such as the Danish polarimetric airborne EMISAR (built in 1994), and the Japanese satellite SAR ALOS and ALOS2 launched in 2007 and 2014, respectively. The latter have adopted Livingstone's FP architecture through the routing of the co- and cross-polarized signals to separate receivers that have independently controlled gains. This permits an improvement of HV and VH signal to noise ratio by a factor of 8 (about 9 dB).

The unique CCRS FP implementation strategy, which was validated with the Convair-580 SAR in 1989, required the development of a new calibration model. A new calibration model, named the Touzi-Livingstone model, was introduced to cover FP systems based on the Livingstone strategy which uses two distinct receiving configurations according to the commanded transmitted polarization (H or V). (Touzi, Livingstone *et al* 1993) The general model also covers conventional FP systems whose receiving configuration is independent of the transmitted polarization (one configuration). The model served as the basis for the development of new calibration methods that were validated with both X- and C-band polarimetric Convair-580 SAR data. (Touzi, Livingstone *et al* 1993, Touzi 1992, Touzi and Raney 1993) These methods were adopted by CCRS as the standard method for the calibration of all of the Convair 580 SAR data collected since, and in particular, all of the data collected between 2000 and 2006 during the preparation for the RADARSAT-2 FP SAR mission. (Touzi, Livingstone *et al*. 2006) Since it is now generally agreed that the Convair-580 FP implementation strategy is the most efficient strategy for the measurement of the HV and VH polarization with optimum Signal-to-noise ratio, Touzi-Livingstone SAR calibration model should gain more popularity in the future for the extraction of pure FP measurements HH, VV, HV and VH.

The experience acquired with the calibration of polarimetric Convair-580 SAR allowed CCRS to significantly influence the design and calibration of the Canadian and Japanese polarimetric satellite SAR missions. In 1998 CCRS, as a Member of the RS-2 Preliminary Design Review (PDR) committee, influenced the design of Canadian satellite RADARSAT-2 (RS-2).

CCRS led an investigation to convince the Canadian Space Agency (CSA) and the government contractor MacDonald Dettwiler and Associates (MDA) with the fact that the RS-2 antenna original specifications (with a requirement of -13 dB isolation) were inadequate to meet the RS-2 end-user requirements. A formal report was sent to MDA to justify the need for antenna isolation better than -30 dB. (Touzi 1998) Thanks to the support of A.P. Luscombe, at that time the head of RS-2 technical team, the CCRS concerns about the antenna isolation were given full consideration, and the RS-2 antenna was finalized with isolation better than -32 dB. This allowed RS-2 to provide “pure” HV (at single and dual-polarization modes) that has become the most used RS-2 polarization for maritime surveillance, and ice monitoring. (Touzi *et al*. 2013) The weak cross-polarization coupling in the RS-2 antenna simplifies calibration of polarimetric RS-2 modes, since the original measurements (with an antenna cross talk of -32 dB) meet the CEOS calibration requirements. For high-precision measurements of RS-2 antenna polarization port cross-talk, CCRS introduced in 2007 (right after the launch of RS-2) the use of two transponders deployed at HV and VH configurations. (Touzi *et al*. 2013) At that time, CCRS used long experience with a transponder design originally built and validated (by Dr. R.K. Hawkins) for the calibration of RADARSAT-1. A new transponder calibration model was introduced, and served as the basis of a unique calibration method that permitted reducing the RS-2 antenna cross-talk to less than -43dB. (Touzi *et al*. 2013) It was shown that the CCRS transponder calibration method is required for the calibration of RS-2 polarimetric standard modes. This permits full exploitation of the RS-2 low noise floor capabilities (Noise-Equivalent Sigma Zero (NESZ)[235] better than -38 dB) for the quad-pol standard mode. MDA calibration method, which yields calibrated data with about -33 dB residual error, is still suitable for the calibration of RS-2 quad-pol fine modes with a slightly higher noise floor (NESZ=-34 dB).

The experience acquired with the polarimetric Convair-580 SAR also allowed CCRS to influence the design and calibration of the polarimetric L-band satellite SAR (ALOS-PALSAR) conceived by JAXA and launched in 2004. Following the meeting CCRS (Dr. Touzi) had with the head of ALOS-PALSAR (Dr. Masanobu Shimada (JAXA)), the requirement on PALSAR antenna isolation was increased from -23 dB to -30 dB. As a guest Member of the ALOS Calibration-Validation group, CCRS could significantly influence the calibration of the L-band PALSAR. At the 2007 Cal-Val meeting CCRS was the first to show that the JAXA calibration method based on Corner Reflectors (CRs) deployed in Japan was not adapted for PALSAR calibration. CCRS used the measurements collected by JAXA on CRs deployed in the Amazonian forest (following Dr. Touzi’s request in 2005), to show that the calibration of L-band PALSAR should be conducted using measurements collected at low Faraday rotation. (Touzi and Shimada 2009) Since that time JAXA has adopted CCRS work as the standard approach for calibration of ALOS-PALSAR and ALOS2-PALSAR launched in 2014.

Extensive CCRS experience with polarimetric C-band and L-band polarimetric RS-2 and ALOS allowed CCRS to influence the design of the $1.2 billion Canadian three satellite Radar Constellation Mission (RCM). In 2009, a few months before the finalization of the Design of the RCM, CCRS succeeded through the RCM User and Science Team support, to incorporate the design of an antenna with much higher isolation (-30dB instead of the original -20 dB) for the three satellites of the constellation. This will permit the exploitation of the full potential of “pure” HV to support key applications, such as maritime surveillance and ice monitoring. At the CEOS Cal-Val meeting in 2009 CCRS succeeded in convincing the CEOS Cal-Val community to raise the stated requirement for Dual polarized antennas from -25 dB to -30B, as demonstrated by Touzi *et al* (2010).

6.7.2.4.3. CCRS’s Role in the Introduction of Polarimetry and Promotion of Polarimetric SAR Applications in Canada

Ridha Touzi

In 1998, when the polarimetric RADARSAT-2 mission was approved and MDA was awarded the contract for the design of RADARSAT-2, there was a general lack of knowledge of polarimetry in government agencies, universities and industry in Canada. At that time, CCRS was the only agency in Canada with significant experience in polarimetry, SAR processing, calibration, image processing, and methodologies for polarimetric information extraction and related applications. This experience was acquired thanks to the airborne Convair-580 SAR which was upgraded in 1988 by Livingstone to operate in fully polarimetric modes as described in the previous section. CCRS, which had at that time more than 10 years’ experience with the various aspects of polarimetry (theory, methods and applications), would go on to play a key role in the training of Canadian government institutions, universities and industry in polarimetry. This was all done in the context of the preparation of Canadians for the efficient and effective use of polarimetric RADARSAT-2 (RS-2) data.

[235] NESZ is a measure of the sensitivity of the system to areas of low radar backscatter

With the announcement of the RS-2 mission in 1998, CSA and CCRS initiated a collaboration agreement to prepare for polarimetric data. CCRS made a large volume of polarimetric Convair-580 SAR data sets collected since 1990 available to Canadian government agencies, universities, and industry. The CSA had funded Convair-580 SAR data acquisitions over many sites of interest to end users across Canada. The data acquisitions, experiments and data processing were organized by CCRS (Livingstone and Hawkins), and the Convair 580 SAR data were calibrated using the Touzi-Livingstone[236] calibration method. (Touzi *et al*, 1993)

Unfortunately, at that time, there was no user-friendly package that could be provided to the "new" polarimetric Canadian user community for efficient analysis of polarimetric Convair-580 SAR data. To fill this gap, Touzi led the development of a polarimetric workstation, referred to as the "PWS." The PWS is based on a polarimetric package Touzi started developing in 1988. The PWS was conceived to work on a PC platform, be user-friendly and help the Canadian community to better learn, understand and apply polarimetric data. To prepare federal and provincial governments, educational institutions, and industry for the integration of the new source of information of polarimetric RS-2, the CCRS PWS was licensed to more than 40 groups within Canada.

From 2002 to 2006, Touzi and Lukowski organized and gave a number of seminars on polarimetry at CCRS and across Canada. The objective of these seminars was to familiarize potential users with polarimetry and the use of PWS for the analysis of polarimetric data. Convair-580 SAR images were provided by CCRS to help prepare for the polarimetric RS-2 mission. This work led in 2004 to an issue of the ***Canadian Journal of Remote Sensing*** (CJRS) dedicated to RADARSAT-2 organized by CCRS and MDA. (Vachon and Staples, 2004) This issue included many papers on polarimetric RS-2 applications that used the PWS as the basis for deriving interesting results for a variety of applications using high quality Convair 580 SAR data (calibrated with the Touzi-Livingstone algorithm). The special ***CJRS*** issue included papers from nine CCRS scientists on a variety of applications. The applications included ship detection, ocean wind retrieval, crashed aircraft detection, crop mapping and productivity monitoring, forest classification and mapping, wetland mapping, and Digital Terrain Model generation. The issue included a widely cited review of the theory of polarimetry led by Touzi and co-authored by internationally recognized pioneers of polarimetry. (Touzi, Boerner, Lee and Luneberg, 2004)

In 2007 the PWS was upgraded for the analysis of polarimetric RADARSAT-2 images, and this allowed many Canadian groups (Federal and provincial government agencies, universities, and industry) the ability to fully exploit the unique RADARSAT-2 polarimetric capabilities in support of key information needs. In 2011 the PWS was made accessible via the CCRS online website (ftp://ftp.ccrs.nrcan.gc.ca/software/PWS_5.5/). Since then the PWS has been adopted in Canada and in many countries around the world (India, Brazil, China, France, Russia, and Argentina, among others) as a user-friendly tool for efficient exploitation of polarimetric satellite SAR information provided by various satellite and airborne SARs. These SARs include RADARSAT-2, ALOS, ALOS2, TerraSAR, UAVSAR and Convair580. The PWS has also been an efficient vehicle to promote the most recent advanced tools developed by CCRS such as the Touzi-Decomposition introduced for optimum polarimetric information extraction and those introduced in the following paragraphs.

CCRS has also been important in the growth of radar polarimetry world-wide by developing advanced methods for optimum polarimetric information extraction, and their validation in a variety of applications. In 2002, CCRS introduced the Touzi Symmetric Scattering Characterization Method (SSCM) (Touzi and Charbonneau 2002) for high-resolution classification of coherent scattering. This method was then validated jointly with Raney (then at Johns Hopkins University) for ship classification using polarimetric

[236] Editors Note: It is common practice in scientific circles to name special algorithms or approaches after those who have conceived them. Drs. Touzi and Livingstone have been among the leaders worldwide in polarimetry and thus their names have been attached to several unique tools and algorithms they have developed.

high-resolution Convair 580 SAR data collected over ships in a joint CCRS-Defence Research Development Canada (DRDC) airborne campaign. (Touzi *et al*., IEEE 2004) The SSCM permits identification on the ship of features with bright scattering whose polarization signature is independent of ship pitch and roll angle. The ship polarization signature, which is also stable with varying wind conditions, permits identification of the ship. These results were recently confirmed jointly with DRDC (Dr. ParisVachon) for (large) ship classification using polarimetric RADARSAT-2 of coarser resolution (9m).

New advanced tools, the Touzi discriminators, have also been introduced and validated for enhanced ship detection using polarimetric Convair-580 SAR data. (Touzi *et al*. 2002) These results have more recently been confirmed jointly with DRDC and MDA using polarimetric RADARSAT-2 data. The unique added value of polarimetric RADARSAT-2 for enhanced ship detection is demonstrated using ship verification data from the Automatic Identification System.[237] (Touzi *et al*., 2012)

In 2007, CCRS introduced a new innovative target scattering decomposition, the Touzi Decomposition, for enhanced characterization of natural targets. The new advanced method permits a unique demonstration of the added value of polarimetric SAR for enhanced peatland classification. (Touzi 2007, Touzi 2011, Touzi 2013) This work, first demonstrated using Convair-580 SAR data and presented at PolinSAR 2009 (Touzi 2009), was given a special award by ESA as the best promotion of polarimetric SAR applications. (http://www.esa.int/esaEO/SEMZ7XWPXPF_index_0.html) These results were then confirmed on subarctic peatlands (Wapusk National Park, near Churchill) (Touzi 2011)), and boreal peatlands in the Athabasca oil sand regions (Touzi 2013) using polarimetric ALOS data.

In 2009, the Touzi Decomposition was licensed to Canadian industry (PCI and Array Systems) and implemented by University of Rennes (France) in the ESA PolSARpro package. PWS has also been upgraded to include the new CCRS advanced methods (Touzi Decomposition and Touzi Discriminators). As a result, the Touzi Decomposition has become very popular in Canada and elsewhere (Brazil, India, China, France, etc.) for the promotion of the added value of polarimetric SAR information in support of key applications such as wetland mapping, snow classification, rice monitoring, forest biomass measurement, and forest mapping, among others.

6.7.2.4.4. Conclusion

The significance of this CCRS contribution is that it has enabled the full potential of polarimetric systems (RADARSAT-2 and RCM, ALOS PalSAR and ALOS2-PALSAR) to be realized. Without CCRS's sustained efforts, these systems would not be delivering 'pure' polarimetric measurements, and many of the real-world applications these data are now used for would not work, or would return very poor results. The combination of "well calibrated" RADARSAT-2 and ALOS-PALSAR allowed CCRS (as well as JAXA, ESA and other institutions) to promote polarimetric multi-frequency (C- and L-band) data as a key source of information in support of high government priorities such as monitoring the impact of climate change in the arctic regions, land cover changes, .. etc.).

[237] The Automatic Identification System (AIS) is a "vessel tracking system that automatically provides updates on a vessel's position and other relevant ship voyage data to a marine vessel traffic operator. The federal Navigation Safety Regulations came into force on May 10, 2005 and states: "Every ship, other than a fishing vessel, of 500 tons or more that is not engaged on an international voyage shall be fitted with an AIS…." Source http://www.ccg-gcc.gc.ca/eng/CCG/Maritime-Security/AIS Accessed November 10, 2018.

6.8. Methodology

Ian Crain

6.8.1. Introduction

The Methodology Section began in mid-1973 within the Applications Division with the appointment of three Research Scientists, Drs. Ian Crain, David Goodenough and Fred Peet. Soon after its formation Post-Doctoral Fellow Seymour Shlien joined the team. The objective of the Section was to develop methods to interpret and analyze remote sensing data that would then be used by the scientists in Applications Development as well as in the broader remote sensing community. At the outset the Section did not have a Head and the team reported to the Division Chief, Joe MacDowall. Eventually Dr. Goodenough became the Head of an expanding Section. Both Drs. Crain and Peet had left to go elsewhere by the mid-1970s.

6.8.2. Building Research Capacity

6.8.2.1. Introduction

In 1973, with the exception, perhaps, of the Airborne Sensing Unit, the Centre was an empty shell - there were no tools to process, manipulate and analyze digital imagery, and hence no ability to research and develop applications. On the other hand there was a small group of eager young scientists, and that other vital resource - money to spend, in the form of a "capital budget." This led to a two pronged search for technology - a) computing power, and b) software - including - programs, algorithms, methodologies, ideas, best practices, and success stories of other organizations in other related fields.

6.8.2.2. Hardware Acquisition: The Early Years

To address computing power, steps were taken to acquire a general-purpose mini-computer for the Centre, along with the hunt for more specialized devices. (See the Size Matters" Box below.) The search identified two such devices. The first was the Bendix digital image analysis system and the second was the General Electric Image-100. Both systems were developed for the US Military by their respective companies. The Bendix system was judged to be superior, but its purchase did not include the source code[238] and the "Image 100," which would include the source code, became the target. The Image 100 was built by General Electric's Aerospace Division in Orlando, Florida. The Image-100 reputedly used the latest "parallel processing" technology as an aid to the analysis and interpretation of air-borne and satellite digital imagery.

A first delegation of three CCRS scientists (Crain, Goodenough and Ryerson) was dispatched to evaluate the device for possible use with ERTS imagery, for both applications development and research. Armed with the knowledge that there was a substantial sum available to spend (eventually on the order of $300,000 in 1974$) the team would need to prepare a thorough and well-reasoned evaluation to justify a sole source (rather than tendered) acquisition.

Ian Crain recalls:

"Working from a rather seedy motel in Daytona Beach, the team of Goodenough, Crain and Ryerson (who were all then inexperienced in government contracting rules and negotiating) saw four days spent in and around the GE Labs. The first day was largely spent in their cafeteria, or playing with a flight simulator as a diversion. Apparently the Image-100, recently modified to better meet our needs, was mal-functioning. "It worked fine yesterday..." we were told, but it needed some more tinkering to work with the one ERTS image (of the area around Los Angeles) that was available.

By the second day the device was revealed for demonstration with a small swarm of GE technicians

[238] The source code was judged to be important for without it, CCRS scientists could not modify the systems to meet their specific needs.

standing by apprehensively. It worked (partially). By the fourth day it was somewhat reliable and we had seen enough of the LA image in various incarnations to be prepared to write a positive evaluation report. Following the submission of that report a second group including more senior staff went to Orlando to evaluate the system. This group included Dr. Murray Strome, Florian Guertin, Bob Ryerson and David Goodenough. The final negotiations were held in Ottawa. During those negotiations Ryerson insisted that the system required an improvement to allow one to set the joy-stick (or cursor) on a single specific pixel for the selection of training areas. One of the GE engineers responded by saying "That is a stupid idea." The senior GE representative was aghast. Fearing that the whole negotiation was going off the rails he asked for a time out, took the engineer out into the corridor, loudly berated him (so we could all hear) and returned to the conference room and said "Don't worry – you will get that accuracy and Engineer X is on his way home." We later learned that GE was desperate to sell to the Canadian Government, figuring if we bought one, the US would buy ten. And they did. Other early buyers were the Philippines and Iran.[239]

There were several more meetings in both Orlando and Ottawa, including one where an experienced procurement official from the Department of Supply and Services provided advice on how to deal with GE. His advice included that we should never go anywhere with GE employees unless there were two of us and that we were not to accept the inducements that were hinted at when we drove down the beach at Daytona near Orlando. As part of the negotiating ploy the CCRS team was instructed to keep the GE side guessing as to who the "real" decision maker was…the identification of the key person varied from one encounter to the next. It was comical watching the focus of GE's marketing attention shift depending upon who had been identified as the key person at the time. Eventually the recommendation to purchase was accepted by government authorities, and the first Image-100 in civilian use was delivered just in time for the Fiscal Year deadline March 31, 1974.

Size Matters
Ian Crain

A typical ERTS "scene" consisted of approximately 3000 x 3000 pixels in each of its 4 bands, thus about 9 Mbytes in each of the 4 bands. A total of some 36 Mbytes. Subsequent Landsat scenes had 6 bands with half the resolution i.e. a total of 216 Mega pixels. This was a "huge" dataset in those days.[240] As well, processing speeds of mini-computers of the time were extremely slow. Computer speeds are quoted in 'flops' - floating point instructions per second. Minicomputers in the early 70s (like the PDP-8 and Vax) ran at something like 30K flops. At that speed, a simple calculation involving each pixel in a typical scene would take several minutes, more complex algorithms much longer. (Modern computer chips have processing speeds typically measured in Giga flops, i.e. one million times faster!)

The Image-100 set out to solve this problem by using multiple processors that ran in parallel rather than having to operate on each pixel in sequence. Exactly how many such hard-wired processors is unknown, but it successfully reduced processing times to acceptable levels. Even then it was still slow - calling for an unsupervised classification of a complete scene was definitely a good time to wander off and have a leisurely coffee break. Even though it was a leading edge device, the Image-100 had far less image analysis capacity and speed than current digital cameras – that can detect whether or not a subject has blinked or is not smiling in ... well ... the wink of an eye. **The pioneering research into image analysis algorithms by the RS community in the 70s and 80s formed the basis for today's practical applications from point-and-click photography to the "vision" capabilities of autonomous vehicles.**

Physically the machine was a work-station about the size of a small office desk with a TV-like screen, keyboard and a joy stick. There were two tape drives, a mini-computer and two disc drives the size of a

[239] In the early 1990s Ryerson saw first-hand the system sold to NAMRIA in the Philippines: it was still being used.
[240] As has been stated by many over the years, those in remote sensing have always been dealing with what is now called "big data."

bar refrigerator. The room in which it was housed had a raised computer floor and was the size of a small living room – about 25 square meters. The device could do several image enhancement functions, such as edge enhancement, and speckle removal which could be an aid to visual interpretation of the image. The principal advantage however, was that it could conduct "classification" of a "scene" image using the characteristics of its 4 bands of data. This could be done in "supervised" or "unsupervised" mode. In supervised mode, in a process called "training"[241] the operator would use the joy-stick to identify pixels of interest (which based on the operators knowledge were of a known land cover - such as forest, or grassland or potatoes), and then request the machine to find all other pixels having similar characteristics. (In remote sensing we would say that they had the same "spectral signature" in "spectral space"). This could then be repeated for any number of "classes" present in the scene, with the leftovers being identified as "other." The device did not learn to improve its identification of classes through experience; it merely executed predefined algorithms applied to the operator-selected group of pixels. Several different algorithms were available (such as "parallelepiped" and "maximum likelihood") to guide how the comparisons might be accomplished. In unsupervised mode, using pre-programmed algorithms, the machine would identify the distinct classes and leave the operator to figure out what these might represent on the ground.

The principal advantage was that these calculations were done quickly (relatively speaking) as it used multiple parallel processors that had the algorithms hard-wired rather than processed sequentially through a software program. (See technical note in the preceding text box on the nature of the problem.) The concomitant disadvantage is that you were stuck with these pre-selected hard-wired algorithms that could not be changed or programmed differently. Research on alternative and more advanced image analysis algorithms had to be done using the newly acquired mini-computer.

The CCRS Image-100 workstation was used heavily for many years by Applications Division staff and scientists from other government departments, academe and provincial governments. It was used to do image enhancement for subsequent visual interpretation, as well as for assistance in automated classification until computer speeds and more adaptable and flexible image analysis software caught up. The device was taken out of service in the 1990s to its final home in the National Science Museum where it was on display for a time as part of an exhibit on space and technology.

6.8.2.3. Early Software Acquisition[242]

Another avenue to strengthen the research capacity assigned to Methodology was to locate existing useful software in other organizations. The CCRS experience with this search demonstrated the excellent spirit of openness and cooperation amongst scientists and organizations that typified this era.

The search first led to NASA and its Jet Propulsion Laboratory (JPL) in California where the "VICAR" software, used on unmanned planetary missions was developed. It took nothing more formal than a few telephone calls to get an invitation to meet with Dr. Fredrick Billingsley, a senior project scientist, who was one of the pioneers in the field of planetary exploration, and a developer of the software. Billingsley is also credited with coining the word "pixel" – shortened from "picture element." At a meeting in the sprawling JPL facility in Pasadena, a CCRS scientist was told of the history of the software development for early planetary probes, and was regaled with stories of JPL projects past and current, as well as useful information on how their project proposal and funding system worked.

[241] The use of the word "training" appeared to indicate that the Image-100 had Artificial Intelligence (AI) capability - i.e. that it could be trained or learn to identify land cover classes or objects. In reality there were no AI capabilities.
[242] Editor's Note: Dr. Crain was selected to carry out these software evaluations since he was the one most experienced with actual scientific software development with his background as an oil company geophysicist, in the Geophysics Division of Geological Survey (Larry Morley was Head at that time), and later in the EMR Computer Science Centre.

Developed in the late 1960s, VICAR (short for Video Image Communication and Retrieval), was designed to be open-ended to adapt to multiple video formats and specifications. A recent US government embargo had been placed on providing software to "foreign nationals" without formal approval and some sort of exchange. Having been forewarned, a blank magnetic tape labelled "CCRS Data" was logged in on entry at JPL security, and subsequently exited the premises with the VICAR software copied on to it. The total red-tape of that agreement was a scientist-to-scientist friendly handshake. It is hard to imagine that happening today!

In the end VICAR was never implemented at the Centre, as it was based on the JPL IBM 360 mainframe, and thus not easily convertible to CCRS mini-computer technology. But it was an inspiration for concepts and algorithms. Amazingly some forty years later VICAR still exists - as an extensive suite of open-source image analysis tools maintained by CalTech for JPL, available to all online.

A similar mission was launched to Britain through contacts arranged by the Applications Division Chief, Joe MacDowell, who was formerly with the British Antarctic Survey. Space and Remote Sensing related activities were spread amongst a number of UK Ministries and agencies, including Transport, the Ordnance Survey, and the Military, and coordinated by a Ministry called something like Science and Economic Development. An office there kept a searchable registry of who was doing what with space, remote sensing, imagery, image analysis etc. and they were wonderfully cooperative. They arranged introductions, set up appointments to meet with 8 or 10 departments and agencies with briefing notes on each, with possible topics of mutual interest, and helpful hints on how to travel to these the offices scattered across the Greater London area. In every case the technical and scientific staff members were welcoming and forthcoming, and eager to share information and software.

Ian Crain recalls:

"One exception to the welcoming nature of our early colleagues was the one agency in the UK that seemed to have the most promise - a small office with a mandate reminiscent of JPL, and which might be a source of image analysis software. The Coordinating Office had almost no information about them - no list of current projects or key personnel, only their location (in a small town near Heathrow Airport), and the name and telephone number of the Director. There was much head shaking – "They don't fill in our forms. We remind them but..." Determined to follow up on this lead, I took the very non-British approach of a telephone call – unannounced and un-introduced. In fact I called from Piccadilly Underground station, stuffing lots of coins into a "call box" – many years before cell phones!

I asked to speak to the Director. I was connected, explained what I was doing and he said "Fine come on out" and gave detailed instructions of what Tube and then train to catch, to get off in at Slough station where I would be met by a driver to take me to their office in Datchet. This conversation was interrupted every minute or so by, the thunderous roar of a flight taking off from Heathrow and alternatively at my end with the squeals and rumbles of a Tube train grinding through Piccadilly. But it all worked, and within about an hour I was met on a station platform by a driver tipping his cap with a smiling "Dr. Crain, I presume." At the facilities it was clear that they did indeed have potentially useful software, although it was aimed at imaging from deep space probes, radio-telescopes etc. Still, they proved to be a very open and cooperative group of scientists. When asked why "The Ministry" did not seem to know very much about them, they laughed heartily and said "Ah, yes, we don't fill in their forms... we have invited them to come and visit us, but they never leave their office..." Years later I am sure I saw a scene much like this on “Yes Minister."

6.8.2.4. Methodology Developments: The 1980s and 1990s
Philippe Teillet

CCRS teams led by Dr. David G. Goodenough pioneered image processing and analysis methodologies for information extraction from optical and radar image data. These teams developed two significant image processing and analysis systems, in collaboration with the Applications Development Section at CCRS, Canadian university researchers, and Canadian industry to facilitate technology transfer: the CCRS Image Analysis System (CIAS) (Goodenough, 1979) and the Landsat-D Image Analysis System (LDIAS).

In collaboration with MDA, in 1992 CCRS also developed the Geocoding and Compositing System (GeoComp) to process Advanced Very High Resolution Radiometer (AVHRR) data from the United States National Oceanic and Atmospheric Administration (NOAA) series of satellites. The next-generation GeoComp-n was completed in 1999 and began operational use at the Manitoba Centre for Remote Sensing in 2000. (Adair *et al*., 2002)

Fieldwork was a key element of remote sensing methodology and applications development. (Teillet, 1995) As noted previously a great many CCRS projects included a field campaign component. The methodology R&D of the 1970s and 1980s advanced to the point where, in the early 1990s, the CCRS methodology effort was redistributed into more specialized teams dedicated to scene physics and analysis, and knowledge-based methods and systems. As hyperspectral image data became increasingly important, CCRS developed the Imaging Spectrometer Data Analysis System (ISDAS) to provide efficient processing and analysis of complex hyperspectral data. (Staenz, 1992) A talented, hard-working and important contributor to many of these R&D activities, from field work to software development to sophisticated data analyses, was Physical Scientist Gunar Fedosejevs.

During the highly-productive 1970s and 1980s, CCRS methodology scientists participated in an advisory capacity in the U.S. Large Area Crop Inventory Experiment (LACIE) in satellite-aided monitoring of global crop production, which focused on wheat, and the U.S. Agriculture and Resources Inventory Surveys through Aerospace Remote Sensing (AgRISTARS) program, which extended to other crops, mainly corn and soybeans.

6.8.2.5. Sensor Calibration and Image Correction
6.8.2.5.1. Landsat Radiometric Correction
Frank Ahern and Jenny Murphy

From the inception of CCRS in 1971 until the 1990s, the only satellite data acquired, processed, and used by CCRS was from NASA's Landsat series of satellites and data from the French SPOT satellite series.[243] The primary sensor was the Multispectral Scanner (MSS) for Landsats 1, 2 and 3, and the Thematic Mapper (TM) for Landsats 4 and 5 (although these later Landsat satellites also had an MSS). These two sensors each employed multiple detector elements (six for MSS and sixteen for TM) to build up an image from multiple scan lines, each with thousands of pixels in each of four or more spectral bands. MSS had four bands and the TM had seven (including one thermal band). An ideal sensor would provide data with the same mathematical relationship between the digital value of each pixel and the radiance of the scene at the position of the pixel. Actual sensors cannot achieve this goal without a great deal of work to characterize sensor effects mathematically. Radiometric corrections are then made to the data to remove the undesirable characteristics of the data. At CCRS we found it convenient to separate the radiometric corrections into relative corrections and absolute corrections.

[243] An important exception is a very small amount of SEASAT data that were processed digitally in Canada. That accomplishment, remarkable at the time, led to confidence that data from a proposed Canadian SAR satellite could be processed digitally.

Relative corrections remove effects such as gain and/or offset shifts within and between scenes. However, they are primarily used to diminish the impact of differences between the individual detector elements. The method used relies on evaluating statistics of the image data for the full scene, for each detector within each spectral band, as described by Strome. (1975, 1980) These effects often cause a remote sensing image to show artefacts that are very apparent to the human eye. The most pronounced of these, for both the MSS and the TM, was called “striping,” where adjacent scan lines or groups of scan lines each have a different brightness. This “striping” can be particularly pronounced over uniform dark areas (such as water bodies) or bright areas (such as snow and clouds) in the scene. The primary objective for applying relative corrections is to avoid providing poor quality data that can distract human interpreters and produce false results with subsequent digital processing and image classification.

Absolute corrections create a known and preferably time-invariant relationship between the digital value of each pixel and the radiance of the scene at the position of the pixel. These corrections are needed to provide the ability to detect and characterize long-term and subtle changes in terrestrial targets, such as the health of forests.

In the period from the advent of MSS data in late 1972 until 1978, CCRS struggled to produce MSS data with good radiometric characteristics. This was also an issue for NASA. The most difficult challenge resulted from shortcomings of the method NASA had designed to deal with the radiometric corrections for the MSS. The NASA method depended on an on-board calibration lamp that was an integral part of the MSS system. Since the lamp was illuminated with a tungsten-filament bulb, its colour temperature was much cooler (redder) than the colour temperature of the solar illumination on Earth. Even if the data were perfectly calibrated using the on-board lamp, serious “striping” appeared in Landsat scenes of the Earth. Some progress was made in diminishing the relative calibration problem by 1976, but there was no progress in the absolute calibration.

From late 1976 to 1978, Frank Ahern of Applications Division and Jenny Murphy of Data Processing Division (subsequently renamed Digital Methods Division) worked on a new method that would implement both relative and absolute calibration in a single image-processing step. This method incorporated a more comprehensive understanding and analysis of the scene statistics of each of the individual detectors. It had to compensate for several characteristics of the MSS sensor, but once implemented, proved very successful.

The new Landsat MSS radiometric calibration algorithms were incorporated into image processing systems built by MDA. Since MDA was providing Landsat ground stations to many international customers around the world at the time, the CCRS algorithm was exported around the world. At the same time, Jenny Murphy represented CCRS on the Landsat Technical Working Group, a global group instituted by NASA, and later led by NOAA. She was able to explain and support the CCRS approach at meetings of this group, and the CCRS approach was eventually adopted by NASA and by the USGS Earth Resource Observation Satellite Data Center at Sioux Falls, South Dakota.

Prior to the launch of Landsat 4, which had both an MSS and a TM, CCRS planned to use a comparable approach for radiometric calibration and correction for the TM as then used for the MSS. Before committing, however, Trevor Butlin of Instrumentation Section coordinated the development of an interim system, the TM Transcription System (TMTS). CCRS had recognized the value of providing all the raw data required for TM data evaluation and processing as soon after launch as possible, so TMTS was designed to include not only the raw imagery data itself, but also the housekeeping data required for precision corrections in the geometric, radiometric, resampling and projection domains.

TMTS revealed two specific radiometric characteristics that needed separate treatment. It was already known that the TM differed from the MSS in that it scans in both directions, with alternating east-west scans and west-east scans. TMTS data showed that the overall signal levels for each of those scans was different. Hence the TM must be regarded as having effectively 32 detectors and not 16. Of more importance, however, was the impact of excessively bright targets. These targets included not only Earth areas, such as water bodies, clouds and snow, but also the inflight calibration signals, which cycle through eight distinct levels. For the Earth image data, the data values tend to be depressed immediately after exposure to a bright target. Since the sensor scans alternately in different directions, the imagery will show alternating artificially depressed values for a short distance on either side of the target. No additional corrections were made for this effect in the imagery. However, the calibration data is simpler to rectify, since it is convenient to simply ignore several data samples immediately preceding and following a change in calibration level.

Other minor but consistent radiometric differences were revealed by the data from the TMTS system. Their treatment, along with the scan direction and calibration target effects, were effectively incorporated into the processing system, which as noted earlier, was based on the CCRS MSS calibration and correction approach. The TM processing method was also incorporated into the MOSAICS system by MDA.

The assessment of the radiometric accuracy of CCRS TM products was successfully presented at the February 1983 ***Landsat 4 Science Characterization Early*** Results Symposium using a test scene over the coast of California. An assessment of the radiometric accuracy of Landsat 4 and Landsat 5 TM products was also incorporated into the NASA-led Landsat Image Data Quality Analysis LIDQA Program final conference in September 1985.[244]

CCRS and the Presidential Ranch
Jenny Murphy

In the early days NASA had trouble with the correction of TM data. NASA's assumption that the TM sensor and the TM calibration system would work precisely according to prelaunch specifications meant that they had an inflexible system that did not take into account how the sensor responded, post-launch, to high-contrast features such as snow. When the sensor passed over an especially bright (or dark) feature, several pixels after the feature would be affected and this happened as the sensor tracked back and forth in both directions.

As it happened CCRS chose to use a California scene for the first LIDQA conference to demonstrate how we did the corrections. This scene was selected because it highlighted the peculiarities of how the TM sensor worked in the real-time scenario after launch over areas where there were major brightness changes not only in the calibration system but also in the scene itself, such as water, coastlines, snow and clouds. Our use of this image ended up causing quite a stir.

Murray Strome did the presenting, while I had written the paper, and Trevor Butlin and I had worked overtime to process the scene and produce decent photographic products. I prepared and turned the slides. The stir appeared to be because that scene had President Ronald Reagan's ranch on it, and the US wanted to present a copy of one of the first TM images to the President. With their system, all of the challenges of the TM sensor post-launch were manifested, resulting in a sub-par quality image from a public relations perspective. CCRS had used that scene as a challenge to our processing system, not realizing the significance of the image itself. We are not sure if the image was ever shown to the President after our work, but it was given to a senior NASA official who was told he could pass it on. Regardless, we were gratified knowing that our approach did have an impact on the Landsat program.

In a subsequent piece of backroom dealing, I handed over to John Barker some detailed post-launch output of the background data and calibration scans in return for much more prelaunch calibration data. That data, which had not yet been made available to all of the other Ground Stations, was used to further refine our absolute calibration.

[244] For further information see: Strome et al 1975 and 1980; Ahern and Murphy 1979; Butlin and Murphy 1983; Murphy et al 1984; and Murphy et al 1985.

6.8.2.5.1. Calibration and Image Correction

Philippe Teillet

As noted above, early on CCRS recognized the importance of radiometric calibration and correction on the qualitative and quantitative utility of airborne and satellite image data. (Ahern and Murphy, 1978; Teillet *et al*., 2004a) This led to R&D on optical image correction for radiometric and geometric effects (sun angle correction, radiometric calibration, atmospheric correction, topographic correction, and geometric correction) (e.g., Ahern *et al*. 1989; Teillet, 2016). R&D on radar image preprocessing and analysis soon followed the earlier work. (e.g. Guindon *et al*., 1984) The associated image analysis software was implemented on CCRS systems (CIAS, LDIAS, ISDAS) as well as in commercial image analysis packages.

Also in the early years, CCRS developed a unique field measurement system to provide the physical underpinnings for understanding multispectral and hyperspectral remote sensing imagery. (Brown and Ahern, 1980) This was the Visible and Infrared Laboratory (VIRLAB), which consisted of a large cube van, a hydraulic cherry-picker ladder, and a portable spectrometer that enabled reflectance measurements to be acquired as much as ten metres above terrestrial surfaces such as crops, soils, and geological formations. Measurement campaigns spanning months took place to study crops in Melfort, Saskatchewan. Other campaigns involved potato crops in New Brunswick, forest canopies in Nova Scotia (using a different cherry-picker facility with the same spectrometer), geological formations near Kaladar, Ontario, and Alberta rangeland. In 1985-86, VIRLAB took part in international R&D at locations such as the White Sands Missile Range alkali flats (to develop methods for post-launch radiometric calibration of Landsat, SPOT and AVHRR image data) and the Phoenix lab of the U.S. Department of Agriculture (to study spectral signatures of crops and soils).

Over many years, driven by its user-centric view of radiometric calibration, CCRS played important methodology roles with respect to operational Landsat sensor calibration, in collaboration with MDA, the NASA Goddard Space Flight Center (GSFC) and the U.S. Geological Survey (USGS) EROS Data Center (EDC), among others. (Teillet *et al*., 2004b) CCRS also worked with researchers from the University of Arizona, the U.S. Department of Agriculture, NASA GSFC, and the University of Maryland on operational radiometric calibration of NOAA AVHRR imagery in solar-reflective spectral bands, a very widely used global image source for which there is no onboard calibration capability. (Teillet *et al*., 1990, 2000)

CCRS recognized the importance of understanding the information content from angular signatures (bidirectional reflectance) and was the catalyst for an international effort. (Gauthier *et al*., 1991) Field campaigns were mounted, with a variety of Canadian and U.S. agencies, at the Petawawa National Forestry Institute, and at the Maricopa Agricultural Center in Arizona (1990). CCRS also contributed bidirectional reflectance and imaging spectrometer field data to NASA's Boreal Ecosystem-Atmosphere Study (BOREAS), a large-scale international interdisciplinary experiment in the northern boreal forests of Saskatchewan and Manitoba (1994, 1996).

In the 1990s, led by Teillet, CCRS initiated and hosted three Canadian Workshops on Earth Observation Calibration and Validation involving experts from industry, government agencies, and universities. CCRS also actively participated for several decades in the international Committee on Earth Observation Satellites (CEOS) and its Working Group on Calibration and Validation (WGCV). Dr. Susan M. Till chaired the WGCV for six years, chairing eight international working group meetings, and Teillet participated in many WGCV meetings and meetings of the WGCV sub-group on Infrared-Visible Optical Sensors (IVOS).

In 1997, Dr. Norman T. O'Neill and Dr. Alain Royer at the Université de Sherbrooke formed a Canadian network called AEROCAN, with the help of CCRS, which provided expertise and four Cimel instruments. (Bokoye *et al*. 2001) AEROCAN joined and is still part of NASA GSFC's AERONET, a global network of automated (Cimel) sun-tracking sun-photometer and sky scanning instruments for atmospheric remote sensing and atmospheric aerosol optical thickness monitoring in support of image correction for atmospheric effects.

In a continued collaboration with the University of Arizona, NASA GSFC and USGS EDC, CCRS participated in field campaigns at playas (e.g., Railroad Valley Playa, Nevada) and international working group meetings to help provide post-launch updates on calibration coefficients for radiometric processing of image data products. (Teillet *et al*., 2001; Teillet and Chander, 2016)

6.8.2.6. Imaging Spectroscopy (Hyperspectral) Development
Karl Staenz

Based on national and international activities in imaging spectroscopy which emphasized the potential of this area in various application areas such as mineral mapping, CCRS decided to start the development of imaging spectroscopy in the late 1980s. These early efforts generated a first generation of software to handle, process, and analyze imaging spectroscopy data (Staenz, 1992) and led to the design and construction of the airborne spectrometer, Short-Wave Infrared Full Spectrum Imager (SFSI). (Neville *et al*., 1995)

In 1995, the CSA and CCRS began a coordinated approach to developing a hyperspectral program in Canada in response to the recommendations of the National Remote Sensing Advisory Working Groups. Within this framework CCRS established an imaging spectroscopy program in 1996 with a focus on the development of methodologies and applications, and the transfer of technology to industry. The CSA embarked on work to lead to a hyperspectral satellite program. Starting in 2001, the main activities in this area concentrated on the development of the Hyperspectral Environment and Resource Observer (HERO) mission concept, a Canadian small hyperspectral satellite, involving the Canadian space industry, various government departments, and universities. (Bergeron *et al*., 2008) In these mission concept developments, CSA was responsible for program coordination, for the space segment and mission control, with CCRS having the responsibility for ground receiving stations, applications development, and coordinating the user and science team.

The collaborative efforts resulted in the involvement in the 1996 Australian Resource Information and Environment Satellite (ARIES) mission study, the Spectral Imaging Mission for Science and Application (SIMSA; 1998) and Spectral Analysis of Dryland Degradation for Global Desertification Assessment (SAND; 2002) mission proposed to ESA's Explorer program. There was also the joint development of mission concepts with the GeoResearch Centre Potsdam and German Aerospace Centre (DLR) and Italian Space Agency (ASI) and related industry (e.g., MDA, OHB-SYSTEM AG, Galileo Avionica) in 2003 and 2007, respectively. These joint activities eventually led to the construction of spaceborne hyperspectral missions without Canadian participation to be launched in 2019 (Italian Hyperspectral Precursor of the Application Mission (PRISMA) and 2020 (German Environmental Mapping and Analysis Program (EnMAP)).

In support of the aforementioned mission concept developments, CCRS further developed software for correction of sensor artifacts and atmospheric effects, data visualization, information extraction, and sensor characteristic simulation. These efforts led to the design and construction of the Imaging Spectroscopy Digital Analysis System (ISDAS) Staenz *et al*., 1998), which is still one of the most comprehensive systems for correction of hyperspectral data as well as the simulation of future sensor data. Within this development, CCRS scientists first demonstrated the use of look-up tables for atmospheric correction of hyperspectral data (Staenz and Williams, 1997), automatic selection of pure materials in a scene endmembers (Neville *et al*., 1999), partial spectral unmixing (Shang *et al*., 2008), and various sensor artifact correction algorithms. (Secker *et al*., 2001; White *et al*., 2005; Neville *et al*., 2008; Sun *et al*., 2008) The application of hyperspectral data was also extensively applied to demonstrate the value of these data for calibration purposes. (Teillet *et al*., 2001) The ISDAS software package was applied to various airborne and satellite data for application development, especially in the areas of exploration geology and mapping, environment, and precision agriculture. This demonstrated the need for hyperspectral data to extract products that would only be possible with hyperspectral data or which would be superior to those extracted with multispectral data (e.g., Brown *et al*. 1997; Budkewitch *et al*., 2000; Champagne *et al*., 2003; Bannari *et al*., 2006; Levesque and Staenz, 2008; Pacheco *et al*., 2008).

The development of hyperspectral hardware/software and applications was carried out in close collaboration with Canadian industry, universities, and other government agencies. These partnerships ensured successful technology transfer and assisted industry in entering the expanding market for hyperspectral remote sensing. For example, SFSI was transferred to industry (Borstad Associates) and used extensively for mapping of minerals by the mining industry, and portions of ISDAS were incorporated into PCI's Geomatica.

CCRS also established the specifications for portable field spectrometers used by manufacturers to build a new generation of instruments in the early 2000s. The currently available spectrometers are still mainly based on these specifications. These instruments are essential to support the exploitation of hyperspectral data by providing the necessary scientific underpinnings for the development and validation of data preprocessing and information extraction techniques as well as information products. They are also an integrated part for vicarious calibration[245] and provide valuable information for the determination of the spectral characteristics of airborne and space-borne sensors.

6.8.2.7. Sensorwebs and Integrated Earth Sensing
Philippe Teillet

In the early 2000s, CCRS investigated the converging technologies of micro-sensors, computers, and telecommunications, and the advent of in-situ sensorwebs and Earth science satellite constellations, to advance integrated Earth sensing. CCRS and the Centre for Research in Earth and Space Technology (CRESTech), an Ontario Centre of Excellence, set up ten university pilot projects, funded by CRESTech (Richard Worsfold[246]), to allow Ontario universities to develop new expertise in sensorweb concepts and technologies. In collaboration with experts at Agriculture Canada (Dr. Anne Smith) and MDA, in a project supported by PRECARN funding, CCRS demonstrated the real-time operation of in-situ sensorweb prototypes with autonomous remote data access, in combination with remote sensing data products, for improved crop and rangeland yield predictions. (Teillet *et al*., 2007)

[245] Editor's Note: The European Space Agency http://calvalportal.ceos.org/cal/val-wiki/-/wiki/CalVal+Wiki/Vicarious+Calibration cites the CCRS web site to define vicarious calibration as "techniques that make use of natural or artificial sites on the surface of the Earth for the post-launch calibration of sensors. These targets are imaged in near-coincident fashion by the sensor to be calibrated and by one or more well-calibrated sensors from satellite or aircraft platforms or on the ground."

[246] Worsfold was an early employee of the CCRS Airborne Sensing Unit. He went on to develop a remote sensing based company (Remotech) in Newfoundland before joining the Ontario Centre of Excellence.

6.9. Satellite Data Reception

Tom Feehan

6.9.1. Introduction

This section describes the technical background of the satellite data reception activities of CCRS. The tools dealing with the processing are discussed in Section 7.0.

6.9.2. Prince Albert Satellite Station

With the founding of CCRS, a capability to receive data from polar orbiting earth observation satellites was required. This led to the establishment in 1972 of the Prince Albert Satellite Station near Prince Albert, Saskatchewan. The timing of this event was linked to the U.S. Earth Resources Technology Satellite program (later renamed the Landsat program) in which the Government of Canada (through CCRS) had decided to participate. In collaboration with the Saskatchewan Engineering Division of the University of Saskatchewan (later spun off as SED Systems Ltd.) and Synaptic Systems Ltd. of Richmond, B.C. (which evolved into MacDonald Dettwiler and Associates Ltd. (MDA)), the Prince Albert Satellite Station was developed from the previously established Prince Albert Radar Laboratory operated since the early 1960's by Canada's Department of National Defence. All of the required upgrades and technological developments necessary to receive and process imagery from the U.S. Landsat-1 satellite were in place by satellite launch. CCRS prides itself on the fact that it successfully received and processed the first Landsat-1 image and made it available to the U.S.[247]

The station was also equipped to handle data from the U.S. TIROS satellite program (later renamed the NOAA satellite program). A new system to process and generate data and imagery from the NOAA satellite program Advanced Very High Resolution Radiometer (AVHRR) sensor was developed in collaboration with MPB Technologies Ltd of Montreal. In 1995, the operations' building was replaced with a modern facility, funded by the Western Economic Diversification fund. The boardroom of the new facility was named in honour of Dr. Larry Morley, the founding Director General of CCRS. CCRS continued to technologically evolve the station over the years in collaboration with industry as well as some internal technology development to support Canada's participation in many international satellite programs including those of the U.S. with Landsat and NOAA, France with SPOT, the European Space Agency (ESA) with ERS-1, ERS-2 and ENVISAT, as well as Canada's own RADARSAT program. Satellite data and imagery products were produced until 1991 at the Prince Albert Satellite Station. At that time, exploitation of Landsat, SPOT as well as ERS SAR data were sublicensed to RADARSAT International Inc. (RSI) by CCRS. RSI, later known as MDA Geospatial Systems Inc (GSI), was established as the commercial Canadian entity for the operation of the RADARSAT program. Producing and distributing Landsat and other satellite products would help RSI gain experience and prepare it for eventual RADARSAT commercial operations.

In addition to supporting earth observation satellite programs, the Prince Albert Satellite Station also participated in satellite launch support campaigns with the French space agency (CNES) and the Canadian Space Agency (CSA). In 2014, the scope of the Prince Albert Satellite Station expanded to include the remote operation and centralized management of the Gatineau and Inuvik satellite stations. The Prince Albert Satellite Station was managed by Roy Irwin from its establishment in 1972 until his retirement in 1996, followed by Gerry Bergen until his retirement in 2003 and since then by Kevin Adams.

[247] The image was rushed to Ottawa in time to be shown at the XIIth ISPRS held from July 24 - August 04, 1972

6.9.3. Shoe Cove Satellite Station

The Shoe Cove Satellite Station was established by CCRS on the Newfoundland East coast in 1977, primarily to permit the reception and processing of data from the U.S. SEASAT L-band synthetic aperture radar satellite. The station was built on the site of a former NASA Mercury, Gemini and Apollo mission tracking station. This geographic location allowed maximum satellite coverage over the Atlantic Ocean - an important criterion for the SEASAT ocean-focused earth observation program. The station was also equipped to handle data from the Landsat and NOAA satellite series, complementing the central and West coast coverage provided by the Prince Albert Satellite Station. The station was a showcase for a new technological innovation in satellite station design, known as the Portable Earth Resources Ground Station (PERGS) in collaboration with MDA. The photo above was taken at MDA in Richmond, B.C.

Unfortunately, with the unexpected early failure of the SEASAT satellite, compounded by a significant increase in the U.S. fees for Landsat satellite reception combined with the limited utility of Landsat data in the high cloud conditions on the East coast, the operation of the Shoe Cove Satellite Station was discontinued by CCRS in mid-1982.

The Shoe Cove Satellite Station was managed from Ottawa by Art Collins until 1981 when Paul Thorburn was hired as local station manager prior to its decommissioning.

6.9.4. Gatineau Satellite Station

The Gatineau Satellite Station was established by CCRS in Cantley, Quebec in 1985 initially to allow the reception of data from France's SPOT satellite program over Eastern Canada and the U.S., complementing the coverage provided by the Prince Albert Satellite Station. The initial development of the station was done by CCRS Prince Albert staff and included the redeployment and upgrade of the antenna from the Shoe Cove station to be compatible with the SPOT program as well as the development of the SPOT Quicklook system deployed at both Gatineau and Prince Albert stations.

The station (pictured here in 2015) became operational in 1986 in time for the SPOT-1 satellite and continued to technologically evolve to support Canada's participation in international earth observation programs including the U.S. Landsat, the European Space Agency (ESA) ERS-1, ERS-2 and ENVISAT, as well as Canada's RADARSAT program. The Gatineau Satellite Station showcased innovative Canadian technology developed by MacDonald Dettwiler and Associates Ltd. (MDA) necessary for near real-time Synthetic Aperture Radar (SAR) image processing and delivery to operational users. Such delivery started in 1991 with ERS-1 SAR operations as proof of concept for RADARSAT-1 and evolved to include RADARSAT-1 in 1996 and RADARSAT-2 in 2008. The near-real time ocean information processing and on-line distribution was demonstrated using the Satlantic Inc. developed Ocean Monitoring Workstation to showcase operational Canadian applications development to Federal department users. MDA GSI has continued to operate its RADARSAT SAR processor at the Gatineau station under a CCRS co-location arrangement, providing centralized near real-time RADARSAT data processing and distribution for global data received by the Prince Albert and Gatineau stations. This technology has continued to evolve and its success has resulted in uptake over the years by remote sensing organizations in many countries.

6.9.5. Inuvik Satellite Station

The Inuvik Satellite Station was established in 2011 by CCRS. The strategic location of the station was to allow coverage over the Arctic region for RADARSAT-2 as well as create opportunities for strategic international earth observation collaboration. Initial collaboration arrangements included Germany's TerraSAR and TANDEM-X programs. The Inuvik Satellite Station (pictured here in 2015) is remotely operated and centrally managed by the Prince Albert Satellite Station.

6.9.6. Refurbishing of the Stations: Better Late than Never

In Section 4.4 the poor state of the stations by 2002 was mentioned. It wasn't until Doug Bancroft was Director General and Caroline Cloutier the Director responsible for the stations, that desperately needed new money was obtained (approximately $40M from the federal 2012 budget, and $5M from the DM NRCan strategic reserves). This resulted in the Gatineau and Prince Albert antennae being refurbished by replacement, and an additional new one installed at Inuvik station.

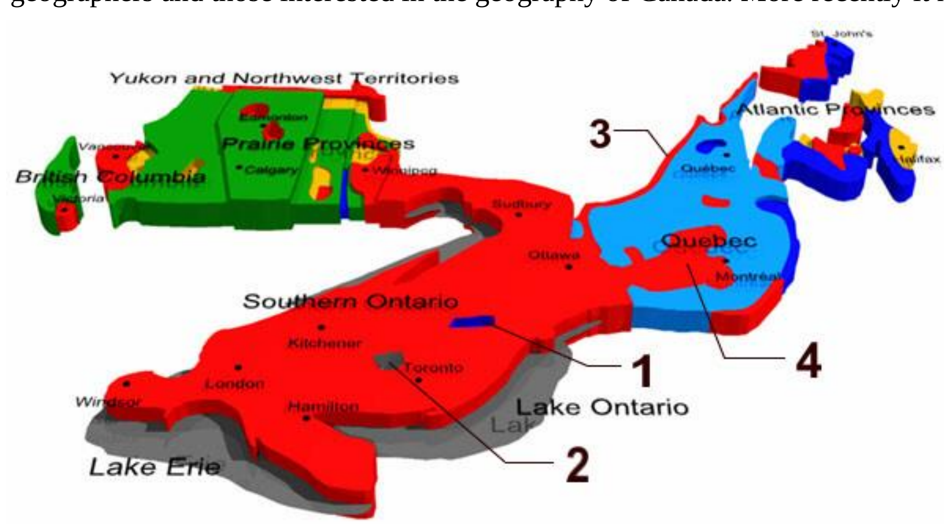
6.10. GeoAccess Division: A History of Successes

6.10.1. Introduction
Bob Ryerson

As noted in Section 4.2, the GeoAccess Division was created in 1996 to fill a vision by Director Bob O'Neil for two orphaned units within Geomatics Canada. The division and its activities remained a key part of CCRS for just twelve years until 2008. Over those twelve years what began as a collection of orphans that no-one other than CCRS seemed to know what to do with became an award winning unit that everyone coveted. This is largely as a result of the solid management team that was assembled and the belief of the staff that what they were doing was important for Canada. And it was. The next section has been written by one of these managers. Other managers included the late Donna Williams (Atlas), Doug O'Brien (Atlas and CEONet), Brian McLeod (CEONet, GeoConnections), Terry Fisher (CEONet), and Cameron Wilson (GeoGratis, GeoConnections).

6.10.2. The Atlas of Canada
Peter Paul

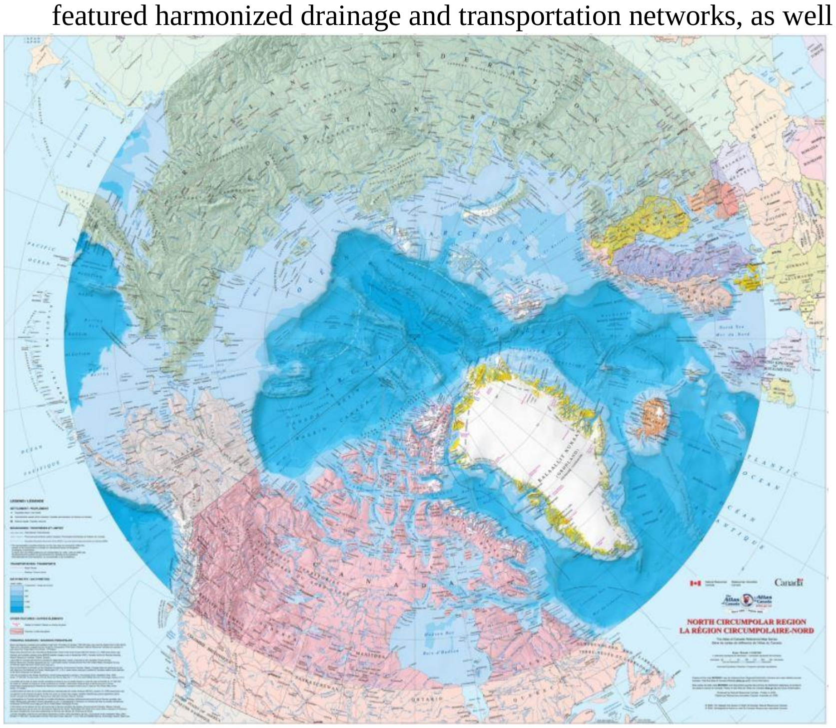
This section presents some of the highlights within the GeoAccess Division as part of CCRS. Before the National Atlas joined CCRS, it had already had a ninety year history and a high profile among geographers and those interested in the geography of Canada. More recently it had gained some profile by producing real-time election maps (made available to national TV networks via the Anik satellite from the Canadian Communications Research Centre) for the 1994 federal election. Soon after joining the GeoAccess Division, another



federal election occurred (1997), and on-line maps were also produced. This time the Atlas partnered with Statistic Canada's Geography Division to include the capability to compare election results with census profiles from the electoral ridings, and featuring an innovative "iso-demographic" election map. This new form of election map challenged our conventional notions of what "Canada" looked like, while at the same time showing more clearly which parts of the country had the largest influence on the election results.

Another aspect of the Atlas that gained it visibility was its use in the schools. The degree to which the on-line presence of the Atlas had permeated Canada became very clear at a geomatics conference held in Ottawa in the late 1990s. The then Minister of Industry (and later Deputy Prime Minister) John Manley was showing a visiting Minster of Industry from another country the exhibit area. He came upon the National Atlas display and when he saw it he asked if he could show his colleague how the system worked. Somewhat surprised the National Atlas staff member relinquished her seat to the Minister who proceeded to demonstrate the system. It seems that the previous evening he had been helping his teen-aged daughter with her homework that required access to the National Atlas and he had been quite impressed. In turn his enthusiasm impressed the National Atlas Staff, and validated what they had worked hard to achieve. During Mr. Manley's tenure, Industry Canada also launched the Schoolnet program to encourage computer and internet usage in schools across Canada – particularly those in rural or remote areas which faced budget constraints. As part of this program, the Atlas of Canada launched the Canadian Communities Atlas, an initiative which encouraged schools to create their own "local Atlas," to complement the national maps. This Atlas program was a recipient of a Prime Minister's Teaching Award in 1996 in partnership with Bill Belsey, a local teacher from Rankin Inlet (Nunavut, then NWT), the first Arctic school to launch their own web site. During the 1990s the Atlas of Canada web site routinely ranked among the top Government of Canada sites in terms of yearly visits by users.

Another Atlas highlight from the Spatial Data Infrastructures Conference involved an on-line North America map produced as a partnership between the Atlas programs in Canada, Mexico, the United States, and the North American Commission for Environmental Co-operation, established as part of the NAFTA agreement. The partnership had created an earlier joint paper map from digital bases which were then published as an interactive "on-line" map from web servers in each of the three countries. The map featured harmonized drainage and transportation networks, as well as the capability for local updates as necessary. Although coming from three different sources, the digital map "blended" together on the screen before our eyes.



In 1999, the International Cartographic Association held its conference in Ottawa. As part of this event very colourful paper maps from countries around the world were on display in the atrium of Ottawa's Government Conference Centre, the former Union Train Station. The winner of the "People’s Choice" award for map design, was the North Circumpolar Map, produced by the Atlas of Canada. This map featured an innovative combination of artistic relief shading and digital bathymetry to render the seafloor topography of the north circumpolar basin. It also used cloud-free composite MODIS imagery classified by CCRS scientists for the delineation of glaciers and ice cover. Later, this map was enlarged and laminated to form a huge floor map which was on display at NRCan's head office, and at the launch of the International Polar Year (2007) at the Canadian Museum of Civilization and in Paris, France.

The $100 Banknote[1]
Bob O'Neil

The Bank of Canada decided to publish a new series of Canadian paper currency. The Bank assembled a blue ribbon committee to suggest themes that might appear on the bills. One committee member was Canada's first person in space, CSA President Marc Garneau.

Marc suggested the theme of Mapping which evolved into mapping from space, and by the time the Atlas was involved it had become a history of mapping in Canada.

A group from the Bank of Canada approached The Atlas, as is noted below by Peter Paul. Involved were the Atlas section heads (Peter Paul and Donna Williams), a few cartographers, and a couple of other people. The Bank delegation was composed of a few people familiar with designing an actual paper banknote. There were only a few (2 or 3) such meetings but I remember them as being very constructive collegial discussions: suggesting a number of objects that could be seen as bookmarks (not always the same as milestones) in the mapping of Canada ... a canoe, Champlain's map of Eastern Canada, proportional dividers for changing the scale of the map representation, the Gatineau Ground Station, RADARSAT, Josef Cihlar's AVHRR composite of Canada processed to reveal the major land cover classes. We provided the (digital) EO objects and passed them to the team at the Bank of Canada and the Canadian Bank Note Company. I am no longer certain where the division of labour occurred between the latter two. I think their team found suitable representations of the other objects on the bill, worried about how the object could be suitably engraved onto a printing plate, laying out the individual objects that would dignify a denomination of Canadian currency, etc.

There were complaints from a few geographers about the "map" in that at the scale on the banknote neither Vancouver Island nor Prince Edward Island should have been separated from the mainland. For that reason it was called a "representation of Canada," not a "map of Canada." Because of the adjusting of islands etc. to make everything "look" correct, cartographer Andy Murray was quoted by journalist Tom Spears as saying "Do not use this for navigation."

As it happened, the $100 bill was not long in circulation ... new technologies made it too easy to counterfeit!

[1] Editor's Note: How the National Atlas and CCRS were involved in the $100 banknote is one of the more interesting stories to have come out of CCRS. The material here is from a personal communication from Bob O'Neil, October 24, 2018.

As noted in the text box above, we were invited by the Bank of Canada to design a Canada Map to be included on the $100 bill to be released in 2006. The key design challenge was to generalize a country of ten million square kilometers into a space of a few square inches. If the larger map was automatically reduced in size, some key identifying features (e.g. Prince Edward Island, Vancouver Island) might disappear, so Atlas cartographers and geographers got involved hands-on. It was a process which involved several back-and-forth drafts over several months, but the end product was quite attractive. The final depiction had something for all of Canada. It showed an early map of Quebec and how maps were once made using canoes for transportation and crude surveying instruments. It also showed how maps were made today using Canada's RADARSAT, a receiving station and the resulting "map" – something for every part of Canada.

Maps, Money and Marketing **Bob Ryerson**
In the end the banknote had other uses. Every two years MDA hosted a major by-invitation-only conference on earth observation for major clients and potential clients from around the world. In 2004 it gave each attendee the banknote encased in plastic. Other corporate representatives in geomatics used the banknote in international marketing. One would show a copy of a local banknote pointing out that what is important in a country usually appears on the back of the local currency. He would then show a Canadian $5 banknote that showed ice hockey. Once the attendees agreed on that point an American $20 banknote showing the White House and then the Canadian $100 was shown and he would ask – "would you rather do business with a company from a country that puts old buildings on the back of its currency, or one that comes from a country that features geospatial information?" He claims to have never lost a sale – and still carries the now discontinued $5 and $100 banknotes in his wallet.

In 2006, as part of the centenary celebrations of the Atlas of Canada, the Royal Canadian Geographical Society recognized the Atlas with its Gold Medal award in 2006. The Society's description of the evolution of the Atlas provides an interesting perspective:[248]

> "The evolution of the atlas mirrors the country's development and Canadian ingenuity and innovation in cartography. The 1906 edition, for instance, focused on transportation and communication networks to entice European investment and immigration to Canada. Knowledge of Canada's remote regions was still sketchy at the time, which accounts for many missing or inaccurately rendered Arctic islands. Rising concern for the environment and interest in socioeconomic matters, such as the national labour force, were reflected in the 1974 edition, which received the RCGS Gold Medal in 1976. In the early 1990s, digital cartography and the collection of data through remote sensing revolutionized the way maps were created. The internet spelled the end of the atlas in book form; in 1994, The Atlas of Canada went online, one of the first online atlases in the world."

The Atlas also partnered with Environment Canada, the Canadian Wildlife Federation and Statistics Canada to create a digital base and subsequent paper map of 'Discover Canada's Watersheds' (published 2006). This spawned subsequent on-line "Find Your Watershed" applications by Environment Canada, and ***Canadian Geographic Magazine***. One of our favourite stories of how the map was used came from the Canadian Wildlife Federation. Apparently the night cleaner in their building mentioned how much he had enjoyed looking at the map, as he had never before realized where his water came from.

The National Atlas left CCRS in 2008, a year after Bob O'Neil retired.

[248] Source: http://www.rcgs.org/awards/gold_medal/winner_gold2006.asp

7. Systems
Florian Guertin[249]

7.1. Introduction
This section details the range of systems developed by and for CCRS to process the stream of data provided by the many satellites that CCRS had access to as well as the advanced airborne SAR system operated by CCRS. The section also provides insights into the role of industry and the attention to the needs of the user that remained hallmarks of CCRS activities throughout the period under study. The linkages back to CACRS meeting recommendations can be seen in most of the activities.

7.2. Ground System Technology Development and Innovation at CCRS
As noted in Section 6.8, following the NASA launch of the Landsat-1 Earth observation satellite in July 1972, CCRS was the first non-American group to receive and distribute the Landsat-1 imagery. At CCRS Dr. Murray Strome planned and led the development of the ground facilities to receive, archive, process and distribute the Landsat-1 data in Canada. The data from the Multi-Spectral Scanner (MSS) and the Return-Beam Vidicon (RBV) instruments on Landsat-1 were received at the Prince Albert Satellite Station in Saskatchewan, described in the previous Section. Before becoming a Landsat satellite ground station, the Prince Albert facility had been known as the Prince Albert Radar Laboratory where, equipped with a large 26-m dish antenna, it had conducted communications experiments starting in 1959 in collaboration with the USA using the moon as a first "communications satellite."

At CCRS under the leadership of Dr. Edryd Shaw a Computing Devices of Canada team built the Landsat-1 ground processing and user products generation systems for Landsat-1. At the Prince Albert Satellite Station (PASS) the Landsat MSS data were recorded on instrumentation tapes using a parallel 28-track wideband Ampex FR-1928 recorder. These tapes were shipped to CCRS on Sheffield Road in Ottawa where the Landsat MSS data were bulk-processed using a DEC PDP-10 computer, and film products were generated on a 70mm film Electron Beam Recorder (EBR) using special-purpose hardware for image correction. The Landsat 4-band MSS digital products were offered in either an uncorrected (raw) data format or a system-corrected format and these products were recorded on 1600-bpi Computer Compatible Tapes (CCT) using Bucode tape drives. The initial CCT format used by CCRS for Landsat MSS images was the CCRS-JSC (Johnson Space Center) format. It consisted of five record types: a JSC header record, a Landsat header record, a geometric transformation record, four radiometric lookup table records and 4 x 2286 data records containing the MSS band-interleaved-by-line image. An MSS image covered a 185-km by 181-km area and consisted of 3240 pixels per scan line and 2286 scan lines.

In the 1970s, following the implementation of the initial facilities, CCRS undertook several new technological developments for satellite data reception, processing and distribution. They were driven by a number of factors: availability of faster and more versatile hardware, improved methodology for satellite image correction and calibration, new requirements coming from future Earth observation missions, the need to replace aging equipment and the need to migrate the end-user product generation to the satellite station for near real-time product delivery. These new developments took advantage of progress in computer technology, in particular microprocessors, data storage devices, database management systems and geographic information systems.

[249] Florian Guertin passed away on July 11, 2018. The community mourned the loss of a man Bob O'Neil called "a reliable and thoughtful colleague who was a fine example of what Canadians should expect from their nameless public servants." Jenny Murphy recalled that his motto for all projects in his Section or Division was "On time, on budget and no surprises." This could also be said to be the approach for all of CCRS – and helps explain the success of the organization. This document is much better because of Florian's many thoughtful and thorough contributions.

Some Comments on the People and Activities of the Early Data Acquisition Group[250]
Keith Langley

Art Collins ran the Data Acquisition group, with Doreen Latour the supervisor of HDDT to EBIR master image quality and cloud cover. Staff varied, but included Gerry Duplessis, Rob Graves, Heather Press, Cary MacDonald, Sandy Farr and others.

Keith Langley ran the Standing Order and Request system which directed HDDT selection and data extraction. Doreen Latour's team evaluated the National Air Photo Library (NAPL) imagery created from the masters extracted from the EBIRs by ComDev technicians and then by ADGA's Byron Willis and others, then by Prologic's Paul Charron, Les Simak, and George Fullerton. CCRS had a related team working on the image processing equipment - Ted Froelich and others, Prologic supported LiDAR IASC-Sharp and HDDT Transcription.

Various individuals did related software support on the "extracted data" tapes containing scenes data - Marlene Newton, from ADGA and then by Prologic - Max Buchheit, Paul McLean, Denis Lafleur

For scene data correction Max Buchheit did mirror velocity profile corrections, and Jenny Murphy did band-wise radiometric corrections.

Max Buchheit later did software for the DICS process including least squares fits, scene physics, S-bend corrections and re-sampling. Carry Macdonald ran a team of image processors which included Heather Press, Sandy Farr, and Patricia Collier. The DICS team processed one complete set of forest imagery for each of the provinces and imagery for Ducks Unlimited along migratory bird routes.

At about this time Prologic ran the SAR/Airborne Products order desk and then the SOC Spot Image order desk with, Don Hodgson, Mary Anne Hoey, and Paul Brown.

Ted Froelic of CCRS developed the Continuous Strip Film Recorder for imaging Airborne sensed data, an innovated technology that re-played the airborne data line by line and a Tritron television with 1- line open and the rest taped over so as the lines flashed 1by1 on the television an airborne camera recorded 1line-by-1line on rolling film leading to a continuous image on film.

Ko Fung was the engineer on the OVAAC8 Array Processor. John Edgecombe supported its software. While two to three CCRS technicians did hardware support, including Ken Hammond and Ted Froelich

Mike Jager was Operations Manager. After he left one of his staff, Mike Prindiville took over the unit with staff of Joanne Plumley, Ian Press, Rob Graves, and a number of operators. Systems software was handled by Forbes Hirsch, then Walt Sullivan and then by Prologic's John Edgecombe.

Prologic had a group of individuals supporting operations and software, Mosaics IA, CSHARP Methius, Radar - John Wolfe, Squis - Dominis Labocetta, and in standardizing the software libraries, Randal Venhola, Denis Lafleur, Pat King - Fire240 Imager & Q-Tips, Ron Johnson-mail client, Paul Charron - technician, Rod Pontefract, Claude Lafontaine, Jacques Lavictoire

Vax systems and cluster support was provided by Simon Greenwood while Lan servers, MicroVax and DECNET were supported by Shane Hutchinson

Max Buchheit went on to the development of DTM via degree-separated Spot data imagery. He later working with Jack Gibson on GEOCOR software and later with Dianne Richardson on Digital Mapping, He is now working for Roger D'Abrieu of Radar data products.

[250] This table has been created from a personal communication from Keith Langley, October 11, 2017. The spelling of names is as recalled by Keith Langley.

Prologic had two image analysis support research assistant contracts in support of Diane Richardson, Jack Gibson, Ko Fung, Bob Gauthier, Paris Vachon, and Jean Thie. We employed a variety of individuals, Pierre Beaulne, Kevin Murnaghan, Andy Macdonald, Christine Burke, David Jacques, Boris Gontar, Lidia Hak, Anne Botman, Ian Neeson, Claude Lafontaine, Judy Guenette, Mike Dickson, Fouquon Zhou, David Jacques, Peter Farris, Kian Fadaie Jacques Lavictoire, Gary Rutledge, Pierre Dore, Peter Farris, Kevin Murnaghan, and Aiqun Guo.

Under Ko Fung and another CCRS staff member, we created demonstration DVDs of before and after the famous Saguenay Flood and in the Pipeline Navigation Project did a review of vegetation change caused by the oil pipeline. Fouquon Zhou did Image analysis and produced data DVDs, with ground-data collection for the Voisey Bay First Nations as a pre-baseline Environmental Assessment before the mining company started digging. Robert Hitchcock did most of Prologic's portion of this joint project - Image analysis and ground work.

In the GISD Division under Bob O'Neil who was Director, Prologic supported Doug Bennet, Terry Fisher and others with Andrea Buffam, Pat King, Cathy Saikaly, Judy Guenette, Ben Kao, and Elspeth Sidaway.

I maintained 16 different Cobol based data retrieval systems since nobody else wanted the job. Later I took over the RESORS software after the death of the software's creator. This required about three months to both trace and document the code. David Rosling re-wrote the code in VAX RDMS, which was a long project that needed to emulate the RESOR's data entry and retrieval. We reported to Jenny Murphy who was Systems Section head at the time.

In the 1980s the trend in computer hardware was towards smaller or networked systems with substantial processing power, large memories, considerable on-line storage and advanced display capability. For computationally intensive applications such as radar data processing they could be grouped in networks consisting of fast computational engines, large file servers and interactive workstations. These developments contributed to the progress achieved in the operational capability of the satellite stations at CCRS. By using generic off-the-shelf computer hardware and software it was possible to avoid designing costly special purpose systems, and it often reduced the on-going operation and maintenance costs. New, modular, computationally intensive capabilities could be added to the satellite stations. The near real-time generation of quick-look Synthetic Aperture Radar (SAR) imagery became feasible. Using modular subsystem architecture, ground station systems could be reconfigured to meet different operational requirements. The same system could be used to process the data from several satellites; each one with its unique sensors, and a cluster of these subsystems could result in a high-throughput facility. Modular systems were less expensive to maintain and to upgrade due to their open architecture and the portable nature of their generic software.

As part of the initial Landsat processing facility in Ottawa, CCRS implemented a microfiche system to assist the centre in cataloguing the Canadian Landsat archive. This included a practical annotation system designed by Elizabeth A. ("Betty") Fleming (Topographic Survey Branch, EMR) where Landsat images were referenced by specifying their nominal scene centre in term of "path number" and "row number". NASA adopted the CCRS scene referencing system and it became the Worldwide Reference System (WRS) for Landsat imagery. Microfiche was an important aid to the users for selecting satellite images and for assessing their cloud cover. In the 1980s video-fiches and online catalogues became available. With the use of low-cost image analysis workstations the Compact Disc (CD) became a popular medium for the distribution of Landsat imagery. With the availability of high-speed telecommunications links, electronic data delivery was added for near real-time applications.

CCRS played a proactive role in the NASA Landsat Ground Station Operators Working Group (LGSOWG), the working group that facilitated the exchange of information between NASA and the international satellite ground station operators' community. In particular CCRS played a leading role in the development of new format standards for recording satellite imagery data on Computer Compatible Tapes (CCTs). When Landsat-3 was launched in 1978 there were nine Landsat receiving stations in six countries around the world, the Landsat MSS data were being distributed in at least three different formats, and there was the anticipation of additional formats for the future Landsat-4 Thematic Mapper

(TM) data to be launched in 1982. This proliferation of CCT formats was due to three factors: the launching of new satellites with their unique data specifications, the development of new more advanced image processing facilities and the user requirements for additional ancillary data. To solve this problem of interchangeable image data formats, the LGSOWG formed the Landsat Technical Working Group (LTWG). CCRS proposed to the LTWG a self-defining format framework for CCTs. This approach was accepted by the working group and it became "The Standard Family of CCT Formats", which was also used by several other Earth observation satellite missions in following years. These standards have guided the development of mission specific formats, and have been adapted to many different types of data. They have also simplified the development of data access software and have contributed to improved data compatibility between users. (NASA, 1979)

7.3. The Concept of Geocoded Products

In the 1970s Geographic Information Systems (GISs) became the enabling technology to integrate geo-based data from multiple sources. This created the requirement for satellite images that had planimetric accuracy comparable to the national topographic digital maps and the need for interoperable catalogues. Several applications required images corrected to sub-pixel accuracy. Agricultural and forestry applications required multi-temporal overlays of repetitive images from the same satellite in order to achieve better discrimination between crop types and conditions, or between ground cover types. For certain applications it was necessary to integrate satellite imagery from complementary satellite missions or with topographic data. Given the end-user systems available at the time, the task of integrating imagery from multiple satellites or combining satellite data with other geo-based data could constitute a major hurdle for the users. Therefore there was a need to develop and offer user products that had a high level of compatibility with existing products and systems with regard to geometric or locational accuracy.

To foster the use of images from multiple complementary spaceborne and airborne missions, and their integration with other databases, it was important for remote sensing data distribution agencies to offer satellite data in a fixed and common cartographic projection such as the Universal Transverse Mercator (UTM) coordinate system. In Canada the UTM projection had the marked advantage of being used for most of the national and provincial databases. Imagery that was transformed to a cartographic projection in which pixel locations were expressed in terms of map coordinates, and therefore independent of the sensor characteristics and of the satellite orbital parameters, was referred to as "geocoded imagery." The objective was to correct to sub-pixel accuracy both for absolute geodetic control and for multi-temporal registration. The end-user products were defined in a sub-scene format derived from the map quadrangle system in order to meet both the user coverage requirements and the constraints imposed by the sensor swath width.

A Technical Look at Geo-Coded Imagery: How They were Created and Why[251]
Florian Guertin

Irrespective of the sensor scan line orientation, the geocoded image lines were aligned with the map projection grid, and the pixels were meshed conveniently with the grid. To avoid any systematic sub-pixel errors in registration or offset between different products, all images used the same XY-coordinate convention relative to the reference grid. For example, the top–left corner of the first pixel of the image should always be on a 1-kilometre grid boundary. The pixel size for the geocoded image should be such that it belongs to a convenient meshing hierarchy such 100 x 100 metres, 50 x 50 metres, 25 x 25 metres, 12.5 x 12.5 metres, and 6.25 x 6.25 metres in order to have an integral number of pixels within each square kilometer. The selection of the geocoded product pixel size should be based on two factors: the sensor resolution and the rotation angle required to align the unprocessed image lines with the projection grid.

[251] Source: Guertin and Shaw, 1981

In order to avoid any significant aliasing caused by this rotation angle resulting from the satellite heading, the pixel size should constitute a slight oversampling relative to the pixel size of the original data. For the geocoded product pixel sizes CCRS used 50 x 50 metres for Landsat MSS data, 25 x 25 metres for Landsat TM data, 12.5 x 12.5 metres for SPOT multi-spectral data and 6.25 x 6.25 metres for SPOT panchromatic data.

7.4. The Digital Image Correction System (DICS)

In the 1976-1979 time frame CCRS developed the Digital Image Correction System (DICS), the first operational facility to produce geocoded imagery from Landsat MSS data. The DICS configuration consisted of a DEC PDP11/70 16-bit minicomputer, running under the RXS-11D real-time multiprogramming operating system. The Landsat MSS images consisted of four spectral bands with approximate scene size of 181 km in the north-south direction by 185 km in the east-west direction. The scanner had an Instantaneous Field Of View (IFOV) of 79 x 79 metres and, due to along the scan line oversampling, the original pixel size was 79 metres (vertical) by 57 metres (horizontal). DICS was a relatively low-throughput system designed to meet the CCRS operational requirements at the time. It accepted as input uncorrected (raw) image data received at the CCRS satellite stations and it produced geocoded imagery products compatible with the National Topographic System (NTS). Imagery was processed on a user-request basis. (Butlin *et al*, 1978)

Technical Details on How the Digital Image Correction System (DICS) Worked
Florian Guertin

The DICS radiometric sensor correction and calibration were based on Landsat radiometric correction and calibration methodology developed at CCRS in the 1972-1978 timeframe. It removed the radiometric striping due to the MSS detector response variations and calibrated the data to a predetermined radiance scale using the MSS 24 detector correction tables derived from the calibration wedge data and from the statistical analysis of the image. The radiometric correction process was divided into three stages. A reference detector was chosen for each spectral band and the corrections required to place the data from this detector on an absolute scale were calculated using the calibration wedge data, the pre-launch calibration data and the maximum and minimum radiance values associated with the response of the spectral band. The relative differences between the other five detectors in each spectral band and the reference detector were calculated, using the means and standard deviations of the decompressed raw data values as calculated from the sums and the sums of the square of the scene data values using the linear portion of the data. Finally the absolute calibration of the reference detector was combined with the relative calibration of the other five detectors within the same spectral band, to provide an absolute calibration of all six detectors in each of the four bands. (Ahern and Murphy, 1978)

The geometric correction method implemented on DICS was based on the research carried out at CCRS on image rectification, registration and resampling in the 1970s. The approach consisted of defining a composite transformation from the corrected image to the uncorrected original Landsat image. This process was composed of three transformations between four spaces: the corrected output image coordinates, the UTM grid, the system-corrected input image and the original (raw) image received from the Landsat satellite. The transformation between the UTM grid and the corrected output image was derived a priori from the pixel size and the geocoded product subscene framing. The system-correction transformation was a nominal transformation based on Earth rotation, sensor delay (inter-spectral band offsets and fractional intra-spectral band offsets), swath length variation, mirror velocity non-linear variation, panoramic error, Earth curvature and pixel aspect ratio. The rectification transformation consisted of two bivariate polynomial correction functions computed by least squares estimation using Ground Control Points (GCP) identified between the NTS maps covering the same area and the Landsat image. The locations of the GCPs were digitized on paper map sheets and were measured in the Landsat image using an image display terminal. (Shlien, 1979)

The geometric accuracy achieved in the DICS products was a function of the accuracy of the MSS sensor correction model for systematic errors, the accuracy of the bivariate polynomial fit geometric correction model, and the measurement accuracy and distribution of the GCPs in the image. For satellite images with no important terrain relief variations, and given a well distributed set of about 20 GCPs digitized from 1:50,000 scale maps, DICS consistently met a geometric accuracy of 50 metres RMS.

DICS offered image manipulation functions to assist the operator in the identification and measurement of GCPs. The portion of the image displayed for GCP identification could be digitally magnified by oversampling the pixels using a Fourier kernel interpolator. Typically an oversampling factor of eight was applied giving an effective pixel size of approximately 9.9 metres by 7.1 metres. Once the geometric correction transformation was known for an image, subsequent multi-temporal images of the same scene area could be corrected by registration with the first image, called the reference image. The registration transformation was obtained by measuring GCPs in both images. These measurements could be made either by the operator using the image display terminal or by digital correlation of subimage chips.

The Landsat image correction and resampling process was performed by a special purpose 32-bit microprocessor-based corrector developed by OVAAC-8, a Toronto startup company, which was sold to PCI Geomatics in 1985. The OVAAC-8 corrector consisted of a 32-bit microprocessor, three solid state memories and a 16-point interpolator for image resampling. This subsystem was capable of doing radiometric sensor calibration, radiometric scenic correction and geometric correction. These corrections were defined by a series of piecewise linear functions expressed in terms of initial values and slopes for up to 64 linear segments. The image resampling was performed by two one-dimensional resampling passes, an X-mode resampling pass along the input scan lines followed by a Y-mode resampling pass along the output image column. This two-pass resampling method had a limitation since it could be significantly non-orthogonal for northern images where the satellite local heading was important. Given the limitations of the microprocessor technology available at the time, this one-dimensional resampling technique was implemented to reduce memory requirement and processing time. The resampling spacing incremental resolution was 1/32 of a pixel and the interpolation had a width of 16 pixels using a 16-point damped $\sin(\pi x)/\pi x$ kernel. The OVAAC-8 corrector could process the Landsat MSS imagery at a rate of 30,000 pixels per second, which was considered a relatively high resampling throughput given the microprocessor technology available in the 1970s.

CCRS started offering on an operational basis to Canadian users precision processed Landsat MSS imagery in a geocoded format in 1979. Each geocoded product covered a four NTS map sheets area (2 x 2 sheets) at 1:50,000 scale, an area corresponding to a 0.5° latitude by 1.0° longitude quadrangle, approximatively an area of 60 by 80 km for southern Canada; the 50-metre by 50-metre pixel size was chosen in order to be smaller than the MSS 79 x79-metre instantaneous field of view (IFOV) of the sensor to avoid significant aliasing due to satellite local heading rotation. Because the grid defined by the pixels was registered on the one-kilometer UTM grid and because sub-scene dimensions were defined by the NTS quadrangles, successive images of the same Landsat sub-scene had the same number of pixels per line and the same number of lines. For the users this facilitated the analysis of multi-temporal imagery. It was possible to perform change detection on multi-temporal imagery by direct comparison of the corresponding pixel areas without having to perform any geometric transformation or correction. The user response to the DICS products was excellent and geocoded imagery became a popular digital product offered by CCRS. Using photogrammetric test points for image rectification control, the Topographic Survey Branch of EMR performed geometric accuracy evaluation tests on the DICS geocoded products; these tests showed that DICS was capable of correcting Landsat MSS images to an accuracy of 30 metres RMS (root mean square). (Fleming and Guertin, 1980)

DICS was in operation from 1979 to 1985 for processing Landsat-1, 2 and 3 MSS data. In 1982 DICS was upgraded to process MSS data from Landsat-4 and the future Landsat-5, which were on a lower orbit compared to the earlier Landsat satellites and consequently had a different image coverage swathing pattern. DICS produced geocoded, map compatible Landsat MSS products for more than 75 percent of the Canadian landmass below 60°, this included extensive multi-temporal coverage for forestland and rangeland management. DICS products were also used for the determination of the geodetic location of isolated islands in the northern regions of Canada. The achieved accuracy for these islands was comparable to the compilation standards used at the time for Arctic mapping. The DICS experience contributed significantly in charting future developments for satellite image data correction at CCRS and in Canadian industry. DICS demonstrated that precision geocoded satellite products could be generated routinely on a production basis. The demand for geocoded products proved that they could promote the use of Earth observation satellite imagery and its integration with other geographic databases.

7.5. MOSAICS, GICS and GEOCOMP

DICS and its OVAAC-8 corrector had been designed specifically to process Landsat MSS imagery. For the higher spatial resolution Earth observation missions planned for the mid-1980s and the 1990s, the next generation of satellite image correction systems had to take advantage of and/or consider:

- The latest advances in computer technology, processing power and work-order based operations;
- The latest methodologies in satellite orbit and attitude modelling; and
- Provision of new forms of correction such as local terrain relief and scene dependent atmospheric effects.

The satellite data requirements resulting from large environmental projects illustrated the advantage of geocoded products and DICS was a forerunner in this area. Although the DICS architecture was adequate for Landsat MSS data correction, it did not lend itself to higher throughput and to future precision processing needs. In 1982 CCRS initiated contract work to meet these new requirements with MacDonald, Dettwiler and Associates (MDA) to develop the Multi-Observational Satellite Image Correction System (MOSAICS), a facility to produce high quality geocoded products from future optical and radar satellite missions. A comprehensive requirements study led to a new design concept for MOSAICS. MDA designed and built MOSAICS as a production system with high throughput requiring minimum operator intervention. MOSAICS was phased into operation at the Prince Albert Satellite Station in 1986. Following its final commissioning in January 1987, MOSAICS has consistently produced a large volume of high quality products, this was demonstrated by extremely positive user feedback and increased data sales. From an industrial perspective MDA has sold the GICS technology derived from MOSAICS to many satellite ground stations around the world for satellite missions such as Landsat, SPOT, ERS-1&2, MOS, NOAA AVHRR, JERS, RADARSAT, Envisat and others. The GICS technology became the de facto world standard, and MDA the leading provider of Earth observation satellite ground system solutions with market share estimated as high as 90%.

MOSAICS: Innovative Architecture to Meet Operational Needs
Florian Guertin

MOSAICS' system architecture was built around a sensor-dependent front-end to process MSS and TM data from the NASA Landsat missions, Multi-spectral Linear Array (MLA) and Panchromatic Linear Array (PLA) data from the French SPOT missions as well as the imagery from future missions. It included a sensor-independent processing channel to transform the raw images into fully-corrected image products and a user-dependent output-end to generate products in either standard geocoded format or in special formats or map projections as determined by the users. This architecture was later extended by MDA for their Geocoded Image Correction System (GICS) configuration in order to process data from other satellite sensors.

MDA designed and built MOSAICS as a production system with high throughput requiring minimum operator intervention. The operator entered information relative to a specific work-order and in the majority of the cases the production proceeded automatically without further operator interventions. MOSAICS could mark GCPs automatically by correlating the input image with image chips contained in a GCP library which had been developed for DICS operation. MOSAICS used a sophisticated spacecraft orbit and attitude model capable of achieving high positional geometric accuracy with few GCPs.

MOSAICS used a three-pass one-dimensional resampling algorithm and a 16-point kernel to keep to a minimum the pixel radiometric error associated with resampling and the aliasing error caused by satellite heading rotation in geocoded products. MOSAICS included digital and film output products to cater to the needs of specific applications. A first-order terrain correction could optionally be applied to compensate for a geometric parallax error induced by terrain relief.(Fisher and Minielly, 1985)

In the following years MDA added new features to the GICS technology. A key technique for reducing the number of GCPs was pass processing. Contrary to single scene processing in which the correction model was determined using GCPs in the area of the scene to be corrected, pass processing used GCPs from anywhere on the same orbital pass of the satellite. The goal of pass processing was to achieve the same sub-pixel accuracy as single scene processing while using fewer GCPs per scene. Since there could be ten or more scenes in a single orbital pass, the average number of GCPs required per scene could be reduced by an order of magnitude, and large areas with no GCPs could be corrected while maintaining a high accuracy. In the late 1980s MDA implemented the pass processing technique on GICS for processing SPOT data. (Sharp and Wiebe, 1989)

With new requirements resulting from global environmental applications, there was a demand for continued continental and large scale monitoring of vegetation using satellite data. As noted in Section 6.6.10 the NOAA Advanced Very High Resolution Radiometer (AVHRR) was the most suitable sensor for this initiative. To meet the Canadian requirements, CCRS funded the development of GEOCOMP, a high throughput AVHRR geocoding and image compositing facility to be implemented by MDA. Geo-compositing differs from classical image mosaicking. A mosaic can be viewed as a “patch-work” of blocks of imagery from individual input scenes while for geo-compositing all available pixel values at each output location are compared and are selected based on a vegetation index criterion. GEOCOMP was built by MDA as a variant of their GICS technology with the following additional features: high geometric precision for co-registration across the full scene swath using pass processing, and accurate radiometric correction with both sensor calibration and atmospheric correction for the complete Canadian coverage.

CCRS and MDA jointly worked to develop and operate facilities to geocode imagery and generate new products from a wide range of Earth observation satellites. These pioneering efforts, particularly in the areas of product definition and system operation and the development of DICS, MOSAICS, GICS and GEOCOMP, have highlighted some of the leading-edge ground segment technologies developed in Canada. (Guindon, Fisher, and Guertin, 1992)

7.6. The SURSAT Program and SAR Digital Processors

In 1976 an interdepartmental Task Force on Surveillance Satellites reported to the Canadian government on the requirements for space-based surveillance and the opportunity for a Canadian Earth observation satellite program. The Canadian SURSAT Program (1977-1979) was approved as a three-year interdepartmental program to evaluate the role of radar satellites as part of a surveillance system over Canada for monitoring the coastal fisheries zones, the continental shelf offshore oil and gas zones, and the Canadian Arctic. At the time the Canadian government was particularly interested in mapping sea ice because of concerns about the possibility of shipping oil from the Arctic.[252]

The SURSAT Program office with Dr. Morley as its director was responsible for the overall project management, for technology and application development and for related procurements. The program included the reception of the NASA/JPL SEASAT SAR data in Canada, the development of the first digital SAR processor by Canadian industry, airborne SAR application studies using the CCRS Convair-580 SAR facility, and application and evaluation studies by the scientific community and industry to verify and demonstrate the use of space-radar data. The SURSAT Program results demonstrated the potential of satellite radar imagery for environmental monitoring and surveillance under all weather

[252] The question of remote sensing of oil spills in the Arctic was the subject of a number of workshops over the years.

conditions. Later the Ice Branch of the Atmospheric Environment Service (AES) of Canada adopted the radar imagery service with real-time processing to meet their operational requirements.

The NASA/JPL plans for the SEASAT SAR mission, an ocean monitoring radar satellite, were of great interest to CCRS. Dr. Morley negotiated Canada's access to SEASAT data, a US decision that took place at the presidential level, and proposed that the Canadian contribution would be the development of a digital SAR processor. An agreement was signed with NASA/JPL that allowed Canada to receive SEASAT SAR data at the new Shoe Cove Satellite Station near St. John's, Newfoundland. The satellite launch took place on 27 June 1978. In the same timeframe MDA presented a $2M unsolicited proposal to build a "low-cost" ground station in a 40-foot trailer for Shoe Cove; this was about one-fifth of the cost of a conventional station facility. This MDA station prototype became the CCRS Shoe Cove Satellite Station where SEASAT, Landsat, and NOAA AVHRR data were received. The proposed concept of a "low-cost" satellite receiving station using the GICS technology for user product generation was very successful and became a major core business for MDA in the following years.

Under the SURSAT Program MDA developed the SEASAT SAR digital processor. On November 29th, 1978 the company produced the first digitally-processed SAR image. The SAR signal data for this first SAR image had been acquired over Trois-Rivières (Québec) and had been received by the Shoe Cove Satellite Station on 17 September 1978. At the international level several teams were competing to be the first to reconstruct a SEASAT SAR image using a digital processor. The MDA team won the race after a two-year effort. So significant was the MDA accomplishment that their first digitally processed SAR image was featured in the 26 February 1979 issue of ***Aviation Week and Space Technology***.

The How, Why and Importance of Digital SAR Processing
Florian Guertin

The general-purpose minicomputers available in the 1970s had barely the necessary processing power required for such a complex algorithm. The MDA SAR processor was programmed in FORTRAN on an Interdata 8/32 minicomputer with only 512 Kbytes of internal memory and two 67-Mbyte disks. The SAR image generation process consisted of four successive computing passes: Pass 1 – range compression; Pass 2 – corner turning, azimuth Fourier transformation and Doppler centroid estimation; Pass 3 – range cell migration correction, azimuth compression, interpolation, detection and look summation; and Pass 4 – intensity mapping, image filtering and image generation. It took 36 hours of computer processing time to generate a SAR image at 25-metre resolution covering a 41 km by 38 km area.

The digital SAR images generated by the MDA digital processor were of far superior quality than those produced by conventional optical processors at the time; these analog processors were based upon laser beam illumination and film techniques. The main advantages of digital SAR processing were the preservation of the full dynamic range of the radar image, sharper focusing and better adapted filtering.

As computer processing power improved, the MDA technological achievement became the standard method for processing satellite radar data. In the following years MDA developed digital SAR processors for several Earth observation radar programs including SIR-B, SIR-C, ERS-1&2, J-ERS-1, RADARSAT-1, Envisat and RADARSAT-2. MDA became the world's largest supplier of SAR processors. In September 2014 at their headquarters in Vancouver, the MDA 1978 achievement was recognized as an IEEE Milestone in Electrical Engineering and Computing; this milestone is the highest form of historical recognition offered by IEEE. (Cumming and Bennet, 1979.)

Following a Canada-wide request for proposals under the SURSAT Program, several application demonstration test sites were selected over both the land and offshore zones of Canada. The NASA/JPL SEASAT mission provided the first opportunity to evaluate the use of spaceborne radar data to meet the

Canadian requirements for surveillance and monitoring. For calibration and verification purposes, the CCRS Convair-580 SAR data, as well as ground data, were acquired at the same time as the satellite passes. The successful completion of the Canadian SURSAT Program in 1979 demonstrated the potential of radar imagery for marine and land-based applications under all-weather conditions. The usefulness of SEASAT data laid the foundations for several follow-on SAR development and demonstration projects under the responsibility of CCRS, and led to the Canadian participation in the European radar satellite missions and, eventually, approval of the Canadian RADARSAT Program.

7.7. Development of the Color Image Recorder (CIR)

At CCRS in the 1970s the Landsat MSS 4-band images were recorded as four separate black and white images on 70mm film using the Electron Beam Recorder (EBR). The EMR National Air Photo Library (NAPL) created colour composite film and print products from these black and white negatives using photographic and contact printing processes. Following its inception in 1976, Imapro Inc., a startup company in Ottawa, initiated the development of a high-resolution digital color film recording system called the Color Image Recorder (CIR). Designed to meet the stringent satellite image requirements, the CIR recorded full colour digital images from the Landsat satellites on 9-inch colour roll film.

The Colour Image Recorder (CIR): Details on How it Worked
Florian Guertin

The CIR recorded up to 4500 x 4500 pixels at 24 bits per pixel (8 bits for each of three bands) with a registration accuracy of four parts per million. "Four parts per million" means 4/1,000,000 of the width of the 9-inch film; this would mean an XY registration accuracy of 0.000036 inch.

As an alternative to an earlier attempt in the 1970s to develop a colour laser beam recorder, the CIR proposed and developed by Imapro Inc. used novel high precision technologies to generate colour film products that were free of cyclical horizontal variations called "banding" in colour density. In order to achieve the required mechanical precision, the CIR used a granite base and air bearings for rotational horizontal and translational vertical positioning of the pixels illuminating the film, and a gravity-driven oil bearing hydraulic piston to position the pixel lines in the vertical direction. The horizontal rotation used an encoded pancake DC motor current-driven servo while the vertical translation was controlled by metering out hydraulic fluid using a laser interferometer that measured the position in 316-nm increments.

The light sources to produce the colour light needed to expose the film consisted of three electron gun lamps that used high speed red, green and blue phosphors, each one focused into a single large spot. The three spots were mixed using three fibre optic bundles that were combined into one. They were further mixed into a homogeneous light object and the output of the colour mixer was focused onto the film using a high power microscope objective. The 9-inch roll film was formed into a semi-cylinder and the light spot from the microscope objective was rotated in the cylinder to form a horizontal line while the gradual dropping of the film from its top position under the force of gravity was used to produce successive lines in the vertical direction.

Interfaced to a minicomputer the CIR was a standalone system where the image data were transferred from a Computer Compatible Tape (CCT) or hard disk to produce the colour film products. The CIR was the world's first high-resolution digital film recorder system. In Ottawa the CIR was used on an operational basis for colour film production until 1987. The colour film production was transferred to the Prince Albert Satellite Station after the commissioning of MOSAICS in 1987. At Prince Albert the MOSAICS facility had been interfaced to a MDA FIRE 240 colour recorder for the generation of a broad range of film products.

7.8. The CCRS Convair-580 SAR Facility[253]

In 1974 CCRS initiated talks with the Environmental Research Institute of Michigan (ERIM) regarding their airborne SAR system. This resulted in CCRS leasing this airborne facility and installing it on the Convair-580 aircraft. Under the agreement ERIM provided technical training for CCRS engineers and technicians, and had access to the Convair-580 SAR facility to meet their own requirements. This facility gave Canada access to SAR technology and complemented the Centre's role in the NASA/JPL SEASAT mission. Eventually CCRS bought the ERIM SAR system, enhanced its radar sensor capability, and conducted numerous airborne SAR campaigns for the Canadian SURSAT Program, and for other national and international initiatives including initiatives in cooperation with the European Space Agency (ESA).

The Convair-580 SAR facility under-flew the NASA/JPL SEASAT satellite over various test sites to confirm and validate the potential of radar imagery for several applications. It became a workhorse for experimental research in SAR applications in Canada and around the world, in particular to support the RADARSAT-1&2 programs, the European ERS-1&2 missions and other spaceborne missions. Eventually it was operated by Environment Canada. Its last flight was to the Canadian Aviation and Space Museum on June 23, 2015.

The CCRS Convair-580 SAR Facility: Technical Details
The C/X SAR was installed in the 1986-1988 time frame and was different from the original ERIM SAR which was removed in 1985. The system operated in two radar bands: C-band (5.66 cm) and X-band (3.24 cm). Cross-polarization SAR data could be recorded simultaneously for both channels. The C-band channel could be operated as a polarimetric radar. Imagery could be acquired for three different imaging geometries: nadir mode (0-74 degrees with a 22-km swath), narrow swath mode (45-73 degrees and an 18-km swath) and wide swath mode (45-85 degrees and a 63-km swath). The data could be collected at two different spatial resolutions: high resolution at 6 x 6 metres and low resolution at 10 x 20 metres (azimuth x range). In addition to being a fully calibrated SAR system for quantitative measurements, the facility had a second antenna mounted on the aircraft fuselage to allow the C-band channel to be operated as an along-track and across-track interferometric SAR for terrain elevation mapping.

7.9. Early Cooperation with ESA for European and Canadian Radar Missions

In the 1970s there were only two civilian airborne imaging radar systems in the world with a C-band SAR sensor: the NASA/JPL's AirSAR facility and the CCRS Convair-580. In 1977 CCRS and ESA started discussions on the possibility of a formal cooperation agreement in space. The Europeans were particularly interested in the Convair-580 SAR facility for testing novel sensor technology for their future ERS radar satellite missions. The first five-year cooperation agreement between Canada and ESA was signed in December 1978, and the agreement has been renewed ever since. Canada became the first "cooperating member" of ESA in January 1979. The agreement required Canada to participate in and to contribute financially to the European general studies concerning future space related projects that are part of ESA basic activities, and Canada could also participate in ESA optional programs, including the Earth observation programs, in exchange for an annual financial contribution to the optional programs selected by Canada. The agreement stated that ESA would ensure a fair industrial return to the Canadian industry to the same extent as that provided to the industry of the European member states.

[253] Editor's Note: this material, written by the late Florian Guertin, is given here as well as elsewhere in sections written by other authors to provide additional context for the work of the Systems Division under Florian's leadership.

Under this agreement CCRS became involved in the European ERS radar missions program. A joint European airborne SAR campaign with the ESA member states was initiated, and during June and July 1981 the Canadian Convair-580 SAR facility acquired airborne radar imagery over selected test sites in ten European countries. This was part of a comprehensive European radar data acquisition program called the European SAR-580 Experiment undertaken by ESA with the participation of the European Commission Joint Research Centre. The purpose was to acquire multi-disciplinary radar data sets that would be evaluated in their own right and that would be simulating the SAR data from the future ERS radar missions. The evaluation of this imagery and the demonstration of its application potential were carried out for more than 50 approved experiments in Europe between 1981 and 1984.

In 1981 ESA initiated the ERS radar preparatory and development program. The ERS Program consisted of two high-resolution radar missions, ERS-1 and ERS-2, designed to observe oceans and coastal zones, sea ice distribution, sea surface wind, and oceanic circulation, as well as land areas. The ERS payloads included an Active Microwave Instrument (AMI) combining the functions of C-band SAR as well as the functions of wave and wind scatterometers, a Radar Altimeter (RA) and an Along-Track Scanning Radiometer (ATSR). The C-band SAR (5.66 cm) had VV polarization, a 20-degree incidence angle, a 100-km swath, and 10-m and 30-m spatial resolutions. The ERS-1 satellite was launched in July 1991, and it was followed by ERS-2 in April 1995; Canada and Canadian industry participated in both missions. In the 1985 Gibson Report titled "***A European Assessment of Canadian Opportunities and Future Options for Association with the European Space Activities***," by Roy Gibson, (Director, General Technology Systems Ltd., Middlesex, UK), the Canadian participation in the ESA ERS program was viewed as "a major asset" primarily because of the role of the Canada Centre for Remote Sensing. CCRS was described as "the leading body in remote sensing. It had a good team, the necessary resources and long experience". "The Gibson Report also noted that MDA, which had been awarded the prime contract for providing the SAR data processing technology at the two ERS satellite stations in Europe, had become a leader in the field. (Dotto, 2002)"

With the launch of ERS-1 and ERS-2 the CCRS Gatineau and Prince Albert Satellite Stations became part of the ESA Foreign Station Network. MDA provided the equipment for ERS-1&2 SAR data reception and processing in Canada. In the following years the Canadian stations have received and distributed ERS SAR products to European and Canadian investigators and operational users. In addition, under the Canada-ESA cooperation agreement, the Gatineau Satellite Station has provided near real-time Low-Bit-Rate (LBR) radar data products to institutional users in Europe on a cost-recovery basis. Participation in the ERS Program provided a unique opportunity to gain technical expertise and operational experience for the Canadian RADARSAT Program. An additional benefit of Canada's cooperation with ESA has been access to the C-band mission-proven travelling-wave tube amplifier technology developed in Europe for the ERS missions, a technology that was used to power the microwave sensor on the RADARSAT-1 spacecraft.

In the 1980s during the preparatory and approval phases of RADARSAT-1 under the leadership of Dr. Edryd Shaw as Director of the CCRS RADARSAT Project Office, the RADARSAT-1 end-to-end capability was specified and designed. It was to be implemented as a state-of-the-art facility to meet the users' stringent near real-time operational requirements for routine monitoring and surveillance of the Arctic and other coastal and landmass regions. Furthermore, it was to offer coverage day and night regardless of weather and cloud conditions. The RADARSAT mission required several key technologies including the development of electronic phase shifters by COM DEV for the RADARSAT payload and the high-throughput near real-time digital SAR processor by MDA. Launched in November 1995, during its 17 years of operation RADARSAT-1 provided Canada and the world with an operational, commercially-focused radar satellite system capable of timely delivery of large amounts of radar data. As noted in Chapter 5, RADARSAT-1 was a Canadian-led mission involving the Canadian federal government, the Canadian provinces, the United States and the private sector. Its commercial operations were conducted by MDA.

7.10. Conclusions

This section detailed the range of systems developed by and for CCRS to process the stream of data provided by the many satellites that CCRS had access to, as well as the unique and complex airborne SAR system operated by CCRS. True to the general approach to the development of technology and conduct of research at CCRS, the focus was on meeting the needs of Canada in a practical manner with simple, cost-effective and workable solutions. The linkages back to CACRS meeting recommendations can be seen in most of the activities. The approach to engaging industry to build and commercialize the results was one that was initially seen as unique, but which has since come to be seen as a “best practice” duplicated literally around the world.

8. Kudos, the "Geography" and People of CCRS

8.1. Introduction

Bob Ryerson

This chapter is less formal than those preceding. It addresses the "kudos, geography and people theme" of the history as laid out in the opening chapter. Section 8.2 details a very small sample of the many awards and kudos received over the years by the organization and its people. It closes with a Subsection that details what was said about CCRS when it was nominated for the most prestigious award an organization in the field can receive. Section 8.3 describes the "geography" of CCRS as recalled by the author – the many buildings and homes of various CCRS sub-groups. Some of these buildings were functional by design and others had to be significantly modified to accommodate a growing and evolving organization – and some were never regarded as functional. Many wonderful anecdotes revolve around these buildings and their eccentricities – not to mention the eccentricities of those of us who, in general, took great delight in inhabiting them. Some of the personalities are also brought out in the People of CCRS in Section 8.4.

8.2. Awards and Kudos over the Years

8.2.1. Introduction

When this project got underway it was assumed that we would simply list the awards that CCRS and its staff had won – I had won a few, and I knew of a number of accolades that had been received by my colleagues – publicizing them was part of what we did in marketing. Of course we also knew of the many honours received by our founding Leader, Larry Morley – perhaps the most prestigious after his passing being one of but sixty inducted into Canada's Science and Engineering Hall of Fame.

However, when we started accumulating information, it was no longer a simple task. The point is best made by discussing the awards of but one friend and former colleague of the author who provided his CV to give additional background for this history project. A life-long scientist, he alone won 32 awards for everything from significant awards given by scientific societies, merit awards from various levels of the Government, awards from industry, best papers at symposia…and the list could (and does) go on. And he is not unique. The point is that almost everyone at CCRS at one time or other was feted by his or her peers: many have justly earned the descriptor "world class." And those who won awards for their work were not just scientists, engineers and managers. A number of support staff received awards that ranged from Sector or departmental awards on up to awards won in competition with the entire public service.

What follows is a very small sampling of the awards CCRS and its staff have received. To the many scientists, engineers and managers and support staff who are not mentioned here, I apologize – there is simply not enough room to mention everyone – and just about everyone I worked with over my 27 years at CCRS was a "winner," whether formally recognized or not.

Simply stated, CCRS and its staff have won important awards both nationally and internationally. But some of the kudos that mean the most are informal and have come from those with whom we interacted over the years. For example, the following unsolicited comment came in 2017 about one of the first scientists at CCRS – and similar comments exist about many of us who were fortunate enough to work at CCRS.

"On a more personal level, Tom Alföldi was instrumental in lighting my fire on the importance of Landsat in my own field of interest which was and is geology. I am currently president of a company about to open a gold mine." John Wightman, Personal Communication, April 9, 2017. Tom may not get direct credit for opening a gold mine, but there is certainly satisfaction in being identified as one of the catalysts for someone who became a leading figure in the field!

The list of awards and kudos given in the next Subsection is meant to show the range of awards and respect shown to both CCRS and its staff. It is based on published material, the recollections of a number of individuals, and access to the CVs of several CCRS employees.

8.2.2. Awards and Kudos

The CRSS Gold Medal was re-named the Larry Morley Gold Medal. That in itself is obviously a tribute to Larry Morley. There have been 24 winners. Of these sixteen were either employed by CCRS at the time of the Award, or had been long time employees of CCRS:

1. 2019 – Dr. Monique Bernier, INRS (started career at CCRS
2. 2018 – Dr. C.E. "Chuck" Livingstone, DRDC (formerly CCRS)
3. 2017 – Dr. Brian Brisco, Canada Centre for Remote Sensing
4. 2013 – Dr. Paris W. Vachon, DRDC (Formerly CCRS)
5. 2012 – Dr. Robert Ryerson, Kim Geomatics Corporation (formerly CCRS)
6. 2011 – Dr. Vern Singhroy, Canada Centre for Remote Sensing
7. 2010 – Dr. Karl Staenz, University of Lethbridge (formerly CCRS)
8. 2008 – Dr. A. Laurence Gray, Canada Centre for Remote Sensing
9. 2006 – Dr. Philippe M. Teillet, Canada Centre for Remote Sensing
10. 2004 – Dr. David Goodenough, Pacific Forestry Centre, Canadian Forest Service (formerly CCRS)
11. 2002 – Dr. Josef Cihlar, Canada Centre for Remote Sensing
12. 1999 – Dr. R. Keith Raney, Johns Hopkins University, Applied Physics Laboratory (formerly CCRS)
13. 1997 – Dr. Edryd Shaw, Canada Centre for Remote Sensing
14. 1991 – Dr. Frank J. Ahern, Canada Centre for Remote Sensing
15. 1987 – Mr. E.A. Godby, Canada Centre for Remote Sensing
16. 1986 – Dr. L.W. Morley, Institute for Space and Terrestrial Science (formerly CCRS)

Another measure of the success of CCRS is the number of scientists who reached the highest level of the Research Scientist category – RES-5. The text box below the following list describes the criteria for a scientist to reach the RES-5 level.

Simply stated, those who reach this level must be world-class scientists who have been producing at the world class level for some time. They must be recognized by their peers in Canada and internationally. Reaching the RES-4 level is also a significant achievement – a number of CCRS scientists reached that level as well.

Those who were scientists at CCRS during the period we are studying and who reached the RES-5 level include:[254]

- Dr. R.K. "Keith" Raney
- Dr. David Goodenough
- Dr. Ron Brown
- Dr. Josef Cihlar
- Dr. Laurence Gray
- Dr. Philippe Teillet
- Dr. Vern Singhroy
- Dr. Thierry Toutin
- Dr. Alexander Trishchenko

[254] Editor's Note: Others have reached this level or equivalent recognition in academe after leaving CCRS, including Dr. Heather McNairn.

As one may surmise from the requirements to reach the RES-5 level in the following table, all of these scientists have also received national and international awards or recognition for their contributions.

Classification and Promotion Criteria: Research Scientist Level 5
• Exceptional research scientist with outstanding cumulative achievements. • Continued contributions in quantity and quality to evidence outstanding competency and productivity. • Authorship or substantial contributions as coauthor of extensive publications of excellent quality and significance, demonstrating outstanding R&D ability & leadership in a major field of specialization. • Authorship or co-authorship of authoritative reviews in fields of knowledge that are broad in scope, very complex or highly advanced. • Outstanding achievement (e.g. Outstanding new patents or outstanding genetic varieties). • Outstanding record of successful transfer of usable applied science and technology with major impact to users and clients author or co-author of an extensive number of reports having exceptional impact on technology transfer. • Outstanding record of significant contributions as scientific authority in contracted-out R&D, requiring exceptional and original definition, execution & evaluation of activities. • Outstanding record of significant joint venture R&D, requiring exceptional and original definition, execution & evaluation of activities. • Outstanding record of significant contributions; initiator or leader of significant projects requiring exceptional degree of planning, coordination and evaluation, and extensive resource inputs, usually international in nature and perhaps multi-disciplinary. • Outstanding record of significant contracted-in R&D, requiring exceptional & original definition, execution & evaluation of activities. • Demonstrates outstanding creativity in the conception of major ideas, approaches and innovations where no precedents exist and in the generation of major ideas and proposals for R&D. • National and international recognition as an authority. • Extensively cited as an international authority.
Source: Treasury Board of Canada (1990)

Other broad recognitions come from scientific societies that recognize significant achievements by giving members the designation of "Fellow." The following have been recognized for the prestigious award of IEEE Fellow: Keith Raney (SAR processing), David Goodenough (Forestry), Paris Vachon (maritime surveillance), and Ridha Touzi (Polarimetry). Bob Ryerson received recognition as a Fellow of the American Society for Photogrammetry and Remote Sensing (ASPRS) and the Alan Gordon Award from the ASPRS for contributions to remote sensing.

Larry Morley was an Officer of the Order of Canada, won the 1999 McCurdy award in 1974 and, as noted above, was inducted into the Science and Engineering Hall of Fame (posthumously).

Former Section Head, Division Director and Director General Ed Shaw won the Gold Medal from the Royal Canadian Geographical Society in 2004. In 2002 he won the Alouette Award for contributions to RADARSAT and in 2000 he won the prestigious Chapman Award. Josef Cihlar won the Alouette Award in 2000.

Ron Brown, Frank Ahern, Keith Thomson, Karl Staenz and Josef Cihlar won the ASPRS Award for the English Speaking World's Most Outstanding Paper in Remote Sensing in 1983 – ***Alberta Rangeland Assessment Using Remotely Sensed Data.***

Dr. Toutin received the prestigious Prix d'Excellence in 1999 for his collaboration with PCI – one of the longest collaborations between a Government of Canada scientist and industry. Licensing fees paid to the government over the years were estimated by Dr. Toutin to be "hundreds of thousands of dollars."[255]

The GlobeSAR program won a Government of Canada Group Merit Award in 1995. The award was unique in that it was given to some forty individuals from a number of government departments, industry, and NGOs. The award citation listing the recipients was one of many featured in the Larry Morley Boardroom at CCRS.

Several CCRS employees won Government-wide awards. Josef Cihlar won the 1998 Head of the Public Service Award for Excellence in Service Delivery for the National Forest Fire Monitoring System. In 1987 Jean Game and Bob Ryerson won a Government of Canada Individual Merit Award for "outstanding contributions to the effectiveness of the public service" for marketing remote sensing at home and abroad.

Another activity that led to recognition and a kudo of sorts to the National Atlas and CCRS involved staff of the National Atlas – Peter Paul, the late Donna Williams and others. CSA President Marc Garneau suggested mapping as the theme for the $100 banknote. It was coming up to the 100th birthday of the National Atlas. The result was a banknote that showed how mapping was done historically (with canoes and plane tables) and how it is done today with satellites and satellite receiving stations that receive the satellite imagery from which maps are made. The banknote and further details on its creation are shown in Section 6.10.2.

8.2.3. William T. Pecora Award

This award deserves a separate Subsection inasmuch as it provides an independent documentation of the wide range of success of CCRS and its people as nominated by an expert from outside Canada for an international organization award.

On November 15, 2011 CCRS was awarded the William T. Pecora Award, the highest honour in the field of remote sensing for an organization. CCRS was the first organization outside of the US to be so honoured. The following table provides the first two pages of the nomination that was made by June M Thormodsgard, a senior remote sensing specialist in the USGS with whom CCRS worked over many decades.

2011 William T. Pecora Award Nomination for CCRS[256] **June M Thormodsgard, USGS, Reston, Virginia**
I am nominating the Canada Centre for Remote Sensing (CCRS) for the 2011 Pecora Award. CCRS has contributed in a major way to the understanding of the Earth over a period of forty years through the development of important technologies, innovative applications and policies, as well as major contributions to the international community. It has worked successfully with the USGS and NASA as well as other agencies and industry in the USA and elsewhere. Cooperation has been its hallmark. Dr. Lawrence Morley, the founding Director General of CCRS recently stated that "CCRS owes its very existence to the continued cooperation and inspiration provided by the originators of the U.S. Earth Observation Program going

[255] Personal communication by e-mail June 6, 2019.
[256] This is the actual text that was submitted to the Committee that evaluated nominees for this prestigious award. It was sent to the Committee and copied to Bob Ryerson on June 1, 2011.

back to 1968 when the late Bill Fischer and Bill Pecora proposed Interior's Earth Resources Observation System (EROS) program." Dr. Morley, then the Remote Sensing Planning Office Director, was invited by Dr. Pecora to participate in what Bill Fischer called their "Dog and Pony Shows" to familiarize various U.S. Communities with the program. They offered Canadian participation in that program which was later replaced by NASA's Earth Resources Technology Satellite to which Canada was the first country to be accepted to receive the data. The rest, as they say, is history.

CCRS expanded its activities to include an extensive airborne program, including the development of various innovative sensors for both aircraft and satellite use. Over the years CCRS contributed substantially to the success of global remote sensing technology and its application. CCRS has partnered with many different groups, domestically and internationally. CCRS and Canada have benefitted greatly from these collaborations – as have CCRS' partners. CCRS transferred its technology to industry and CCRS scientists and engineers travelled extensively to meetings in many countries promoting the concept of a global system of remote sensing, ground station technology and interpretation of data. CCRS scientists have worked and continue to work on every continent helping to impart knowledge and understanding, leaving behind a cadre of competent, dedicated scientists and engineers who are now contributing to the better understanding of Earth and the management of our resources and environment.
CCRS has long been active in a number of international groups and was one of the drivers behind the creation of CEOS in 1984, was active in and supported various UN Committees involved in space, COSPAR, and professional and technical organizations including IGARRS, ASPRS, a number of ISPRS Commissions, and the Canadian Remote Sensing Society (CRSS). Employees served on the Boards of or have led all of these organizations. The CRSS was started under the auspices of CCRS.

The technical, scientific and policy contributions of CCRS are without parallel for such a small organization. Since CCRS has never had a large number of staff, it has depended on partnerships and close cooperation with users, other governments, industry and academe. If imitation is considered the sincerest form of flattery, CCRS has been flattered in that its approach to organizing a national remote sensing program has been copied in a number of countries whose remote sensing scientists came to work with CCRS. Over the years CCRS had many scientists from around the world working at its facilities including long term visitors from Thailand, Peru, France, Malaysia, Poland, Nigeria, New Zealand, Brazil, Japan, India, and Kenya to name but a few. The CCRS aircraft was used for missions that included training, research, and demonstration projects in China, Vietnam, Thailand, Malaysia, Jordan, Morocco, Tunisia, Uganda, Kenya, Tanzania, Guyana, Brazil, Chile, Bolivia, Colombia, and Argentina. Other work was carried out across Europe with ESA – CCRS provided the test bed for ESA's series of radar satellites.

I believe that this sampling below from the CCRS body of work, more thoroughly documented in the supplementary materials, clearly demonstrates the breadth and depth of the contributions of CCRS across a wide range of activities that fall within the direct purview of the Pecora Award for an organization. The fact that CCRS has been important not only in Canada, but also a willing and able partner to US agencies and others, contributes further to making it an ideal candidate for this award, as does it being tied in its early history so directly to the Award's namesake, Dr. Pecora.

The following lists some, but by no means all, of the major accomplishments of CCRS. CCRS:

- Led Canada to be the first country to join in the USA's earth observation program;
- Developed the Landsat data format used world-wide;
- Brought satellite imagery into the National Atlas;
- Assisted in the development of Landsat & SPOT processing systems that were adopted worldwide;
- Actively participated in the Landsat Ground Station Operations Working Group (LGSOWG);
- Developed methods to calibrate color IR film;
- Received (by virtue of its more northern receiving station) the first ERTS (later Landsat 1) image and presented it at the ISPRS in 1972 in Ottawa;
- Purchased the first commercially sold civilian image analysis system (in 1974 – the Image 100);
- Did the first mid-season operational RS crop area estimation (potatoes in 1980 for Statistics Canada);
- Worked with the USDA to develop crop area estimation methods in the US based on CCRS work;
- Partnered with the Swedish Space Corporation (SSC) and local aboriginal groups to enable the construction of a DLR TerraSAR and SSC receiving station at Inuvik in Canada's Arctic
- Developed the concept for generating a national defoliation composite product that integrates Landsat, MERIS,

EOSD land cover, and aerial survey vectors based on a priority sequence for different data;

- Built a Laser fluorosensor in the 1970s based on work done of the US Coast Guard (USCG). The system involved NASA, USCG, France, Netherlands, UK, Sweden and Denmark. The operational system was invited to participate in surveillance of the Deep Water Horizon blowout in 2010;
- Actively participated in CEOS working groups on Information Systems, Calibration and Validation, and Education, Training and Capacity Building;
- Actively participated in the Open Geospatial Consortium (OGC) (and staff received major OGC Life-time Achievement award for doing so);
- Participated in Global NOAA AVHRR Project led by the USGS EROS Data Center by providing AVHRR data over Canadian territory and by working with US scientists on the calibration and processing of the Global Data Set;
- Transferred SAR technology and applications to over 30 countries through the GlobeSAR program;
- Built on work by the US Office of Naval Research to fly and demonstrate the first LiDAR bathymeter to produce the first IHO standard chart using this technology. Optech, the commercial partner, subsequently advanced LiDAR technology for terrain mapping and bathymetry;
- With Parks Canada, developed and implemented a satellite- based observing system for tracking key indicators of ecological integrity for Canada’s Parks;
- Supported the Group on Earth Observation concept;
- Developed standard products for use with Landsat TM for forest, crops, and geological mapping;
- Began the work that led to the development of RADARSAT including SAR processing and preparatory studies on ice and geological applications;
- Developed methods to measure rangeland productivity (winner of major ASPRS award in 1983 for best paper on RS in the English language);
- Developed and operated at no cost to users RESORS, a searchable data base of all remote sensing literature in the English and French languages. When it finally ceased operation it contained over 100,000 citations;
- Developed methods to operationally estimate wheat production during the growing season (subsequently applied internationally for crop marketing purposes);
- North American Land Use Change Map produced in collaboration with the US and Mexico;
- Influenced sensor design through cal/val activities related to RADARSAT-1/2, ALOS-1/2, and the upcoming Sentinel 2 and 3 series, RADARSAT Constellation Mission, and Polar Communications and Weather Satellites;
- Developed a series of National Master Standing Offers (NMSOs) to allow EO data purchased by any one government department to be available to other government researchers at no additional cost and after a period of three to five years is made available to the Canadian public;
- Developed methods using radar data to identify individual ships and their characteristics;
- Perfected and then commercialized the use of interferometric radar for ground subsidence;
- Developed the Shoe Cove Station receiving station where everything was fit into one trailer to make Landsat data reception more affordable;
- Developed the quick-look recorder that led to CCRS being able to apply Landsat data to real-time ice reconnaissance;
- Carried out airborne missions following the First Gulf war to evaluate environmental impacts;
- Developed and implemented the first national forest fire observing system based on daily AVHRR data;
- Supported NASA and other US and Canadian organizations in planning and executing the Boreal Ecosystem Atmosphere Study in western Canada;
- Contributed to the UN resolution that identified EO data as a key part of a national infrastructure (1999).

8.2.4. GeoAccess Division and the National Atlas

In 2012 the work of the GeoAccess Division was recognized by being inducted into the URISA Hall of Fame. The announcement identified a number of awards and accomplishments (see below) – most of which came when CCRS was the parent. In the words of Bob O’Neil, Director of the GeoAccess Division, “CCRS has received official recognition by several prestigious organizations in the past year or so. Of these awards, this is the most significant to me. In no other, is the contribution of GeoAccess

Division so clear….It was the right organization with the right vision, skills and people in the right place at the right time."[257]

The same comment could be made about many other parts of CCRS over a period of many years

Selected Awards & Recognition

- 1976 - Atlas of Canada received the Gold Medal of The Royal Canadian Geographical Society.
- 2001 - Government Technology (GTEC) Distinction for Enabling Electronic Service Delivery with CEONet
- 2004 - The Association of Professional Executives of the Public Service of Canada (APEX) award for work with GeoBase and leadership in Service Innovation
- 2004 - Atlas cartographers and geographers developed a unique but familiar representation of Canada for the new $100 banknote
- 2004 - ESRI Award of Excellence to Elections Canada, Statistics Canada, and Natural Resources Canada for advancing the development of an addressed national road network
- 2006 - Royal Canadian Geographical Society (RCGS) awarded the Atlas of Canada a Gold Medal at its 100-year anniversary
- 2006 - Canada Post Atlas of Canada 100th year anniversary commemorative stamp to recognize the Atlas's contribution to Canada
- 2008 - North American Treaty Organization (NATO) and the International Security Assistance Force (ISAF) Awards for International Emergency Response for the emergency management team at the Canada Centre for Remote Sensing (CCRS).
- 2010 - ESRI Canada Award of Excellence to the Centre for Topographic Information of Natural Resources Canada (NRCan) for accelerating map production and boosting national mapping productivity with the Map Generator Application.
- 2011 - NASA's William T. Pecora Award presented to CCRS for advancing the understanding of the Earth over a period of 40 years through the development of important technologies and innovative applications.
- 2011 - GeoSpatial World Forum Premier Mapping Agency Award which recognized the exemplary contributions made by NRCan to the growth of geospatial technology and industry around the world.

8.3. The Geography of CCRS

Bob Ryerson

8.3.1. Introduction

Over the period we are examining, CCRS had a total of at least fourteen different facilities or locations, as well as temporary offices of its technology transfer staff in several more locations across the country. At any one time four or five of the fourteen locations were in operation. One should keep in mind that these many locations were managed before the ease of communication that we have today. Each location seemed to have its own personality and eccentricities. This section offers some glimpses into each from the perspective of someone who at one time or other had an office in five of the facilities and was a regular visitor to most of the rest. That CCRS accomplished so much while spread out over so many locations is yet another indication of the quality of management and leadership.

8.3.2. Temporary Building #8

The so-called "Temporary Buildings," each identified by a number, were built as temporary structures in the early 1940s to house the additional staff required by the government during the war years. The last

[257] Personal Communication from Bob O'Neil, September 30, 2012.

was torn down in 2012, belying the descriptor “Temporary.” “#8” was near the corner of Preston Street and Carling facing Carling Avenue and housed the first offices of CCRS. Some CCRS staff members were still located in it as late as 1973, when the Applications Division staff were hired and located at 2464 Sheffield Road. The building was cold and drafty in winter and hot and uncomfortable in the heat of the summer. Eventually the site of “#8” became a parking lot.

8.3.3. 2464 Sheffield

The Sheffield Road building was located in an east-end industrial park in Ottawa. It became the primary home for CCRS around 1972. By 1973 the facility housed the offices of the DG, Program Planning, the Systems Division (those who operated the computer and related systems), the Applications Division, Library, and the necessary administration activities for a growing agency including Administration, Finance, and Personnel. There was a small cafeteria where many interesting discussions took place – some of them about remote sensing!

The back of the building housed the National Air Photo Library Reproduction Centre, leaving a noticeable chemical smell that grew in intensity as one moved to the back of the building. There were few window offices – but in those days almost all offices had doors. When the new recruits for the Applications Division arrived the limited space in the building became even more limited. The three scientists in Methodology (Drs. Goodenough, Crain and Peet) shared one small office while Applications Development (AD) Section Head Jean Thie and Bob Ryerson shared another. AD Scientist Tom Alföldi had his office in the lab with several pieces of interpretation equipment. Whenever anyone wanted to use that equipment, the lights had to be turned off and Tom had to use a small light on his desk. The Applications Division outgrew the space and moved to Belfast Road by 1974.

Rumour had it that the Sheffield Road building once held a brassiere manufacturer, accounting for the rather elaborate and large boardroom with an adjacent change room and call button. As I recall more than forty years later the wallpaper featuring Greek urns and flowers was not quite what one might expect of a scientific agency in government!

The Boardroom was the scene of many major and minor events – from job interviews to the weekly Management Advisory Committee meetings and CACRS Working Group Meetings, to the signing of the agreement to receive SPOT data and, of course, the annual Christmas party.

8.3.4. The Spartan Hangar

The first hangar that housed the Airborne Section including flight planning and the aircraft was referred to as the Spartan Hangar then located at the far eastern end of the Ottawa airport. The offices were, as I recall some 45 years later, rudimentary at best. Some of the first sensor development scientists were housed in the offices in the Hangar.

8.3.5. Prince Albert Satellite Station (PASS)

As noted in Section 2.1.2 the Prince Albert Satellite Station (known from the beginning as PASS) was offered by John Chapman as a read-out station for the first earth observation satellite. The large antennas dominated the facility whose offices and equipment were housed in an old building that was well maintained and managed for the first years by Roy Irwin. Over the years many managers, engineers and technician from around the world came to work at PASS to learn how to operate a receiving station. Further details (and a photograph) are available in Section 6.92.

8.3.6. Shoe Cove

The Shoe Cove Satellite Station was established by CCRS on the east coast of Newfoundland in 1977, primarily to permit the reception and processing of data from the U.S. SEASAT L-band synthetic aperture radar satellite. The station was built on the site of a former NASA Mercury, Gemini and Apollo mission tracking station. The short-lived but important Shoe Cove Station is described in more detail in Section 6.9.3.

8.3.7. 717 Belfast Rd.

As the Applications Division began to grow and as new equipment was soon to arrive (the Image 100 – see Section 6.8.2.2), the Applications Division and Library moved into a building not far from the Sheffield Road office in fiscal year 73/74. The front of the building contained offices while the back contained a moving company. CCRS had half of the offices on the first floor while the other half contained the offices for the moving company. Our portion contained a reception area, a visitors' area, the Library, boardroom and a lunch room. The entire second floor of the building contained offices for the Applications Division's two sections – Applications Development and Methodology and labs for equipment. The Deputy Director General also moved into the building. Every scientist had a private office with a door and windows that opened – a situation that came to be much more appreciated after moves into other buildings some years later!

There are many stories about the unique clientele that came to peruse the quick-look image collection. Jean Game of the User Assistance Unit helped all sorts of users find the right imagery. On one occasion two gentlemen arrived in a pink Cadillac convertible after having seen a satellite image of forest fires in ***Canadian Geographic***. They knew that "special" mushrooms grew a year or two after forest fires in certain types of forests. They bought imagery of forest fires that they then compared to forest inventory maps to locate potential sources of these mushrooms. There were prospectors who looked like they had just stepped out of the bush (which many of them had). One of these gentleman used Landsat data to better plan his prospecting for what he thought was a potential gold deposit. This led to the Hemlo gold field and many tens of millions of dollars for the prospector. One of the features of the activity was that users could expect (and got) absolute confidentiality. No-one other than Jean Game knew who was buying what imagery – or for what purpose.

Other requests were not as easily met. At least once a year someone engaged in law enforcement wanted to know if we could use our heat sensing to find buried victims. (We couldn't.)

The Applications Division's Image 100 and the various equipment housed at Belfast Road also made it a popular place for tours. It seemed that every new Minister came for a look at the Image 100 and the apparent magic it could perform. (Remember that it was the first image analysis system in the world bought by a civilian agency.) Many college and university students got their first taste of the excitement of remote sensing through tours of CCRS. On one such tour there was excitement of another sort. One group of college students thought that it would not be advisable to smoke marijuana in front of the CCRS office. So they crossed the road. They were quite surprised when a big bus identified as belonging to the RCMP stopped right in front of them. When a number of uniformed RCMP officers got off the bus the students scattered. If they had asked we would have told them that there was an unmarked RCMP office across the road.

8.3.8. 3484 Limebank Rd.

The Limebank Road facility was typical of the type of building one would find in an industrial park. It was one floor with offices for the Director, section heads in charge of satellite operations, sensor development and scientists. It also contained elaborate equipment used to calibrate and test sensors as well as a machine shop. While unremarkable for its architecture, it did feature lively conversations in the lunch room, memorable Christmas parties, and pot-luck lunches and celebrations of birthdays, work anniversaries, birth of children, and other events deemed worthy of celebrations.

8.3.9. Courtwood Crescent
From 1982 to 1987, CCRS rented a building on Woodward Drive to accommodate the Methodology Section of the Applications Division. The building was perhaps best known for its general lack of windows. Staff were quite happy when the section was moved to 1547 Merivale Road.

8.3.10. Gatineau
The Gatineau Receiving Station was purpose built to receive Landsat and SPOT data for eastern Canada and eventually was upgraded to serve as the main reception centre for RADARSAT. Built on a prominent hill north of the city of Gatineau across the river from Ottawa, it featured a beautiful vista of colourful leaves every autumn and a challenging access road in the depths of winter. Snowmobiles were kept at the base of the hill for the really bad days! Rumour has it that the family of bears that was displaced when the station was built often came for a visit.

8.3.11. 1547 Merivale
As the facilities on Belfast Road and Courtwood Crescent became more crowded, and as a new Division, the Major Projects Office (MPO) was formed under Bob O'Neil (including the Methodology Section), new facilities were sought. For a few years Merivale Road became the home of the MPO, Applications Division, Library, and office of the Director General. The fact that they were located in a prominent MP's riding in the City of Nepean was a bonus. CCRS occupied the top two floors of the office building. Located in a shopping mall, nearby were a number of restaurants, a city library, and a major hardware store. The building was cleverly designed so that there were eight corner offices on each floor. Each of these was occupied by a senior scientist, Section Head, Director or Director General. One of my lasting memories about the place was the number of cars that were broken into in the ground floor of the lower level of the parking lot.

8.3.12. 588 Booth
Part of CCRS, notably Bill Bruce's Section, moved into the un-air-conditioned 588 Booth Street in the mid-late 1980s. Before 580 Booth Street (The Tower) was built, 588 Booth held the Minister's office. Bill Bruce and his team used the former Minister's office (wood paneling and all!) as a lab and storage room. From there, the Training and Technology Transfer Section moved to the basement of 615 Booth for about 2-3 years, before moving back to 588 Booth. They had three large rooms with bright orange carpeting and did not require air conditioning, but there were no windows or wood paneling. It was around the time of the move to 588 Booth Street that the CCRS library was consolidated with the Geomatics Canada Library.

When it was decreed that much more of CCRS was to move into 588 Booth, Director General Dr. Leo Sayn-Wittgenstein looked over the building – and saw the potential for refurbishing the wood paneling in what were once the Department's executive offices. He also made two decisions. First, we would not move until the building was air-conditioned. (Leo gained a lot of credit with staff for that decision!) Second, he asked Bob Ryerson, who reported to him, to come up with a plan and rationale to make the former Minister's office the office of the Director General. At that time one of the major activities of CCRS was to help industry sell Canadian technology internationally. To that end Ryerson had visited the offices of many of the leaders of remote sensing in client nations such as India, Thailand, the Philippines, Malaysia, China and Indonesia. In every case these leaders had large, well-appointed offices featuring wood paneling, leather furniture, and board room tables. The logic Ryerson came up with was that a large office would serve as a Boardroom **and** would put CCRS in a good light when visitors came from client nations. It wouldn't do to have the DG of CCRS welcome someone from a developing country in a smaller office than that occupied by the visitor – especially if the visitor was buying a $20 million receiving station from Canada! As

shown in the photograph taken in 2002, the paneling was re-furbished as were the built-in book cases and the office had a new oak board room table for six, a 3-seat chesterfield, two wing back chairs and the five foot tall globe that once sat in the corner of Larry Morley's office.

After 2004 the office was eventually taken over by the Assistant Deputy Minister and the DG occupied an office that was still much larger than was usually allowed for an EX-3 – but still a comedown from what was once enjoyed.

The building had solid walls along a corridor and offices (with doors!) on either side. Tearing down the walls to make open concept offices was not feasible, so the offices were left intact. Virtually every scientist had his or her own office and could work and think in the quiet such an arrangement allowed. There was a boardroom on each floor. The main board room was named after Larry Morley and featured many of the significant awards that CCRS had won over the years, as well as photographs of all of the former Directors General. The most interesting of these was likely that of Ed Shaw. As I recall, his photograph was made up of a number of pixels from imagery of the appropriate colours that had been created by the brilliant graphics design expert, Marguerite Trindade.

8.3.13. 615 Booth

When the National Atlas was brought into the CCRS fold, the first open concept offices experienced in CCRS were developed. They were roomy, well organized and seemed to work well in the collegial atmosphere that the team developed. Dr. Bob O'Neil, the Director and his Section Heads had private offices and there was a boardroom and several meeting rooms, one of which served as an unofficial lunch room. Over time, as with many open concept offices in government, as the number of staff grew, the office sizes shrunk.

8.3.14. Hunt Club Hangar

With the arrival of the much larger Convair 580 and the growth of Airborne Operations a larger hangar was required and CCRS took over what is now the Sander Geophysics Hangar at 260 Hunt Club Road. The modern facility with much better office space and a large area for flight planning was still too small to house the entire CCRS fleet. A mental image still exists of the hangar doors partly open with the tail of the Convair outside while staff worked on the aircraft inside. For many years the planning and office side was managed by George Fitzgerald with Bud McKibbon engaged in project planning and liaison with the users.

8.3.15. Inuvik

This is the one facility that the author has not visited. CCRS eventually built a receiving station at Inuvik. Construction of a station in the Arctic was proposed by a number of CCRS people over the years, including Ian Press when Ryerson was DG. It was when Doug Bancroft was DG that the funds were obtained and the station built. As stated on the Government of Canada's (GoC) web page "The GoC established the Inuvik Satellite Station Facility (ISSF) in 2010. It was built north of the Arctic Circle to take advantage of the strategic geographic location. Situated above the Arctic Circle, the Inuvik satellite station is uniquely positioned to track and receive data in real-time from polar-orbiting satellites for scientific, mapping, weather, surveillance and other purposes." Further details are available at https://www.nrcan.gc.ca/earth-sciences/geomatics/satellite-imagery-air-photos/satellite-facilities/ISSF/10953

8.4. Interesting People and Stories

Bob Ryerson[258]

Over the years something like 1000 to 1200 people worked for CCRS at one time or another. It is interesting to note that some forty of them have contributed to this document. In spite of the odd difficult employee or supervisor, and the curious behavior of some colleagues, CCRS was blessed with an interesting and generally a fun group of employees. The role of social events such as pot-luck lunches, summer picnics, Christmas parties and informal interaction at coffee breaks has been detailed above. While these social events brought out the personalities of the staff, the people of CCRS often displayed their wonderful personalities in other ways in the formal work setting, at conferences and meetings, as well as outside the work environment. Here we present but a few vignettes – and all of them are positive – which is how most of us who worked at CCRS thought of our time in the organization.

There was a great deal of laughter and an appreciation for the value of a sense of humour in our work. We did serious work, and did it well, but we also were able to laugh about ourselves and the often curious situations that developed. And the humour often came at unexpected times, as is shown in the following text box.

My Interview for a Scientist's Position at CCRS[1]
Tom Alföldi

In May of 1973, I drove up to Ottawa for my job interview at CCRS and boy was I nervous. I was interviewed by four people: my future supervisor – Jean Thie, the head of personnel – Francis MacDonnell, a scientist from Agriculture Canada – Dr. Alec Mack, and the Associate or Deputy Director General of CCRS – Lee Godby. They asked me to give a detailed description of my education as it related to remote sensing and I went through a long list, almost forgetting my then-underway Master's thesis.

When I finished, they turned to their own prepared questions. The first one, which immediately floored me, was: "When do you think we'll have a fully automated, digital system for monitoring crops in Canada?" This question was there, no doubt, to please Alec Mack, who was seen to be a major contributor and partner and customer of our technology. However, it was very inappropriate for me at that time, because I had made no reference in my presentation to knowing anything at all about agricultural applications of RS or of digital techniques, and we had no steady commercial source of satellite data. Remember that this was early 1973 and computers were extremely scarce. I believe that all of the University of Toronto had but one or two at that time, and most organizations and homes had none! So what was I supposed to say? I did remember my father cautioning me when I left for Ottawa, not to joke during the interview. But I just had to reply: "1979 if you hire me; 1983 if you don't". Well, that brought the house down! They weren't expecting that type of answer so there was lots of laughter. Then they asked for a serious answer and I gave them one as best I could.

[1] Editor's Note: Tom Alföldi was one of just two Applications Development Scientists hired in 1973 from the hundred or so who applied. This is his account of part of his successful interview, showing that humour and people quick on their feet were appreciated at CCRS.

Another interesting anecdote that illustrates the importance accorded the ability of being able to think on one's feet and make the best of a difficult situation comes in the following text box involving the hiring of another valuable member of the CCRS team.

[258] Except where noted, this section was written by Bob Ryerson

An Ill-Fated Appearance or a Fortuitous Opportunity[1]
Heather McNairn

As a recently graduated Masters student, I recall how nervous I was riding the train to Toronto to present at my first major conference. It was the 1992 Canadian Symposium on Remote Sensing (CSRS) and the venue was quite intimidating to this young scientist. At that time, there were no parallel sessions at CSRS, only one very large auditorium and one very intimidating stage. Participants had a limited choice; attend my presentation or go for an early coffee. 1992 pre-dated digital PowerPoint presentations. There was but one option and that was a slide presentation. CSRS organizers asked presenters to bring their slides pre-loaded into their own slide carousel, in order to facilitate the smooth running of the symposium. I don't quite remember walking up the stairs to the podium, but I certainly recall what happened next. A brief introduction to my co-authors was followed by a click of the remote control for the slide projector to advance to my background slide. Or so was the plan. Many clicks of that remote led to no advancement of slides. I was stuck on that title slide. The chair looked at me and I gazed back like a deer in the headlights. Clearly I needed a plan, and quickly. With an apology and a request for indulgence so that I could return to my seat in the auditorium (across that stage to descend those stairs and walk down that aisle), I assured my audience that I had presentation notes in my briefcase, that I would retrieve these and that we could quickly resume the presentation without my slides. I was certain I must have brought some notes with me. But as I opened my case, I realized I had nothing. The case was empty with the exception of some blank note paper. As I had descended the stairs, I could see out of the corner of my eye the shadow of the symposium technician climbing the scaffold behind the screen to try to fix my slideshow. Quite entertaining for the audience, as I was told later. I was certain I couldn't go back up those stairs with nothing. How would that look? I pulled a couple of blank pieces of paper from my case, giving the impression that I was well prepared and on top of the crisis. With those blank pages, I marched back up those stairs and across that stage, and winged my presentation from memory. Of all the scenarios I had gone through in my head pre-presentation, none included this catastrophe. I learned a great deal from this experience, including bring a copy of your presentation.

But most fortuitous for me, Dr. Ron Brown (lead agriculture scientist at CCRS) was in the audience. In 1993, Drs. Brown and Brisco interviewed me and offered me a job. After I was hired, Dr. Brown's words to me were this. I knew that someone who could stickhandle that situation was someone I wanted on my team.

I am most grateful to the mentoring received from both these great CCRS scientists and I suppose in a way, grateful that my performance left such a fortunate impression.

[1]Editor's Note: Dr. McNairn became a valued member of the CCRS Applications Division until the changes at CCRS in the early 2000's saw her move to Agriculture and Agrifood Canada. There she is now a RES-5 mentoring more junior staff, confirming the faith that the late Dr. Ron Brown and others at CCRS showed in her.

CCRS People are Weird! In the original Applications Division in the early-mid-1970s the scientists and post-doctoral fellows were all about the same age – from their mid-twenties to early thirties, but had wildly different backgrounds. The differences were manifested in how we dressed and presented ourselves. At the 1974 Canadian Symposium on Remote Sensing in Guelph, some of the relatively new scientists at CCRS were an unknown quantity, having been repatriated from other countries and related fields such as astronomy and geophysics. One scientist was dressed in a normal sports jacket and tie. Another looked very professional in a three piece suit – and then the fun began. One Post-doctoral fellow got up to give his paper in plaid Bermuda shorts, a white and pink striped shirt with little green flowers in the pink stripes and a big red polka-dot bow tie. Another scientist demonstrated his western roots by wearing a bolo tie and yet another wore a flowing African robe. I was sitting behind Drs. Keith Thomson and Bob Bukata, then scientists at the Canada Centre for Inland waters and I recall one of them saying with some amazement – "Oh my god, there is another one of those weird CCRS people." While they thought we were weird, we thought of ourselves as eccentric, if we thought about it at all. Obviously it wasn't too much of a problem for a few years later Keith joined us at CCRS for a few years before he went on to a long and successful career at Laval University.

An Egg Head. And speaking of Keith Thomson another story comes to mind. After he joined CCRS Keith used to bring his lunch to eat in the lunch room at Belfast Road. That lunch often included a hardboiled egg. Keith used to crack the egg by tapping it on his forehead. One day someone substituted a raw egg for the hard boiled-egg. We need not say more!

Landsat Island. In 1973 Photogrammetrist Betty Fleming of the Topographic Division of Surveys and Mapping, a sister Branch to CCRS, was interested in determining the minimum size of an object that one could map from ERTS-1 (later Landsat) imagery. A small island just 25 x 45 meters was found off the coast of Labrador using Landsat and was officially named Landsat Island. With the Island's location off the coast Canada's area increased by some 68 square kilometers. Interestingly enough the story was still being told in April of 2006 in NASA's "Did You Know?" series https://Landsat.gsfc.nasa.gov/Landsat-island/ and even more recently in the NASA Observatory Image of the Day web page for April 10, 2018. https://earthobservatory.nasa.gov/IOTD/view.php?id=91972&eocn=home&eoci=iotd_readmore While CCRS cannot take credit for Betty's work, she provided one of the first examples of people using satellite data to better meet the mandates of their organizations.

Gerry "Doc" Duplessis worked in the Systems Division with a responsibility for Quality Control. Gerry was a fun-loving chap, who was always smiling and who did his job well. He lived not far from the Booth Street headquarters of EMR and it was in this neighbourhood where he became more widely known as a "character" in the true (and positive) sense of the word. He turned his garage (which he called the "Garage Mahal") into his cottage. In an article in the 2013 Ottawa Citizen (Bruce Deachman, July 2, 2013) it was described with the accompanying photos in full colour as "a junk collector's dream" with a partial listing of the many "treasures" included a description of the way in which it began life as a local meeting place. Many of us from CCRS visited his "cottage" to have a beer with Gerry and talk over old times. Gerry passed away in September of 2014.

Whales on Landsat. There are many instances of extraordinary capabilities being incorrectly assigned to satellite imagery. One of the most memorable came from an Atlantic Canada researcher who suggested that 80 meter resolution Landsat MSS data could be used to do a census of whales. Aside from limited spatial resolution, Landsat data had virtually zero water penetration capabilities. The researcher was, in effect, laughed off the stage into obscurity.

Don't rely on Spell Check. Many years ago a citizen wrote a letter to our Minister with some comment on the Public Service. Bob Ryerson was one of those tasked with responding to such letters when they dealt with remote sensing, so it came to him to respond. He wrote the response and it went through his Director, Deputy DG, DG, ADM and finally it was sent back directly to Bob by Bruce Howe, the Deputy Minister at the time with notation in big RED letters beside the red-circled words "Pubic Service" which had been used in place of "Public Service," of course. The comment said: "It must be fun to work where you do!" The message from the Deputy Minister was never shown to anyone else. Spell check was never fully trusted ever again.

Direct flights vs fast flights. The Applications Division's first Secretary was Marion Rollinson, an older and very efficient lady. She kept track of the many divisional files, and served as the secretary for the few staff at that time. Among her duties was the arrangement and booking of all travel. Marion did not like to change aircraft when she was flying and thus booked us in the same way. It was for that reason that we found ourselves flying from Ottawa to Victoria in the same aircraft with stops in North Bay, Thunder Bay, Winnipeg, Regina, Calgary, and Vancouver. The flights to Orlando during the Image 100 procurement were just as bad. We would end up flying to Orlando with stops at Syracuse, Baltimore, Charlotte, and Atlanta. After a few such episodes we managed to ask for and obtain the fastest routing.

Cloud Erasers. The Applications Division hired a significant number of summer students and students from Sherbrooke and Waterloo on co-operative work terms, as well as summer students from other universities. They were often assigned to help scientists in their work interpreting Landsat imagery on the Image 100. Of course Landsat imagery was often plagued by cloud cover. A common rite of passage with almost every student assigned to do such work was when the student was asked to go to the office to get a "cloud eraser." Some caught on immediately – and played along with the gag, while others would return sheepishly after finding that they had been sent on a wild goose chase.

Communist Spies? In the late 1970s/early 1980s we were told that we would have two Polish scientists join us to learn about remote sensing. There were some concerns about security so the powers that be in the field of counter-espionage decided that we should have locks on all doors of all offices and labs before our guests arrived. This was done during the weekend before the Monday arrival of our visiting scientists. Our visitors were told that we started work at 8:00 a.m. and thus they arrived at 8:00 a.m. As we all came into work we found that our offices were locked – and keys were given to us by the locksmith. Our visitors thought that this was normal – we would arrive to locked doors. We later became quite close to the older more knowledgeable scientist. He was accompanied by a young lady who was also said to be a scientist – but he had never met her before the flight left for Ottawa and she seemed to know very little about remote sensing. We were all convinced that she was his "minder." She was the one who always seemed to be trying to get a look into the innards of the Image 100 and who became very irritated if she ever lost sight of her colleague. We later exchanged messages with the "real" scientist and used code words just to bug the censors – for example he referred to our children as our "pixels."

Some CCRS Humour Visiting the Gatineau Satellite Station. The Gatineau Satellite Station was a "must visit" location whenever there was a visiting delegation, a remote sensing conference, or remote sensing-related meeting held in the Ottawa area. As head of Marketing I (Bob Ryerson) was often called upon with Jean Game to lead tours to the station. The station was located almost an hour from our offices on Booth Street on top of a remote hill north of the city of Gatineau, Quebec. Just after one turned off the main road on to Chemin St. Andrew, the road took a sharp turn to the left. The first time I visited the station I noticed that in the back yard of the house at this corner there was an old rusty 2 meter satellite dish. That rusty dish gave many a visitor a big surprise! En route to the station those of us who brought visitors by bus or van would regale the visitors with stories of the bear family that lived near the station, the wild-life we might see, and the fact that snowmobiles were kept at the bottom of the hill so it was always accessible even in the midst of a major snow storm. And then we got to the famous corner. There we would stop the bus and proudly point to the rusty dish and say "Ladies and Gentlemen welcome to the Gatineau Satellite Station…we will get off the bus just around the corner." The stunned silence was usually immediately followed by loud laughter when it was usually (and often quickly) realized that we were joking. And when our guests did get to the station, they were certainly very impressed after our short hesitation at what I came to call the "bogus" station.

Pornography? Our computer systems were all networked and set up to automatically shut down any computer that appeared to be accessing pornography. When that occurred a message would automatically be sent to the Head of Computer Operations (Mike Prindiville, when this anecdote unfolds) and to the supervisor of the individual whose computer was deemed to have attempted to access such sites. When such a message landed on the supervisor's computer the screen turned red, flashed on and off and named the alleged miscreant. The only time I ever heard of this happening while working at CCRS was in early 2002. No sooner had the screen turned red and started flashing on my (DG Bob Ryerson's) computer on the third floor than an out-of-breath Ian Press arrived at my door from Ian's second floor office below to exclaim "I was looking up the Israeli satellite, Bob, that's all it was!" The Israeli satellite was called the Earth Resources Observation Satellite – or EROS. It was one of the keywords that started the shut-down process. The other funny part of this story was that the other person who was sent the notice reported to Ian. Ian passed away in June of 2016 after an all too short a retirement earned by working his way up from computer operator to Division Director through hard work, attention to detail and the application of his intelligence.

CCRS Memories from the Atlas[259]
Peter Paul

When the Atlas of Canada program was amalgamated with CCRS as part of the newly-formed GeoAccess Division in the late 1990s, there were many administrative and strategic details to be worked out. When I think back to those days, though, I remember the new group of people we began to work with, and the lessons we learned from having the opportunity to work together. These are comments about some of the wonderful people we worked with in those heady days.

Kathy Laity taught us all about team spirit. She was without doubt the most organized procurement person I have ever worked with – keeping meticulous records and paperwork which bailed me out several times. You just knew that if Kathy was tracking a purchase or a supplier, the situation would be resolved. But her true contribution to the Division went far beyond that. She was a key organizer behind all of our GeoAccess potlucks, Christmas parties (including special events for all the employees' children), Valentine's Day, Halloween, and individual birthdays. She was such a dedicated, loyal person (and friend) that you could not help but be inspired by working with her.

Marion Normoyle was an exceptional office manager for the Division – handling all of our travel (which included considerable national and international trips as part of the GeoConnections and CEONet programs). She had wonderful people skills – keeping us 'on-track', but always with patience and tact, and always with class. Marion and I happened to have offices beside each other, and I will always remember the first week she and Bob moved to 615 Booth St, because I could hear her singing quietly to herself while she was doing her work. What a breath of fresh air Marion was! We always thought that she would have made a tremendous head coach for the Ottawa Senators.

Mike Prindiville ran likely the most capable IT Support group in the entire Department. He found a way to assemble and maintain (particularly challenging with computer staff in those days) a very talented group of specialists who assisted with operating systems, data management, networking, and web sites. Mike's team meetings (and his terse meeting minutes) were something to behold. Behind all of this was a wonderfully dry sense of humour, and a genuine concern on his part for the individuals involved. I'm sure that's why they were so loyal to him.

Jeanne Rochon ran the CCRS financial system when we first became part of the Centre. She knew the administrative regulations like the back of her hand – you could always count on the information or advice which she provided. Most of all, though, she was a 'people person' who cared about her staff and thus (like Mike Prindiville) inspired support in turn from them. Jeanne was a person whom you could go to with a budget or purchasing problem, and know that she would do her best to resolve it – never breaking the rules, but using them to arrive at a solution, usually in half the time you expected it to take.

Christian Prévost was a remote-sensing specialist who had a strong desire to ensure that this science was made understandable to non-specialists, and that it was clear to them how it might be used to improve their day-to-day lives. This was particularly helpful to people like me from the Atlas who had very little previous knowledge about remote sensing, and could definitely use a hand navigating the terminology and, more important, understanding its application. I recall Christian spending countless hours with tour groups of high school students, teachers, and members of the public during Science and Technology Week. He was also unfailingly patient with my attempts at speaking French.

Tom Alföldi showed me that being a Section Head could be fun. I remember going into his big office (when people had big offices) at 588 Booth. He had puzzles on his desk, and things hanging from the ceiling. He had somehow

[259] Editor's Note: This unsolicited commentary on some of the people at CCRS provided by Peter Paul in 2018 again underlines the importance of respect and personal relationships at all levels that helped define the character of CCRS.

jury-rigged the hinges on his office window so that they appeared to be bolted shut, but in fact he could open it at will for fresh air. Tom came to work with our Atlas program for a year-long assignment before the Divisions merged. Significantly, this was the very year that the Atlas began web mapping – an exciting time of change, and Tom was part of this. He later parlayed this experience into building the first CCRS Web site with many innovative components – a tribute to his creativity and knowledge. Tom also had a phenomenal database of peoples' birthdays (no one was ever sure how he procured this personal data), but to this day I still receive emails from him on my birthday, and I'm sure I'm not the only one. He always found a way to 'humanize' the office workplace.

Florian Guertin was a wonderful Director – tremendously knowledgeable, tirelessly conscientious, and always willing to make time to help if I had a concern or an idea to discuss. I can recall going to Florian with some Intellectual Property (IP) questions about the Atlas's home-grown web mapping application. His experience in previous IP discussions between CCRS and the private sector were invaluable. Florian was another example of a person who had begun his career as a very talented engineer (hired, incidentally, by Ed Shaw), who then became a very capable manager, because he understood the science and how it could be applied. I remember being impressed at how conscientious a worker Florian was, the hours that he put in, but also impressed with what a positive attitude he projected.

Bert Guindon was an extraordinary scientist who was always thinking about new approaches to apply Remote Sensing science to solve real-world problems. Bert was a very reticent guy, but once you knew him, he always took the time to share ideas. I can recall Terry Fisher mentioning how Bert had helped save the day during one of the multi-million-dollar MacDonald-Dettwiler contract projects which CCRS had managed in the early days.

Terry Fisher was a very effective manager for the complex CEONet program – involving extensive stakeholder work (with the Canadian Space Agency, and other international partners), and a significant budget for managing a large metadata repository to facilitate access to Canadian remote sensing data. I would often see Terry on teleconferences with stakeholders (using the same small, low-tech conference-call unit in his office). I recall his projects winning several prestigious departmental and international awards, and how Terry would always ensure that each team member (senior and junior) was recognized publicly for the contributions which they had made.

Les Whitney had a very unique role at CCRS. He was not a scientist, but rather he helped evaluate the benefits which Remote Sensing provided to the outside world. He also ran the CCRS Project Selection and Review Committee when the Atlas joined the Branch. Ed Shaw likely believed that the Atlas should be part of this, so we were asked to participate – a great way to learn about CCRS projects, about CCRS people, and about how they selected and evaluated their projects. Although it was an extra step in project approval, I always believed that the PSRC added value by forcing a conversation about 'why' the project was being done and about who would benefit. As Les would often say, we were not questioning the quality of the science, but just having the conversation about who would benefit. The goal in those days was primarily technology transfer, so this often came into the discussions. From the hundreds of projects which we heard presented at PSRC, I recall very few that were ever rejected entirely; but in many cases the project plans were revised based on our conversations with the project leader. I think we all learned from that. I also recall hearing that Les helped start and maintain a youth rehabilitation center as part of his community work.

Nigel Denyer was a Section Head from the Data Acquisition Division who sat on the Project Selection and Review Committee with me when the Atlas first joined CCRS. I recall his considerable knowledge about procuring and managing large data storage units, but also his kindness in welcoming me as part of PSRC, and making me feel like part of the team rather than an outsider. Sometimes, this came simply from the 'small talk' we would have about our families and outside activities before the PSRC meeting would formally begin. Nigel had a good sense of humour and a healthy disrespect for officiousness.

Jocelyne Rousse was the Director General's Executive Assistant, and the epitome of the term 'grace under pressure'. Every time I came to deliver something, or to meet someone at Ed Shaw's office, Jocelyne was there. She would always first take the time to greet us personally and in a very sincere way before we got to the business at hand. Little gestures like that make all the difference. Jocelyne was so capable in her job – keeping everything organized and flowing on time. She made a very difficult job look easy. She was also a person who encouraged me to use my French, and was very patient with my pronunciation and vocabulary. I remember her telling me once that she knew the french-Canadian folksinger Félix Léclerc – that they had grown up together in the same town, and that she would see him when she was home for the holidays. I know that Ed Shaw truly appreciated her help, and that he made sure she knew that.

Tom Feehan managed the Ground Systems Operations for CCRS's Data Acquisition Division. I can recall Terry Fisher mentioning once that Tom had the 'hardest job at CCRS', because of his on-going responsibility for quality control within tight time deadlines ensure that data were gathered reliably and was accessible to multiple internal and external clients. I will always remember Tom's wonderful Newfoundland accent, and even more so his generous Newfoundland spirit – always time to wave hello, and a share a smile or a story – all the more remarkable given his work pressures.

Jean-Marc Chouinard was our Director briefly during the period just before the Atlas was transferred back from CCRS to the Mapping Information Branch. It was a time of fairly significant change for the Atlas, but I will always appreciate Jean-Marc's personal warmth, and his willingness to consider new ways of approaching impending challenges – either personal, or organizational. He was an avid cyclist, who enjoyed being with his two daughters, and always asked about ours. He had many interests outside of work, and a natural curiosity. I recall us discussing the origins of some historical place names in Québec. Mostly, I recall how supportive he was personally, and how good he was to people he worked with who were also dealing with significant job transitions. Above all, I remember him making the time to personally visit with one of our Atlas colleagues who had been confined to home with cancer. This was a person who had become sick long before Jean-Marc arrived on the scene, and whom he did not know personally,, but nevertheless took the time to visit.

Bob Ryerson was a CCRS Section Head when we first met. At that time, we would be most likely to have a conversation about activities our children were involved in. I remember how dedicated he was to coaching his kids' soccer teams, and how much he enjoyed that. Even after he became Director-General years later, he would drop by the Atlas lunchroom for an informal chat with the gang over sandwiches, or while serving meals at the CCRS Christmas dinner. Bob had all CCRS staff out to Mooney's Bay for a picnic one year, and wasn't afraid to wear his Senators shirt to work. He was, and always will be, a breath of fresh air -- and a friend.

Bob O'Neil was our Director when we first joined CCRS, and led our group during the period when we enjoyed our most successful years there. I will remember Bob as a person who took a while to get to know because he was quieter, but a very thoughtful person – both in the personal sense, and in how he approached his job. He liked to think things through – conceptually. Sometimes this involved late-afternoon conversations before we were both ready to head home for the day. Bob cared about people and also about four-legged friends. I remember him making home-made stew for our Atlas potluck lunches, his ability to reminisce kindly about people when asked to speak at their retirement ceremonies, and the times he brought his beloved Wheaten terrier (Cinders) into the office. After Bob took the time to sort through the complexities of what a national Atlas was and could be, he became one of our strongest supporters – and was responsible for allowing us to tap into a level of funding (GeoConnections Program) which we had never previously been able to access.

Ed Shaw was our Director-General. He always struck me as an approachable person – a guy who had lunch each day in the cafeteria in the basement of 588 Booth. He encouraged anyone to join him, to share concerns or ideas or just to talk. I recall doing that once or twice. Although he had a doctorate in electrical engineering, Ed was also a person who remembered his roots in a Welsh mining town, and a person who loved the game of rugby. He appreciated and encouraged everyone's contribution. He never seemed too comfortable in the limelight – preferring to serve (as he did at the wine table, at the annual CCRS Christmas potluck in Camsell Hall). He would show up at PSRC meetings because he was genuinely interested in a new project idea, regardless of where it came from. He was a wizard at managing year-end budgets -- this talent was so helpful to those of us rookie managers. I recall him regularly bringing in a new book with him to CCRS Management meetings (Tom Peter's In Search of Excellence, for example), just to keep our minds open to fresh management approaches. He was always supportive of the role of the Atlas within CCRS and within the GeoAccess Division. Having our DG and Director in sync made all the difference.

In Summary: The merger of the Atlas with CCRS during the nearly ten-year existence of the GeoAccess Division meant that we had access to new data, new science, and new funding. Perhaps most of all, though, it meant that we had access to new colleagues who shared their knowledge, their experience and their personal qualities with our group. All of us at the Atlas benefited from that.

Like Peter Paul above, each of us who worked at CCRS will have our own list of special people – people who were good at their jobs and yet were caring friends and colleagues. How is it that there were so many special people at CCRS? Perhaps that is yet another aspect of solid management, good leadership and sound human resource management as mentioned by Paul Hession in Section 2.3.2. Good managers and leaders attracted good people – and, when necessary, good managers were not afraid to encourage those who did not fit in to move on.

9.0. Executive Summary and Lessons Learned
Bob Ryerson

9.1. Executive Summary
We the authors of this history and "how-to" guide freely contributed our time and knowledge to its creation. Why? Because we appreciate that what we accomplished together was something special: something that no other group anywhere in the world accomplished no matter their size or budget. We want to explain not only what we did, but how we did it to provide some guidance for others in government who seek to apply science to meet the future needs of Canada and Canadians. This short summary is intended to whet the reader's appetite and provide an overview of what the Canada Centre for Remote Sensing accomplished – and why. The summary ends with the lessons learned – lessons that are as relevant today as they were when first applied by CCRS.

One of the best explanations of how so much was accomplished comes in Section 5.5 – the conclusion of the Section on RADARSAT by Dr. Keith Raney, a former Chief Scientist at CCRS and arguably the world's leading radar scientist in the period this history covers. His explanation:

> "Long-term enterprises become successful only to the extent enabled by the steadfast leadership of their management, sustained by enthusiastic quality staff, and high level support. Leadership and senior management need to be willing to accept risks, when the road ahead is well prepared, and the benefits of success are clear. RADARSAT-1 is a good example. The all-important user advisory groups set up by management (inspired by Larry Morley) in the early 1970s became essential resources leading to a remarkably responsive satellite SAR launched two decades later. The CCRS SAR-580 program that provided radar data products and user-oriented analysis techniques were an essential component in developing and expanding a knowledgeable user base, both in Canada and world-wide."

Former Scientist and Director Dr. Bob O'Neil elaborated on the conditions for success in Section 6.5.3 when he stated that "CCRS hired people with a range of backgrounds with two common attributes: pride in what they did and the drive to meet what sometimes seemed like unattainable goals."

This history of the Canada Centre for Remote Sensing (CCRS) was written at the suggestion of the late Dr. Lawrence "Larry" Morley, who has rightfully earned recognition as one of Canada's all-time leading scientists and engineers. In 2014 Dr. Morley was inducted posthumously into Canada's National Science and Engineering Hall of Fame: he was one of but sixty members. He was the founding Director General and led CCRS from its inception until the 1980s. Dr. Morley always said "Canada was made for remote sensing" given the limited budget of CCRS and the enormous size of the country we were setting out to monitor and help map. While this document has been written as a history, along the way it also outlines how to do effective science in government. This is as Larry intended: as with most work done by CCRS two objectives have been met with one output.

CCRS was known world-wide as a world-class organization that consistently punched well above its weight in the important area of earth observation. It served as the model for a number of countries and how they approached remote sensing and the geospatial sciences. We the authors believe that the CCRS organization "model" is more widely applicable than to just remote sensing and related fields. The organization – from management structures to the library – was built to foster innovation. As is explained in Section 6.4, innovation was not something that was just hoped for, or that we relied on luck to achieve. Innovation was built into our organization's DNA.

This is the story of CCRS – both what it did, how it did it and, most importantly, the lessons learned that might be usefully applied by Government in other areas of science and technology. There is a great deal of focus on supporting and international activities inasmuch as they were, in retrospect, critical to the long term success of CCRS and the growth of the industry that CCRS nurtured. It is believed that it is particularly important to emphasize these supporting activities since most scientists and science advisors tend not to give them the attention that they deserve if the goal is to create a successful and sustainable science-based activity to support the national interests of a country. And CCRS always kept in mind the truism: **the value of a new technology comes not from its creation, but rather from its use.**

This history is not just about CCRS. It recognizes the important roles of industry, academe, other levels of government and other government departments with which CCRS worked as a truly national centre of excellence. At the same time we also agree with the point of view on the important role of government in innovation espoused by Dr. Mariana Mazzucato in her *TED Talk* filmed in June of 2013 that was titled "Government – Investor, Risk-taker, Innovator." We recommend viewing her presentation as a point of departure before reading this work:
http://www.ted.com/talks/mariana_mazzucato_government_investor_risk_taker_innovator

The accomplishments of CCRS and its staff are truly amazing in both their scope and importance. Almost every page identified yet another leading edge development or a first in the field: there are far too many to list them in this summary. For this executive summary we have extracted some of the most significant achievements and activities in the following table. For each we have identified the section where further details can be found.

The reader will find that some topics are covered more than once from different perspectives. For example a specific technology may be described by the scientist or engineer who invented the technology as well as by the applications scientist who used the technology. We believe that these different perspectives give a more rounded and complete view.

Following the table are the more than sixty lessons learned that have been extracted from this work. We hope that the Lessons Learned over the next pages will be widely and wisely shared across government.

Some of the Significant Achievements and Activities of CCRS and Its' People[260]
Awards and Accolades • In 2011 CCRS was the first organization outside of the US to win the prestigious William T. Pecora Award, the highest honour in the field of remote sensing for an organization. Over 35 accomplishments are cited in Section 8.2.3.[261] The nomination letter begins with the following paragraph: "I am nominating the Canada Centre for Remote Sensing (CCRS) for the 2011 Pecora Award. CCRS has contributed in a major way to the understanding of the Earth over a period of forty years through the development of important technologies, innovative applications and policies, as well as major contributions to the international community. It has worked successfully with the USGS and NASA as well as other agencies and industry in the USA and elsewhere. Cooperation has been its hallmark." • CCRS employees have won hundreds of awards for contributions in the field. Section 8.2 documents some of the most important.
Advisory Structure • To truly understand the organizational genius of Larry Morley, Lee Godby and University of Waterloo professor and management consultant Don Clough, one need only look to the Canadian Advisory Committee on Remote Sensing - CACRS. The Committee and how it functioned as an inclusive truly national advisory body was responsible for much of the success Canada enjoyed in the field. Section 2.2. • CACRS provides a useful model for guiding science in government. Section 2.2. • There are two significant new programs that came out of CACRS Recommendations: the development of

[260] Editor's Note: Summarizing the accomplishments over a period of forty years of such a talented group is not easy.
[261] Several of these are repeated in this table.

the airborne radar program; and RADARSAT. Sections 6.7.2 and 5 respectively.

Active on the World Stage

- Larry Morley was the individual who did more than anyone to make the world's remote sensing community a global village based on cooperation and sharing. Section 2.1 and Appendix F.
- The CCRS Library provided world-wide access to the first searchable data base of English and French publications in remote sensing and by so doing became the world's go-to source for information in the field. Section 6.3.
- Canada's first cooperative agreement with the European Space Agency was initiated by CCRS for ESA to gain access to the Convair-580 SAR. In a 1985 assessment of the relationship with ESA, Canadian participation in the ESA ERS program was viewed as "a major asset" primarily because of the role of the Canada Centre for Remote Sensing. CCRS was described as "the leading body in remote sensing. It had a good team, the necessary resources and long experience". "The same report noted that MDA, which had been awarded the prime contract for providing the SAR data processing technology at the two ERS satellite stations in Europe, had become a leader in the field. Section 7.8.
- The Convair-580 aircraft and the systems on board were used to provide SAR imagery, share our experience, and demonstrate our excellence in Asia, Africa, the Middle East, Latin and South America, and, of course, Europe. Sections 6.5.6 and 6.7.2.
- CCRS was a founding member of the Committee for Earth Observation Satellites (CEOS) and played a pivotal role in data calibration, standards, and the like – helping Canadian industry (such as MDA, PCI and others) along the way. Section 3.6.3.4.
- As a result of the award-winning GlobeSAR program additional sources of groundwater were found in Jordon. The Syrian refugee camps in eastern Jordan currently rely on this water. Section 6.6.6.
- CCRS had both bilateral and multi-lateral relationships around the world. Section 3.6.

Responsive to National Priorities

- Key issues faced by the government of the day were always kept top-of-mind by CCRS management – and scientists. For example the thread of protecting sovereignty has run through CCRS and remote sensing from their beginning in Canada. There was also an early focus on thermal imagery for assessing heat loss in buildings in response to the energy crisis in the early 1970s, while climate change became top of mind in the 1990s. Sections 6.5.3 and 6.6.10.
- CCRS worked with a wide range of other federal departments and agencies as well as the provinces and academe. Sections 3.1, 3.2 and 3.4.
- In the massive budget cuts of 1994-95 the only program in all of Government to obtain substantial new funding was the space program which obtained some $800M over the next decade or so and most of that was earmarked for remote sensing or earth observation (EO). CCRS wrote much of the EO justification and the industry CCRS worked with provided support. Sections 2.3.4.2, 3.3.2.6, 4.3 and 6.6.1.

Relationships with Industry

- Dr. John MacDonald, founder of high tech success story MDA, was quoted as saying "it was from Larry Morley that we learned how to build a high tech company in Canada." MDA got its start working with CCRS. Section 3.3.4.5.
- CCRS was considered so effective in its development of industry that it was studied to gain insights into how science could lead to commercial success. Section 3.3.1.
- CCRS contracting and related policies led to international success for several companies including PCI Geomatics and Intera. Sections 3.3.4 and 3.3.3.
- MDA has sold the Geometric Image Correction System (GICS) technology derived from MOSAICS for CCRS to many satellite ground stations around the world for satellite missions such as Landsat, SPOT, ERS-1&2, MOS, NOAA AVHRR, JERS, RADARSAT, Envisat and others. The GICS technology became the de facto world standard, and MDA the leading provider of Earth observation satellite ground system solutions with market share estimated as high as 90%. Section 7.5.

High Impact

- The CCRS Convair-580 Synthetic Aperture Radar research aircraft and work by CCRS scientists on polarimetry provided the proof-of-concept and scientific backing for an **estimated $10 billion investment by Japan, Europe and Canada in radar remote sensing satellite systems.** Unlike most other countries, we in Canada used aircraft to prove and develop concepts before launching spaceborne systems – a cautious but effective Canadian approach. The CCRS Convair-580 Synthetic Aperture Radar research aircraft flying laboratory is a symbol of how we approached scientific research: cautiously and in support of our economic, environmental, and foreign policy goals. Sections 6.5.6 and 6.7.2.
- During the 1990s the GeoAccess Division’s Atlas of Canada web site routinely ranked among the top Government of Canada sites in terms of yearly visits by users. Section 6.10.
- In 2006, as part of the centenary celebrations of the Atlas of Canada, the Royal Canadian Geographical Society recognized the Atlas with its Gold Medal award. The Canadian $100 banknote was produced to celebrate the same centenary. Section 6.10.2.

National Leadership

- CACRS was originally set up as a national advisory body including all sectors and regions of Canada. Section 2.2.
- The Canadian Remote Sensing Society led by Larry Morley was the first national society anywhere with remote sensing in its name. Section 3.5.2.
- “The ground breaking work by CCRS supported many a graduate thesis and advanced many a career…and has most certainly yielded dividends.” Section 6.6.3.9.4.

Efficient and Well Managed

- The Auditor General could find nothing to criticize! The ultimate stamp of approval on how CCRS was managed and the results obtained came from a study involving the Auditor General and a report of the Auditor General of Canada. Section 2.3.2 and 3.3.1.
- The GeoAccess Division was a part of CCRS for just twelve years. Over those twelve years what began as a collection of orphans that no-one other than CCRS seemed to know what to do with became an award winning unit that everyone coveted. This is largely as a result of the solid management team that was assembled and the belief of the staff that what they were doing was important for Canada. And it was. Section 6.10.
- While CCRS developed a wide range of new technology, CCRS used generic off-the-shelf computer hardware and software where possible to avoid designing costly special purpose systems, and by so doing reduced the on-going operation and maintenance costs. Section 7.2.

Technology Developments

- CCRS did a significant amount of the world’s basic research in civilian radar remote sensing. Section 5 and 6.7.2.
- Working with CCRS MDA developed the first digital SAR image – forever revolutionizing the use of SAR data. MDA became the world’s largest producer of SAR processors. Sections 3.3.2.6, 3.3.3.6, 5.1.2, and 7.6.In the 1976-1979 time frame CCRS developed the Digital Image Correction System (DICS), the first operational facility to produce geocoded imagery from Landsat MSS data. Section 7.4.
- The CCRS Colour Image Recorder was the world’s first high-resolution digital film recorder system. Section 7.7.
- The Polarimetric Work Station developed by Dr. Touzi of CCRS has been adopted in Canada and in many countries around the world (India, Brazil, China, France, Russia, and Argentina, among others) as a user-friendly tool for efficient exploitation of polarimetric satellite SAR information provided by various satellite and airborne SARs. Section 6.7.2.4.3.
- CCRS developed methods to use SAR data for individual ship detection. Section 6.7.2.4.3.
- The pioneering research into image analysis algorithms by CCRS and the rest of the RS community in the 70s and 80s formed the basis for today's practical applications from point-and-click photography to the "vision" capabilities of autonomous vehicles. In particular the CCRS work led to a successful export

industry. Section 6.8.2.2.

- Data from the US's flagship Landsat Thematic Mapper sensor had serious problems (striping in the data) that the US could not solve. It was CCRS scientists Frank Ahern and Jenny Murphy who developed a solution to the problem. Their approach was subsequently adopted world-wide – including by the US. Section 6.8.2.5.1.
- CCRS successfully received and processed the first Landsat-1 image and made it available to the U.S. The image was rushed to Ottawa from Prince Albert in time to be shown at the 12th ISPRS Congress held from July 24 - August 04, 1972. Section 6.9.2.

Leading Edge Applications

- CCRS led the Great Lakes Land Use Mapping Project – the world's first large area project where information derived from existing map data, satellite data, airborne data, and census data were incorporated together in a GIS. Section 6.6.3.3.2.
- CCRS worked with Statistics Canada to produce the first real-time pre-harvest operational crop area estimation done anywhere. Section 6.6.3.6.
- An operational crop monitoring system was developed with and for the Canadian Wheat Board. It was later taken over by Statistics Canada which received a government-wide award. (See Section 6.6.3.5.)
- The unique CCRS approach to monitor rangeland condition won an award for Drs. Ron Brown and Frank Ahern for the English speaking world's most outstanding paper in remote sensing in 1983. (Section 6.6.3.7 and 6.6.3.1.2.
- CCRS was a major contributor to the BOREAS Program. Canadians have benefited from improved weather forecasts resulting from a better understanding of the energy exchange over the vast boreal ecosystem. Section 6.6.10.4.
- CCRS was an early player in the area of climate change and national monitoring. Section 6.6.10.
- CCRS's contribution to Canadian agriculture is measurable and remarkable." Section 6.6.3.9.4.

Technology Transfer, Education and Visibility

- CCRS was active in technology transfer and the development of training materials used at home and abroad. Sections 3.1.7 and 3.2.4.
- CCRS had an active marketing and public awareness program. Section 6.2.

9.2. Lessons Learned

9.2.1 Introduction

This is believed to be the most important section of this work. The lessons learned over the history of CCRS provide both positive advice and some advice on how not to do things with regard to science policy and implementation of that policy in government. The lessons learned are identified in the next nine Subsections. The topics considered are:

- Management and leadership (not the same thing!);
- Advisory bodies;
- Working with industry, academe and government agencies;
- Identifying opportunities;
- Innovation and problem solving;
- Building research capacity;
- Putting innovation into operation;
- Understanding politics and politicians: and
- International relations.

One of the interesting aspects of re-reading hundreds of papers, advisory reports and meeting minutes concerning CCRS was the realization that the early leaders of CCRS knew that they were forging a new way of doing science in government – and that other organizations might learn from studying CCRS. This was clearly stated in Canadian Advisory Committee on Remote Sensing (CACRS)[262] reports, for example. And while many did learn from CCRS, we hope that this document will lead to many more gaining insights from what amazing things CCRS accomplished and how it did so.

9.2.2. Management and Leadership

- To ensure knowledgeable management and leadership, all levels of management and the leadership should have experience relevant to the discipline.

- Leaders should be expected to lead, not just manage.

- To ensure succession planning in both management and leadership, efforts should be made to identify potential managers and leaders among the engineers and scientists involved in the program. (At CCRS many people identified as having management and/or leadership potential went on to become Directors, Directors General, and Assistant Deputy Ministers in organizations in governments across Canada. A number of others became leaders in industry.)

- Secondments, participation on interdepartmental committees, mentoring and formal training can be used to further staff development and expand the impact of the organization.

- All projects and programs must be on time, on budget and there will be no surprises.[263]

- There should be no fear of failure…such fear limits the potential for success.

- While failure can be tolerated, both project managers and senior management should know when to cut losses – and not be afraid to do so. A project selection and review committee of senior scientists and their managers chaired by a member of the leadership team will help in this regard.

- Management should have plans in place to rapidly absorb extra budget should funds become available. At the same time, it is wise to know what projects or programs might be sacrificed should there be calls for budget reductions.

- Everyone in the organization is important and should believe that their role is important.

- Management by walking about is important. Leaders and senior managers should be seen and should be available on an informal as well as formal basis.

- Management should keep in mind that Research Scientists are promoted based largely on publications and related metrics. Technology transfer and operational applications of science are sometimes best left to those not in the Research Scientist category.

- Constant reorganization and changing linkages and mandates tend to result in reluctance to embrace changes – even beneficial changes.

[262] Pronounced KACK-ers.
[263] Editor's Note: These are the words of the late Florian Guertin who gave so much to CCRS – and this document.

9.2.3. Advisory Bodies

- To ensure that widely-based and appropriate advice is received, a broadly based advisory body should be established at the outset to provide advice to government.

- To avoid hearing only limited advice, the main advisory body should meet annually with its constituent working groups that cover the key areas within the discipline including technical areas, potential users, industry, researchers, and appropriate levels of government. (This may be done at a relevant national symposium.)

- In that some science and industry policy may be related to national security and industrial development, some elements of the advisory body's deliberations may have to be held in secret.

- If the research involves natural resources or other areas that fall mainly within the jurisdiction of the provinces, as CCRS work did, then the provinces and territories must be fully engaged in the advisory structure.

- As science and research lead to new ideas, evolution and change in advisory bodies and their working groups should be both expected and accepted as the norm.

- Advisory bodies that advise the scientific level as well as the political level are more effective than those that advise the political level alone.

9.2.4. Working with Industry, Other Government Agencies and Academe

9.2.4.1. Introduction

How CCRS worked with those in industry, other government agencies and academe is one of the keys to its success. Words like collaboration, partnership and technology transfer were all part of the vocabulary at CCRS. By and large CCRS listened to its stakeholders both through advisory structures and bilaterally. Furthermore CCRS was generous in sharing success, and paid strict attention to its mandate and those of its partners to ensure cooperation. Here industry, other government agencies and academe are grouped together inasmuch as certain elements of working with others cross these sectoral boundaries.

- The organization should actively build and maintain links with partners and stakeholders in industry, government, and academe as well as with key international partners.

- By partnering with outside organizations, including those engaged in R&D, one can leverage work for broader application to a much wider community. CCRS was able to exert an influence far out of proportion to its small size.

- Words like collaboration, partnership and technology transfer should be part of the essential vocabulary of everyone in the organization.

9.2.4.2. Industry

- Government can be an effective beta client for industry's commercialization activities.

- Do not compete with industry: allow industry and the advisory body to decide what is or is not competition.[264]

[264] This was a bone of some contention. The Ontario Centre for Remote Sensing was accused of unfairly competing with industry, as were some of the other provincial centres.

- Industry should be fully engaged in advisory bodies.

- Recognizing that industry will, in the end, likely be the agent to make the science operationally useful, mechanisms to involve industry in technology transfer should be in place from the start. These may involve industry employees being embedded in or seconded to government, government staff seconded to industry, incubators, or other mechanisms including Public Private Partnerships.

- In that governments should not be involved in selecting winners and losers, mechanisms to engage industry should be open and transparent and involve independent evaluations of proposals.

- Project reports, not just scientific papers, should be readily available to Canadian industry to lead to commercialization for the benefit of Canada (and the taxpayers who paid for the research).

- To obtain the best result for the dollar expended and to avoid "low-ball" bidding all requests for proposals should indicate the dollar amount set aside for the contract and proponents should be encouraged to make innovative use of the funds available to maximize the return on the expenditure. Such an approach leads to innovation and reduces the potential for less competent "low-ball" bidders winning contracts that they cannot complete or which yield results that they are unable or unwilling to commercialize.

- If industry or other governments have benefited from the R&D done, benefits should be quantified and brought to the attention of the political and senior bureaucratic levels – preferably by industry or the other levels of government most involved.

9.2.4.3. Working with Other Government Agencies

- If the research involves natural resources or other areas that fall mainly within the jurisdiction of the provinces, attention should be paid to cooperation and the development of mechanisms to transfer technology to the lower or other levels of government.

- If the research will serve, or can be expected to serve, another government ministry or agency, the nature of relationships and responsibilities should be formalized to maximize the potential benefits. These agreements may include cost-sharing, secondments, how credit is shared, and how results and benefits are calculated.

- Joint projects with other levels of government and other government agencies or ministries tend to amplify expertise.

9.2.4.4. Working with Academe

- Education is a provincial/territorial responsibility – a Federal agency must be mindful of that fact.

- Academics from universities and colleges should be fully engaged in advisory structures.

- Researchers in academe should have access to data and the necessary information for both research and education.

- Beneficial working relationships with academe can take many forms including hiring summer or co-op students, secondments during professorial sabbaticals, or government scientists serving as adjunct professors, thesis examiners, visiting faculty members, or advisors on program structure and/or content.

- Agencies may find it useful to contract research to academics (e.g. funding graduate student research), or contract education and training associated with international activities of the government agency.

- Government scientists participating in research teams involving academics can be an important way to share and further research.

9.2.5. Identifying Opportunities

- To ensure success, work must contribute to the needs and priorities of the government (See Section ES2.9 below.) and, ideally, other levels of government, industry and the international market.

- New government or other funding programs (including international opportunities to which Canada has access) should be evaluated as to their relevance to the organization's activities.

- Creating positive relationships with the media and publicizing successes should be a key activity supported at the highest levels. While perhaps once seen as unusual in a science-based organization in Government, public awareness and marketing should be part of any science program. Such activities will lead to the widest possible understanding of the science and/or technology to ensure that serendipitous applications have a greater chance of being identified.

- There may well be opportunities to contribute to foreign policy, trade and/or international development: these opportunities should be explored.

- All of the above imply that a broadly-focused and technically and scientifically aware marketing activity is required.

9.2.6. Innovation and Problem Solving

- A research and development organization must be a safe place for new ideas: calculated risk is to be encouraged.

- Do more with less – every time. One way to accomplish this is to ensure that every project or activity has more than one potential beneficiary and more than one purpose – i.e. projects should be planned to produce multiple outputs to meet multiple objectives with the same input.

- Build on the verifiable research of others – but do not do "me-too" research (research that simply proves that someone else was right in their conclusions).

9.2.7. Building Research Capacity

- Not every area of needed expertise can be covered by a Canadian – you may have to hire some people from other countries to put you "over the top."

- If the research involves natural resources or other areas that fall mainly within the jurisdiction of the provinces, consideration should be given to how or if research capacity should be built up[265] to meet provincial and territorial needs.

- A diversity of scientific backgrounds of staff can lead to a broader range of potential solutions to research problems.

- A diversity of cultural and linguistic backgrounds of staff can lead to a broader range of potential international markets, as well as a wider range of approaches to scientific questions.
- Budgets must be predictable from year to year to allow for multi-year projects.

- Capital budgets are easy to cut, but such cuts may lead to failing infrastructure in the future.

9.2.8. Putting Innovation into Operation

- **The value of a new technology comes not from its creation, but rather from its use.**

- Recognizing that there is no one appropriate approach to operationalize an innovation, various ways may be used including allowing industry access to scientists through some form of collaborative mechanism (such as an incubator), licensing, transfer mechanism to address other levels of government, etc.
- Ensure that the required suite of technology development tools and relationships are available when and as needed. For example, CCRS had sensor development expertise (scientific, engineering, and technological), test and demonstration capability, applications development expertise and wide connectivity with government and private sectors within Canada and abroad to keep its work relevant and cutting edge.
- To ensure that appropriate companies are engaged to further operationalization of the science governments should try to work with companies that have had success in commercializing R&D.

- Researchers often want a perfect or near-perfect solution. Even the near-perfect solution is often too expensive to implement: industry (or users) should be engaged early in the process (ideally at the beginning) to allow earlier commercialization and early use of the resulting technology and by so doing, be first to market.

9.2.9. Understanding Politics and Politicians

- Obtaining or maintaining financial support for a government program requires the support and interest of the political level. Linkages must be shown between the program and the important issues of the day as outlined in Minister's letters, Speech from the Throne, or policy announcements. These issues may be creating a clean and sustainable environment, job creation, increased exports, etc.

- Members of industry and academe including those active in broadly-based advisory bodies and working groups can contribute to increased visibility, awareness and understanding by the political level through outreach activities, pro-active media coverage, meeting with parliamentarians, etc.

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[265] Built up here implies the full range of activities that might be envisioned – how research capacity is organized, strengthened, structured, or enhanced.

9.2.10. International Relations

- A world-class organization must be both outward-looking and highly competitive.

- International activities must benefit international partners as well as Canada.

- Recognizing that science and the markets to apply innovation from science are international, identifying sufficient funding for international activities is critically important.

- To stake out an interest in a new or developing market for a new area of innovation, it is important to establish a leadership position in the international community. This may be done by volunteering to chair and host a new international committee or working group, lead a technical standards body, or serve as a host repository for information. This may be done through the UN, a development bank or independently. On a much grander scale, one might develop an international training institute or facility – much like the International Space University or the former ITC in the Netherlands.

- Virtually every new technology and its application must be considered in the international context in terms of the science, its application, and the market, including the potential for development assistance through Canadian and international mechanisms.

References

A note on references. With over 30 authors and over 300 references we have tried but have not always been consistent in how we format references. We have usually provided no more than three authors for any reference. Some topics have many more references than others – that is largely a case of some authors providing more background while others were more selective. Note that the ***Proceedings of the Second to Eleventh Canadian Symposium on Remote Sensing*** were refereed and accepted as such by the Natural Science and Engineering Research Council of Canada, the primary funding agency for academic research in Canada in remote sensing.

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Appendix A: Summary of Canadian Advisory Committee on Remote Sensing Recommendations 1973-1985

Appendix A: Summary of Canadian Advisory Committee on Remote Sensing (CACRS) Recommendations: 1973-1985

On how to read this table: this table covers more than 30% of the period forty-year period we are investigating. The recommendations shape almost every major remote sensing activity up to and including the two RADARSAT satellites, and often point the way to issues still seen to be important as this is written in 2017.

We recommend that the reader simply scan the table to get a sense of both the consistency from year to year and the increase in specificity of recommendations over the first few years as remote sensing and the role that CCRS and CACRS could play were better understood. A quick reading will also serve to identify the changes that occurred in what was considered important.

Year	Recommendation	Page &/or Reference	Result
1973			
	There should be a receiving station in eastern Canada	p8, 3.2.1.2	Done
	CCRS should have airborne capabilities over the Arctic and oceans	p8, 3.2.2.1	Done (CV-580, 1976)
	CCRS should develop a high resolution all-weather sensing system and microwave sensors (2 recommendations)	p8, 3.2.2.2	Done (CV-580, 1976; RADARSAT)
	CCRS should be given the responsibility & support to document/do case studies for applications in resource management and environment	p8, 3.2.3.2	Done – the basis of Applications Division
	There should be a training officer to advise regional centres, organize workshops, courses and seminars	p9, 3.2.5.1	Done some years later by Bill Bruce
	There should be a user liaison office to route enquiries to CCRS experts	p9, 3.2.5.2	Done in 1983
	There should be a marketing office for NAPL/CCRS	p9, 3.2.5.3	CCRS User Assistance and Marketing Unit (UAMU) staffed 1979
	The technical information service should be enlarged to maintain indexing and allow user access	p9, 3.2.5.4	Done in 1974
	There should be provision for lower cost recovery charges for beginning users	p9, 3.2.6.2	Not done
	Seven recommendations referred to areas where CCRS, Working Groups & Provinces could cooperate to further develop the use of RS in Canada	p9, 3.3	These were dealt with years later
	Efforts should be made to improve liaison between imagery users and producers	p10,3.4.1.3	Not done
	Users should document results of their airborne program data	p10,3.4.2.5	Done
	CCRS should support programs for improving methods to identify and delineate permafrost	p10, 3.4.4.1	Work continues on this in 2016
	Research on the electromagnetic properties of rocks, soils, crops and other types of vegetation should be undertaken	p10, 3.4.4.6	
	Pilot programs for operational ice reconnaissance and aerial hydrography	p10, 3.4.4.8	Done – led to

	should be initiated		work by Optech and Intera
	A CCRS contact should be identified to liaise with provincial contacts	p10, 3.4.5.2	Done
	There were several recommendations on improving the visibility of RS through publications, newsletters, seminars, etc.	p11, 3.4.	Done mostly ad hoc until 1984
	CCRS should have bilingual staff to liaise with outside users. (This was a recurring recommendation through the 1970s.)	p13, 3.5.4.2	Started 1975/76 See text box
	ERTSFICHE (microfiche) should be used as a quick-look tool to decide what frames (non-cloudy) should be processed on a higher priority	p13, 3.6.5	Done
	Proposals should be requested from non-gov't agencies to perform routine production and distribution of ERTS imagery	p13, 3.6.7	Done – with varying results & consequences
1974			
	CACRS should form an environmental working group to examine pilot operational systems to meet legal requirements for reporting	p6, 3.2.2.	Not done
	Careful consideration should be given to cost recovery for airborne remote sensing	p6, 3.2.3.	Cost recovery a continuing issue
	CCRS should change the emphasis from experimental to operational RS	p6, 3.3.1.	A continuing balancing act
	CCRS should fund the development of a training syllabus	p6, 3.3.3.	Done over many years
	CCRS should undertake more aggressive marketing of RS data and CCRS should staff a marketing position (2 recommendations)	p6, 3.3.4. & 3.4.12	CCRS marketing unit staffed 1979
	CCRS should foster the development of low cost image analysis systems	p6, 3.3.6.	Done indirectly
	CCRS should provide services to external users re sophisticated systems	p7, 3.3.7.	Done
	CCRS should do a detailed cost-benefit analysis of various sensing platforms to prepare for a Canadian resource satellite program	p7, 3.3.8.	A continuing activity
	Requirements and implementation plans for a Canadian satellite should continue	p7, 3.3.9.	Done
	Canada should support an open skies regime to assess world food supplies	p7, 3.3.11.	Done
	Forestry should explore the feasibility of an operational system to collect national forestry statistics using new remote sensing methods	p7, 3.3.13.	Now operational
	There were several recommendations on the importance of supporting a vigorous program on microwave, assessing SLAR (Side Looking Airborne Radar) and participation in SEASAT.	p10, 3.5.8 p8, 3.4.8. 3.4.9. and p9, 3.5.6	CCRS obtained the CV-580 SAR
	CCRS should compile and publish case studies on RS applications	p8, 3.4.15	Done – slide sets and papers
	CCRS should produce geometrically corrected CCTs from Landsat to allow multi-temporal studies	p9, 3.5.4.	1976 DICs development started
	A new Canadian ground station should be established in Newfoundland	p9, 3.5.5.	Done - 1977
	CCRS should recruit a geoscientist	p10, 3.5.12	Done 1975
	Canada should continue to participate in the RS programs of other nations, particularly the US	p11, 3.7.12	Done with US, France and ESA, not India &China
	CCRS should foster the development of standards for remote sensing that are comparable to those of the Interdepartmental Committee on Aerial Survey	p10, 3.7.18	By 1978 CCRS led world-wide efforts, not just national
1975			
	There should be studies to investigate bilateral programs with other countries to develop components of RS satellites	p5, 3.2.2.1.	This did take place over time

	There should be increased support for practical demonstrations of RS applications using digital date for operational programs like: biophysical mapping of the Arctic, extension of the Arctic ice reconnaissance season, non-visual geological applications…	p5, 3.2.1.2.	This did take place over time, and continues to today
	IACRS should encourage the development of RS expertise and facilities in specialty centres	p5, 3.2.1.3.	Development did occur, but limited
	There should be no direct competition between gov't owned aircraft (operated by an industrial partner) and those in the private sector	p5, 3.2.2.2.	Only minor complaints
	A scatterometer and SLAR* should be put on the CV-580 and the potential for Landsat/SLAR composites should be reviewed *Here we assume SLAR meant SLAR or SAR	p5, 3.2.2.3.	Done – lease of ERIM SAR in the CV-580
	CCRS should acquire the ability to obtain RS data from 20,000 m or 70,000 feet	p5, 3.2.2.4	Not done
	CCRS should examine the on-line digital data distribution systems and interchange of data with systems like the Canadian Geographic Information System	p5, 3.2.3.2.	This prescient recommendation came to pass in The work of the GeoAccess Division
	CCRS should be receptive to university requests to serve on thesis committees, consulting on methodologies of applications, sponsoring R&D, and assisting universities to obtain equipment.	p6, 3.2.5.1.	Except for equipment, all of these have been acted on for >40 years
	CACRS should establish an ad hoc committee to investigate the need for a Canadian training centre for the analysis of RS data	p6, 3.2.5.2.	Committee reported, limited action took place
	CCRS should request Atmospheric Environment Services to set up a specialty centre to report on their activities	p6, 3.2.8.1.	Done. AES embraced RS
	The Agricultural Working Group should set up a subcommittee on rangeland	p6, 3.2.8.4.	Done. Rangeland work done with users by CCRS
	CCRS should ensure the development of a low cost ($50,000) image analysis terminal to encourage wider use of digital RS data	p7, 3.3.2.1.	Applications Div. worked with industry to try to do this
	NAPL-RC and CCRS should ensure that a high level of quality control and repeatability is maintained consistently in photographic products	p7, 3.3.3.1.	Eventually the contractor was replaced
	Methods should be developed and implemented to correct for atmospheric effects on Landsat.	p7, 3.3.3.5.	Done
	Spaceborne imagery should be geometrically corrected to provide data that is readily related to existing maps This was the start of the end of topographic maps…there was a small study done of topo map sales and WorldSat products several years later that showed a decrease in map sales over every area where WorldSat produced an image map.	p8, 3.3.3.6.	Done (DICS and MOSAICS)
	CCRS should increase its efforts at marketing and acquainting the public with remote sensing capabilities (seven specific suggestions were given)	p8, 3.3.4.1.	All suggestions acted on or responded to
1976	*The recommendations for this year were fewer in number and more general in nature than in previous years. In some cases working groups suggested research priorities rather than recommendations.*		
	CCRS should have and use the freedom to adjust its budget to provide adequate support for the transfer of technology efforts by the user departments and agencies.	p34	Done. (A Tech Transfer Unit was eventually created in 1982

			under Doug Heyland)
	CCRS should strongly support the immediate acquisition of SLAR[*] systems for the Canadian operational ice reconnaissance program. [*]Here SLAR meant SLAR and/or SAR	p36, 3.10.1.4.	Done – lease of ERIM SAR in the CV-580
	Planning and technological development should continue toward the long range goal of a Canadian remote sensing satellite program	p36, 3.10.2.1	Referred to SURSAT office – predicted no action until 1979
	CCRS should continue to strongly encourage …demonstration projects and the development of these to an operational status	p36, 3.10.2.3.	Continued subject to budget
	CCRS should promote the practical application of RS (a number of potential recipients and approaches were identified	p37, 3.10.3.1	Referred to CCRS UAMU – done after several years
	User familiarization experiments should begin immediately using aircraft-borne imaging radars and complementary sensors	p37, 3.10.4.1	Done (SURSAT Office)
	A program should be initiated to sell remote sensing to the executive level of resource management agencies across the country	p37, 3.10.5.3	Referred to CCRS UAMU – done after several years
	Canadian industry should be encouraged to benefit from Canadian involvement in foreign satellite programs	p38, 3.10.6.2	Done
	A digital analysis system should be made available at CCRS for which the first priority is the user concerned with the development of operational applications of Landsat data…(such as)… operational crop forecasting	p39, 3.10.8.1	Done – Image 100.
1977	*In 1977 it was becoming clear that remote sensing was already developing useful applications and more would come with the higher spatial and spectral resolution of the US Landsat-D and French SPOT data. This CACRS meeting saw a major push to ensure that Canada obtained these better data and catalogued the value of their application. CACRS Working Groups sought a more prominent role in the selection of projects within CCRS, but this was rejected. CACRS was to provide general advice, not control. Within CCRS the Management formed the Management Advisory Committee (MAC) which met weekly. It was to advise the Director General. As one DG said a few years later "MAC is what it says – it is an advisory committee, we do not vote, and I decide what advice I take."*		
	It is essential that Canada participate to the fullest extent possible in the US NASA Landsat-D program	p.3, 3.2.1.	CCRS asked for and obtained the funds to answer this two-part recommendation
	Canada should obtain the facilities necessary to receive, process, distribute and analyze Landsat-D thematic mapper data of high quality in a timely fashion	p.3, 3.2.1.	
	CCRS should exercise the greatest influence possible to influence…SPOT and Landsat-D…compatibility to make it economically and technically feasible to receive, process, distribute and analyze the data from both satellites	p.3, 3.2.2.	CCRS met with CNES and NASA to make this happen
	A definition of "operational" suitable to CCRS and CACRS should be prepared and used by all working groups	p4, 3.3.1.	Done – a paper was prepared by CCRS
	The national remote sensing program should place emphasis on practical demonstration projects in all disciplines to as a means of extending the operational use of remote sensing	p4, 3.3.2.	Generally done by CCRS Applications Development
	Case histories relating to the successful application of RS be prepared by CCRS and outside contractors for …a major promotional drive	P5, 3.3.5.	Some done by CCRS Applic. Dev. and UAMU
	A modest marketing and promotional budget be set up and used (to)…impact certain vertical markets		

	CCRS should expedite analysis of data from test flights of the aerial hydrographic system and provide a definitive report on the overall feasibility of the project	p5, 3.4.2.	CCRS provided a detailed review of the success
	CCRS should make software for digital analysis developed in-house available to the user community at no charge as a part of technology transfer	p5, 3.5.1.	CCRS software transferred through industry & directly at no cost where it was possible
	CCRS should report regularly to CACRS on the preservation of the Landsat archive: as to what measures have been taken to protect the data from damage, deterioration or loss	p6, 3.7.5.	The issue of archive is still topical in 2017
	CACRS Working Group representatives should be included in the CCRS Project Selection and Review Committee (PSRC)	p8, 3.10.1.	PSRC is internal to CCRS Mgmt., therefore denied
	That Treasury Board be advised not to judge the success of the program on the basis of products (sold), but on benefits realized through various applications	p8, 3.11.5.	This has been a continuing issue that led to many benefit studies
	An interprovincial advisory committee should be appointed to advise CACRS	p9, 3.A	Done.
	A representative should be appointed from the two Territories	p9, 3.B	
	The User Assistance and Marketing Unit (UAMU) should be given adequate strength to act as ombudsman for the users and be responsible for keeping provincial representatives regularly posted on the national program	p9, 3.D	Done – while keeping existing contacts and responsibilities
1978	*There were more recommendations in the 1978 report than in previous years. Many of them seemed to ask CCRS (or the government in general) to do things far outside of the CCRS mandate or they required financial support that far exceeded what was possible within the CCRS budget. Usually such recommendations were eliminated before the reporting stage. It is not clear why this was not done in 1978. In any case, but for one or two examples, recommendations that have here been judged to be outlandish or of peripheral interest for this study have not been included. The reader is referred to the 1978 Report, pages 3-13.*		
	CCRS should pursue the idea under the BC Ministry of Forests (BCMF) of demonstrating the idea of a distributed information network that incorporates RS for regional environmental monitoring	p3, 3.1.1.	CCRS developed a relationship with BCMF
	The provinces suggested CCRS should establish a project to demonstrate RS data for environmental monitoring at a suitable location	p3, 3.3.1.	CCRS asked for suggestions, none came
	The Government should assume the costs of acquiring Landsat data and users only pay costs for dissemination	p4, 3.4.2.	This was the approach at that time.
	Because of inconsistent data quality CCRS should permit separate contracts for production at its various facilities.	p5, 3.6.1.	CCRS agreed to look at this issue
	While CCRS has an excellent reputation in developing countries, it should develop assistance in kind to help less developed provinces	p5, 3.6.4.	CIDA $ fund overseas projects, funds from Dept. of Regional Economic Expansion can be sought in Canada
	There should be closer liaison between the operational units of CCRS and the organizations active in RS in industry	p6, 3.7.4.	UAMU is meeting industry
	CCRS should assign high priority to R&D towards establishing direct links between digital analysis and computer information systems	p7, 3.9.2.	R&D is being done in CCRS

			Methodology
	Adequate funding should be given to Canadian industry to design and produce an advanced imaging radar	p7, 3.10.1.	CCRS will keep the ERIM SAR and convert one channel to C-Band
	Present R&D on the use of field spectroscopy to evaluate crop parameters be supported and continued	p7, 3.10.3.	CCRS has developed a mobile lab to do this
	An operational Canadian crop information system should be developed through the efforts of Agriculture Canada, CCRS, AES and others and that the government of Canada provide the funding and manpower to implement the system	p9, 3.11.8.	CCRS cannot fund a fully operational project, but can do a demo
	CCRS should act upon …the recommendation of the (1977) recommendation for the establishment of a grants system to assist universities	p12, 3.17.	CCRS cannot legally provide grants, & lacks $
1979	*As was the case at the 1978 meeting, there were many recommendations in the report. A number were reported even though they were either defeated or withdrawn. Many other recommendations related to products, support for specific publicity material or interest groups were referred back to the group that submitted the recommendation. Few of these ever came to light again. None of the defeated or questionable recommendations are included here.*		
	The following were identified as potential demonstration projects: 1) Alberta Grassland; 2) BC Forestry Service Monitoring of Forest Change; 3) Yukon Wildlife Habitat Study; 4) Insect Defoliation in Maritime Conifers; 5) Aerial Hydrography; 6) Ice activity in Newfoundland Vicinity.	p4, Note 2	Except for (3) all of these were eventually done – several as major activities
	There was significant discussion on the role of Working Groups and how CACRS should be organized in the future.		
	CCRS should be involved in discussions with other countries about Canada's participation in other countries satellite programs (e.g. ESA and USA	p6, 3.1.1	CCRS was so involved and helped start CEOS
	An RS satellite program that meets Canada's needs should be part of Canada's space program to foster a healthy space industry	p6, 3.1.2	RADARSAT
	Canada should develop as a first priority an all-weather RS satellite	p6, 3.1.3	RADARSAT
	CCRS should review the needs and capabilities for archiving Landsat data	p7, 3.2.1.	A data archive has been a CCRS focus up to the present
	Laser bathymetry should be given a high priority	p8, 3.4.2.	This led to the commercial work by Optech & Terra Surveys
	Canada should give the highest priority to the development of synthetic aperture radar systems for satellite remote sensing	p9, 3.4.5.	RADARSAT
	Priority should be given to obtaining the highest resolution satellite data of Canada from all future platforms	p9, 3.4.6.	This goal led to SPOT 10M data, but limited acquisitions after
	It was recommended that ISIS (the company that was producing satellite data on contract to CCRS) be advised to improve quality control to prevent poor quality imagery being sent to the user.	p10, 3.5.2.	CCRS took over production – (complaints were reduced to almost

			zero)
	CCRS should investigate the routine production of large scale enhanced Landsat products at, for example, 1:50,000	p13, 3.8.9	Experimental images were produced. There was no market.
	The provincial and territorial advisory body should play an active part in the technology transfer program of the federal government	p13, 3.9.1	This was done in 1982.
	Because of its experience and reputation in thermography for energy conservation CCRS should monitor and support those entering the field	p14, 3.9.4	CCRS could not monitor, but it was willing to advise
	Since Landsat-D Thematic Mapper data will be critical in the Maritimes, CCRS should ensure full availability	p14, 3.10.1	CCRS submitted a proposal to Cabinet that was approved (see 1980)
1980	*The discussion at the 1980 meeting revolved around new programs, ramping up production of data to meet operational needs, technology transfer and preparation of materials and projects to promote the increased use of remote sensing. There was also discussion on reorganizing CACRS for by this point the provinces had become a more important part of the national remote sensing community. There was also push-back by CCRS in areas where CACRS delegates suggested that they wanted to directly influence the internal management of CCRS.*		
	CCRS give high priority to arranging participation in the SPOT program	p5, 1.1.	
	The federal program should prepare to expand to receive and process Landsat D data	p5, 1.2.	Funding was approved
	A crop reporting information system using RS be implemented by 1984/85	p7, 3.2.	Work began in 1980 with success at StatCan in 1981/82
	CCRS should submit a feasibility study on inclusion of an optical sensor on RADARSAT.	p8, 4.1.	Approved and done by the RADARSAT Project Office
	Given the number of firms offering RS image acquisition services, CCRS provide technical assistance and quality control	p9, 5.1.a.	CCRS cannot provide QC, but can provide occasional advice
	Action should be taken to reduce the time required to receive an imagery order	p9, 5.4.	Delivery improved by a production line at Prince Albert
	That the MOSAICS project be operationalized as soon as possible	p10, 8.2	Phased-in operation began in 1986
	That more CCTs (especially DICS) be produced faster (4 per day, 7 day turnaround) for agricultural users	p10, 8.3.	Faster output than was called for was ready for 1981 crop season
	CCRS and the Maritime provinces should provide human and technical resources for technology transfer and applications development	p10, 8.3.	This was done under the TEP
	CCRS should ensure that image analysis software developed for it should be readily transportable to other systems This was one of the early discussions of compatibility of software. CCRS became a pioneer in the transport of geo-information	p11, 9.6.	A lengthy report on this topic was prepared by Dr. Goodenough.

	There should be a quality demonstration project in Atlantic Canada to overcome the caution that has resulted from previous failures	p11, 9.7.	The Technology Transfer Program developed projects
	Industry should be involved in RS developments ready for application and a strong program should be developed to transfer RS technology to the end user	p12, 9.9.	CCRS developed a unique program to transfer RS to industry & users
	CCRS should give priority to obtaining higher resolution data from other countries (inference was to SPOT)	p12, 10.1.	CCRS obtained SPOT 10M data
	Given the importance of CACRS in exchanging ideas leading to RS applications, future CACRS meetings should focus on the exchange of information and ideas	p13, 11.3.	Presentations on key topics were given at future meetings, but symposia were seen as better to meet this need
	A directory should be produced on RS-related facilities available in industry, government, and universities	p14, 11.7.	A directory was produced, but was not updated on a regular basis
	CCRS should take action on the 1979 recommendation for the production of a brochure on operational RS techniques	p14, 11.9.	Brochures were produced on forestry & geology by Jan1982 and for agriculture in 1982
	More RS research should be commissioned by universities and some minimal funding would be required	p15, 12.3.	CCRS cannot provide grants to support research, but it can issue contracts for specific tasks
	Increased emphasis should be placed on the application of RS to oceanographic and near-shore phenomenon	p2, 1.3.2.bi	CCRS worked with DFO to do more work in this area
1981	*There were over 70 recommendations made at CACRS for 1981. Only twelve are reported here. Many of them were in support of RADARSAT or other initiatives – most of which required financial support and which were referred back to the proponents with advice to seek funding themselves. In other cases the proponents were advised to submit their ideas to the agencies that had the mandate for the area addressed by the recommendation. Topics such as continuity of data, cost of data, technology transfer and training activities and increasing the visibility of remote sensing were all addressed by two or more suggestions or recommendations. Industry representatives were also present, expressing an interest in offering RS services.*		
	The second sensor on RADARSAT should be a steerable Visible IR Scanner	p5, 3.1.1.	The proponents were advised to submit a brief to the RADARSAT Project Office
	CCRS should ensure that there are adequate manpower and financial resources in future SAR programs to develop land applications such as in agriculture at Melfort , Saskatchewan	p5, 3.1.3.	CCRS suggested submitting a project – work was eventually done in Melfort

	CCRS should assess the best means of making RS training materials available	p5, 3.1.6.	Materials were developed over time by the Tech Transfer Office
	Canadian educational establishments be assisted in developing 3 day to one month long RS courses such as are given in the US	p7, 3.2.7.	A contract to assess such needs was let
	The Treasury Board's "Benefit-Coast Analysis Guide" for evaluation of economic benefits be distributed to CACRS members	p9, 3.4.6.	The summary was circulated
	CCRS should provide the necessary financial, equipment, data, and technical manpower to support a full-scale technology transfer program	p10, 3.6.2.	A proposal was presented and funding obtained – with 5 staff by 1989
	CCRS should prepare suitable educational packages for RS applications	p12, 3.8.4.	A program to do this developed over time
	The cost implications of the new generation of satellites for image processing and availability of systems should be evaluated by CCRS	p12, 3.8.5.	A report on this was given to CACRS in 1981
	Given that education is a provincial responsibility, CACRS should ask provincial and territorial members to explore how they may help educational institutions improve RS teaching in their provinces	p12, 3.9.3.	A report was to be prepared by V. Zsilinszky
	Canada should acquire a ground-based scatterometer and radiometer to carry out microwave studies in support of applications development	p12, 3.10.2.	This was done
	The Applications Division of CCRS should perform or cooperate in research related to machine classification of digital SAR data of sea ice	p13, 3.11.2.	A project was developed
	The potential of SPOT data for mapping should be evaluated	p14, 3.13.2.	This had already been done by CCRS using simulated data
1982	*The theme for 1982 was "New Initiatives in National Remote Sensing Program." There was a panel of representatives of ten companies that offered comments on the national program. Data continuity and new data sources of data provided one of the foci. Technology transfer was also a major topic – noting that government rules prevented technology transfer by CCRS. (Hence the name of the new program being "Technology Enhancement Program.") Of 64 recommendations made, 55 could be dealt with by CCRS and the rest were referred to IACRS.*		
	CCRS should prepare a contingency plan to assure a continuous supply of Landsat-4 MSS and TM data	p5, 3.1.1.	A plan was being prepared
	Priorities for Landsat data and airborne MSS data should be coordinated by a committee of representatives of the provincial and federal gov'ts, industry and universities.	p5, 3.1.2.	CCRS agreed
	CCRS should maintain a strong involvement with the Landsat and future SPOT program	p5, 3.1.3.	CCRS agreed
	With the closer of the Shoe Cove Station every effort should be made to provide Landsat and NOAA data to Eastern Canada as timely as required and cost-effectively with a full archive to allow back ordering. Several similar recommendations were made related to the Shoe Cove Station closure and the rising cost of data	p5, 3.2.1. to 3.2.4. and p6, 3.3.2.	CCRS made arrangements with the US to obtain data. Data cost was outside of CCRS control
	Support for the Technology Enhancement Program in the development of information products should continue	p6, 3.4.1.	This was referred to IACRS
	Quebec recommended that CCRS should reserve funds to support technology transfer to industry	p6, 3.4.3.	An agreement was signed under the aegis of the

			NRC's PILP Program
	CCRS should ensure that funds are available for the Technology Enhancement Program to continue in the Maritimes after March 31, 1984	p6, 3.4.4.	CCRS asked for (and received) additional funds
	Given that most users of RS are government scientists it is recommended that government scientists be involved in exchanges to work in industry	p7, 3.4.5.	A number of exchanges and transfer mechanisms were developed
	CCRS should offer the opportunity for visiting scientists and resource managers to work on new initiatives. (The next recommendation applauded CCRS Applications Development Section for work with the user community	p7, 3.4.5.	This became a key component of how CCRS worked
	CCRS should not make duplicate CCTS from the original data since the originals deteriorate. Rather, CCTs should be copied from the first CCT made. (preservation of data has continued to be an issue)	p8, 3.6.5.	Funds were not approved to do this at that time
	CCRS should keep users better informed such as Canada's failure to advise users that it would have no capability to process Landsat-4 TM data until two years after launch, nor were users informed about changes in the CCT format	p8, 3.6.6.	CCRS noted the problems and promised to do better in future
	CCRS should investigate the use of microcomputers (i.e. PCs) in RS to provide direction, coordination and assistance	p9, 3.6.12.	Others led the drive to use PCs
	CCRS should continue negotiations to acquire SPOT data	p10, 3.8.1.	CCRS did
	Research is needed to develop applications software and algorithms	P10, 3.9.1.	This R&D continued with the LDIAS
	CCRS should be careful privatizing data production and privatization should be delayed	p10, 3.10.1.	CCRS delayed privatization
	A brochure or movie should be prepared to inform potential international buyers, especially in developing countries, of the RS services available from Canadian private industry	p10, 3.10.2.	CCRS asked for proposals. Was eventually done in 1987 by UAMU
	The Association Quebecoise de Télédétection (AQT) recommends that representation at CACRS reflects the proportion of Canada's Francophone population. The CQCT, AQT and CCRS should meet to ensure better representation at CACRS.	p11, 3.11.2. and 3.11.3	CCRS agreed & a meeting was arranged for 1983
	The national RS program should give funding for RS education and support institutions that do not have the resources to advance RS	p11, 3.12.2	NSERC has $, this is not in the CCRS mandate
	Low-cost lab materials should be prepared for instruction at technical schools. A series of adequately documented teaching sets be developed for Radar, multispectral and thermal imagery	p11, 3.12.3. & 3.12.4.	CCRS suggested this could be done by industry and provinces. They & CCRS did some
1983	*The emphasis in 1983 was on the economics of remote sensing in Canada – a number of economic studies were presented by an expert panel. There was again concern expressed about access to data in Eastern Canada, and support for the Technology Enhancement program. For the second year in a row personal computers were mentioned as being important in the future. The budget difficulties could be seen in the many requests for funding from CCRS for everything from sponsoring workshops, doing more marketing, and supporting specific projects proposed by the working groups – and the generally negative response to such requests. There were, however, some bright spots and advancements.*		
	IPTASC recommends that CCRS re-open talks with NOAA to gain	p7, 3.1.1.	CCRS was not

	reception rights for Landsat data over eastern Canada. (There were other recommendations related to the concern for data access over Eastern Canada.		hopeful – there is no budget for reception fees
	The Interdepartmental Committee on Space (forerunner to the CSA) through CCRS should be aware of the requirement for timely Landsat MSS data over other countries for grain marketing	p7, 3.1.2.	CCRS advised IACRS…in fact MSS data were never used for this application
	CACRS and IPTASC should develop strategies to promote the use of RS in operational programs of the provinces and territories in forestry, agriculture, land-use monitoring, crop inventory, studies of water resource quality and wild life ecology	p8, 3.3.1.	IPTASC was so advised. ADS has been given more resources & TEP is also a response
	CCRS should sponsor a series of workshops on RS applications in resource management	p9, 3.3.2 Several different requests were given in this one section	Workshops can be given through the CRSS
	CCRS should avail itself of the growing expertise outside CCRS in technology transfer		The TEP already does this
	CCRS should foster the use of personal computers (PCs) in remote sensing applications and make Landsat data available on media suitable for PCs. A similar request was made on page 13, section 3.13.1		CCRS was responding to this in several ways
	An agreement with SPOT-Image should be finalized as soon as possible so Canada can play a major role in this program	p9, 3.4.1.	A CCRS/SPOT MOU will be signed soon
	CCRS support should be given to a study on the capabilities of available technology for ice reconnaissance	p10, 3.6.1.	CCRS will do this, budget permitting
	CCRS should involve itself more in oceanographic RS studies	p10, 3.6.3.	CCRS hired an oceanographer in 1983 (M-C. Mouchot)
	CCRS should take steps to ensure that all RADARSAT and ERS data are archived	p11, 3.7.2	All data will be archived
	The agricultural working group will have three sub-committees: agriculture-Radar (in support of RADARSAT); Rangeland, and Crop Information Systems	p11, 3.9.1.	This was done and reflected the work at CCRS
	CCRS should continue to evaluate sensors and/or topics of interest to the ice community including: multi-frequency airborne SAR, HF radars, surface-based marine radars, sonar for beneath ice, etc.	14, 3.14.1	This request was to the CCRS PPEU
1984	*The 1984 CACRS meeting had as it focus the approval of a proposal for planning the involvement of industry in the reception, processing and marketing of remote sensing data in Canada. The meeting saw the usual concerns about access to data, data continuity and funding for projects proposed by attendees The meeting was unusual in that part of the meeting was held under the security level of "Canadian Eyes Only." This meant that only Canadians could attend that portion of the meeting and the results and decisions were not made public, nor was it generally known what the plan entailed. The "Canadian Eyes Only" portion of the meeting approved an aggressive marketing plan for CCRS and Canadian industry. The plan was presented by the head of the UAMU. The plan, to be rolled out over a period of a number of years, aimed at increasing sales by Canadian industry internationally. It proved to be far more successful and obtained far broader support from other government agencies than was initially anticipated. It is regarded as a model that might be applied elsewhere.*		
	The issue of incomplete data over Atlantic Canada was raised in several recommendations	p7, 3.1.2. 3.2.1., 3.2.3	CCRS has tried to obtain data
	A commitment should be made to complete RADARSAT for a 1990	p8, 3.3.1.	RADARSAT

	launch		was launched Nov. 4, 1995
	The airborne C-Band radar should be made operational for the 1985 field season	p8, 3.3.2.	The system was ready for March, 1986
	CCRS should ensure that sufficient funding be available to make the Ground Microwave Lab operational	p8, 3.3.4.	The funds were secured
	CCRS should provide data on a per pixel or other basis for small volume users	p8, 3.4.1.	Sent to UAMU – not done
	CCRS should support the five university programs in RS in Canada through the EMR Research Grants Programme of EMR	p9, 3.5.1.	CCRS does not offer grants, but supports R&D in other ways
	CCRS should provide experts to and pressure on NSERC to support RS research	p9, 3.5.2.	CCRS met with NSERC
	CCRS should maintain a strong airborne program for the collection of multi-spectral (MEIS-II and MSS) and LiDAR data for studies of the atmosphere, geometric correction and resource management	p9, 3.6.1.	CCRS will continue best efforts
	CCRS should continue and expand its support of research to develop case histories of geo-botanical remote sensing in Canada	p10, 3.7.1.	CCRS continued work in this area
	The Oceanography WG suggested that CCRS should place greater emphasis on oceanic applications of RS such as relating sea surface temperature to fish stocks	p10, 3.7.2.	CCRS awaits the WG report before redirecting R&D
	CCRS should lead the coordination of the investigation of diverse sensors for ice remote sensing	p11, 3.7.4.	CCRS is hiring an ice specialist & notes an ice RS project data base at C-CORE
	CCRS should apprise CIDA of Canadian (government and industry) expertise in remote sensing and land evaluation and rangeland applications	p12, 3.8.4.	CCRS is working with CIDA and will explain these
	CCRS should publish the Manual on RS of Rangeland by Watson and VanRyswyck	p12, 3.9.1.	CCRS Tech Info was advising
	CCRS should publish an illustrated compendium of RS applications like "Landsat for Monitoring the Changing Geography of Canada"	p12, 3.9.2	CCRS published brochures but industry did more (e.g. image maps & book Satellite Images)
	CCRS research priorities should reflect the following: it is important to link RS outputs to GIS's, geometrically corrected data will be needed to link to GIS's; spatial classifiers will be needed for the next generation of satellites; and expert systems will have to be integrated into the next generation of image analysis systems	13, 3.10.1	CCRS is responding with work in Methodology Section
	CCRS should direct the necessary effort to ensure the rapid development of Micro (PC) based image analysis software through cooperative development programs with the private sector	p13, 3.11.1	CCRS is supporting this with contracts to several companies
	CCRS should conduct a study of laser disk technology (and other low-cost media) to input RS data to micro-computers.	p14, 3.11.3	CCRS is following media developments
	Commercial organizations concerned with cost-effective applications of RS should be more fully represented in on the CACRS working groups and at the annual meeting	p16, 3.15.5.	CCRS reported that 26.3% of all WG members are from industry

1985	*By the time of the 1985 meeting the winds of change from the Neilson Task Force and Program Review (Aspinall et al, 1986) were beginning to blow and budgets were tighter. This is reflected in many of the CCRS responses to recommendations such as "CCRS is doing what it can with limited funds," or "there are no funds." Budget cuts also could be used to defend lack of action (or response) on some of the suggestions made. While optical work was still seen as worthwhile, it was also clear that CCRS was beginning to focus on microwave.*		
	An ad hoc committee should be established to introduce SPOT imagery by obtaining information on the data, policies and restrictions; assessing the need for new software, and coordinate research	p7, 3.1.2.	Existing groups should do this. CCRS will send out information
	Given proposed cutbacks to the airborne program, it should be evaluated by an independent consultant based on the long term impact of the program	p8, 3.1.4.	CCRS MAC will determine if $ are available for this
	Efforts must continue to ensure the planned microwave airborne system is available for early in 1986	p8, 3.2.1.	It was available in March 1986
	Attention should be directed to RS to assist with 1:50,000 mapping north of 80^0	p9, 3.3.3.	CCRS is doing what it can with limited funds
	CCRS and other funding agencies should support research on narrow-band sensors for crop condition and soil mapping	p9, 3.3.5.	CCRS agrees, but has limited funds
	Three areas are recommended as important areas for research: TM and SPOT for parkland and range; NOAA for rangeland and drought assessment; and quantitative estimates of biomass in native and tame forage	p10, 3.3.7.	CCRS agreed & encouraged the WG to do the research
	If the US receiving station moves from NASA Goddard to central US, Gatineau should provide coverage for Eastern Canada	p10, 3.4.2.	CCRS cannot afford fees for 2 stations
	CCRS should establish low cost fees for data for universities	p11, 3.5.2.	CCRS provides a tape library for use in teaching
	A relationship should be established between the Rangeland committee of the Ag WG, CCRS and CIDA to promote Canadian expertise internationally	p11, 3.6.1.	Referred to CIDA
	The provincial RS centres should make a deal for a standing offer of all cloud free Landsat data in 10 x 10 inch colour transparencies	p11, 3.6.2.	Industry will provide imagery in future
	(1) CCRS should continue support for MEIS for spectral geobotany research; (2) support to develop and provide access to special software to process high res MEIS data and (3) support research outside CCRS with its airborne program	p11, 3.7.1. & 3.7.2. & 3.14.3.	CCRS is doing (1) and (2) but (3) airborne focus is on radar
	CCRS should provide person years and $ for internal studies and external proposals to develop methods and algorithms to ensure proper interpretation of radar data including scattering models for ice	p11. 3.8.1	There are no funds for this now
	Siting of ground stations should be optimized for oceans as well as land & US obtained data should be accessed to complement data obtained directly in Canada	p12, 3.10.1	CCRS will keep this in mind
	Funding for the provision of a dedicated ocean data management system be included as part of the RS submission to the Canadian Space Plan	p12, 3.10.4.	Very little money available for this in the Space Plan
	A subcommittee of the Agriculture WG evaluate hardware and software of GIS's and suggest ways to incorporate RS into such systems with emphasis on micro-computers	p13, 3.11.2.	CCRS agrees but this needs a more general approach, not just agric.
	CCRS should provide software at cost to anyone, especially data format	p13, 3.11.3.	This raises issues

	as well as Landsat TM data		of copyright – referred to CCRS MAC
	CCRS funding should continue for research projects to sustain and provide credibility for geo-botany research in Canada	p14, 3.14.1.	Projects are selected on each projects merits
	An optical scanner should remain a high priority for RADARSAT	p14, 3.15.2.	CCRS must get $ from industry – thus the market will likely decide
	With the completion of the TEP in the Maritimes, CCRS should increase support for RS in education, research and industry in the region	p15, 3.16.1.	CCRS will try to do so

The text box below, drawn in part from a history of remote sensing (Ryerson, 1999), provides further background to the 1973 and 1976 recommendations on the use of French in CCRS.

CCRS and Bilingualism[1]

CCRS is believed to be one of the first science and technology agencies of the Government of Canada not based in Quebec to embrace bilingualism. While minor in-roads had been made prior to 1976, the main impetus came in that year.

"In 1976 one of the recommendations from Quebec, which presented its report in English and French, focused on the English nature of the Centre and its publications. In essence the complaint was that that Quebec could not easily make use of much of what had been done in CCRS or the rest of Canada. At the same time it became apparent to those working strictly in an English milieu that there was also a loss to the program since a great deal of good work was being done in Quebec to which a Anglophones did not have access. Foremost among applications was the innovative monitoring of the 135,000 square miles of the James Bay Hydro Development. By 1976 only a few Francophones occupied senior scientific and managerial positions[2]. Shortly afterwards a number of Francophones joined the Applications Division of CCRS[3], greatly enriching the quality and range of work to which CCRS had access and which it could disseminate in what was then a truly national program. Eventually CCRS was to make working in French a viable option for its staff, and young scientists could feel at home in at least part of the organization."

Over time some working groups reported in French, and the main CACRS report was produced as a bilingual document. CCRS Management Meetings were still primarily conducted in English, although French was often used. By the 1990s 40% of the management team was Francophone, and many of the other participants were functionally bilingual.

[1] The material in quotes is drawn from Ryerson, 1999, p. 433.

[2] In the early years of CCRS before 1976 there were but a few Francophone employees and these were in effect forced to work in English. Those we can recall included Bob Hamelin who was the CCRS driver and in charge of the stock room, Florian Guertin a young engineer, and Jean-Claude Henein who was involved in planning. Guy Rochon, later a well-known businessman, joined for a short time as the first Francophone applications scientist in 1975. Were there others in 1973-75?

[3]Those who joined following the 1976 recommendation included Dr. Monique Bernier and Christian Prevost. Over the years many more Francophone scientists joined CCRS including Thiery Toutin, Marie-Catharine Mouchot, and fluently bilingual Drs. Philippe Teillet and Marc D'Iorio. For a brief time Dr. D'Iorio was Director General of CCRS.

Appendix B: SAR History Paper Source Data

Chuck Livingstone and Bob Hawkins

March 14, 2017

Editor's Note: This Appendix provides a timeline for SAR development in Canada with a focus on CCRS and its international partners. This formed the basis of a paper given at the Canadian Symposium on Remote Sensing and the ASAR Workshop, June 2017 (Livingstone, 2017) which is in turn the basis for Section 6.7.2.2 of this document.

1. Early days:
    a. CCRS start in 1970 with the Mission to develop and promote remote sensing technology for Canada and to foster the development of a Canadian remote sensing industry.
    b. Focus on airborne systems as platforms
    c. Sensor development: Optical
    d. Applications development: space and airborne optical images Landsat 1, 1972
2. CV-580 purchase 1974
    a. CCRS had three aircraft that had been modified as optical R&D platforms and proceeded to acquire and modify a former Johnson & Johnson long-range executive aircraft airframe, power and navigation systems to create an R&D platform suitable for radar research.
3. The ERIM (Environmental Research Institute of Michigan) SAR (synthetic aperture radar) was installed in the CV-580 aircraft in 1976 and was commissioned in 1977
    a. Fully analogue R&D radar signals were recorded as Fresnel zone plates in fine grained 70 mm film. Optically processed to images by ERIM
    b. The radar was an analogue instrument and had few digital components. The operators sat in 3 chairs to run it
    c. The aircraft was maintained and operated by Innotech Aviation. The radar was operated under contract by a number of firms including F.G. Bercha and Associates and Intera after 1978. CCRS scientists, engineers and technologists were intimately involved in the radar maintenance and upgrades..
4. Surveillance Satellite SurSAT program 1977 to 1979
    a. Spawned from the report to cabinet Satellites and Sovereignty 1975
    b. Work was triggered by the upcoming launch of SEASAT-A and a growing interest in the possible use of radars as remote sensing sensors .
    c. Program focus: investigate possible remote sensing applications of SAR (natural terrain) and build a framework for Canadian industrial engagement.
    d. Investigate a need for a Canadian space-based radar capability
    e. Roy VanKoughnett led the SurSAT program.
    f. Identify sea ice as a driving focus for future Canadian SAR
    g. Spawned the RADARSAT project office in 1980 to develop initial requirements and cost estimates for a Canadian SAR satellite.
5. SEASAT-A 1978
    a. 105 days functioning on orbit. Firmly demonstrated the possibilities for space-based SAR in earth observation.
6. SEASAT-A proc 1979
    a. MDA developed a digital processor for SEASAT-A SAR data.
7. 1978 Intera won the contact to operate the CV580 equipment and support flight planning
8. RADARSAT project office spawned from SurSAT project office in 1980 to develop initial requirements and cost estimates for RADARSAT-1

a. Multiple government departments
b. International discussions
c. Industrial discussions

9. 1980 CCRS redesigned the SAR 580 antenna control for a two axis azimuth-elevation drive and built the first version of the existing drive platform.
10. 1981 HDT recording (ERIM pre-summer, time expansion buffer and 14 track HDDT recorder) and a low resolution real-time processor was built under contract to CCRS by MDA. The digital recorder and real time processor with a dry silver paper (laser) display were installed in the CV-580. Digitally recorded data volume was constrained. Resolution reduced by pre-summing I,Q data from the 4 bit ADCs.
11. 1981 A C band SAR channel added. Only L or C could be operated at any one time with the master X-band radar.
12. 1981 European SAR campaign (Intera organized and provided logistics support) (2-Jun-1981 to 25-Jul-1981)
    a. Objectives: investigate SAR technology for remotes sensing of a variety of surface types. Make quantitative measurements.
    b. Results were mixed. The radar was not stable enough to hold a calibration. Radar configuration was still an art.
    c. Started intense investigations into the limitations of the CCRS-ERIM R&D SAR system and identify equipment upgrades needed.
13. 1981CCRS studies to replace the ERIM SAR begin (MDA and CAL contracts)
14. 1981 CCRS scatterometer and radiometer studies of sea ice demonstrated quantitative microwave measurements could characterize seasonal ice type and growth phase.
    a. The sea-ice results had a major impact on the development of radar scattering models.
    b. It was decided that the next generation of remote sensing SAR instruments must support quantitative measurements.
15. 1981 NASA SIR-A mission
16. GSAR prototype 1982
    a. Modified version of the SEASAT-A processor. Perkin Elmer computer, could create a 5k, x 10 km 16 bit SAR image at 3 m resolution in 69 minutes. MDA-DLR interactions started
17. 1982 ComDev C-band SAR antenna built
    a. SAR C-band mode now has a good SNR
18. 1982 Start of the CCRS / MDA SAR requirements definition and specification development
19. 1983 Intera STAR-1 SAR imager based on ERIM design and lessons learned from CV580 R&D. Relatively stable imaging tool. Limited R&D capability. Good data delivery. Ice Service contracts. Test direct data downlink services.
20. 1983 CV-580 ADAS replaced by MAID flight and sensor data monitoring system and became the primary auxiliary data source to support SAR data analysis.
21. 1984 SIR-B SAR mission
22. 1984 MIZEX Greenland marginal ice experiment provided extensive SAR imagery of ocean features and the marginal ice zone using the CCRS SAR system.
23. 1984 ESA Windscatterometes Calibration, L'Orient France, 4-Feb-1984 to 2-Mar-1984
24. 1984 CV-580 SAR flights in support of DLR SAR development research.
25. 1985 EMR proposal to build a Canadian SAR satellite $770 M
    a. Multi-partner discussions to 2000 ($ 540 M estimate outcome)
    b. Canadian Space agency control 1990 (CSA was born May 10, 1990 with an initial budget of $484 M)
    c. RADARSAT-1 Launch 1995 ($681M estimated actual cost in 2002)
26. 1985 ComDev builds X-band SAR antenna.
27. 1985 SAR RTP output downlink from the CV 590 to Beaufort-sea ships successfully tested

28. 1977 to 1985 Development of SAR mission planning and execution processes and SAR data analysis and SAR image interpretation technologies for a wide range of application areas
    a. Create a tightly linked government industry team to plan and conduct SAR data acquisition
    b. Develop capabilities for field maintenance of the SAR system
    c. Document and upgrade the SAR equipment
    d. Develop improved SAR signal processing capabilities for digital data
    e. Develop SAR remote sensing expertise for Forestry, Agriculture, Hydrology, Mapping, Oceans, Sea Ice,
29. 1985 The ERIM SAR was decommissioned and returned to ERIM
30. 1985 JPL Convair-990 burns on runway
31. 1986 Alamaz T launched
32. 1986 Gatineau satellite receiving station commissioned
33. 1986 MDA C-band SAR installed and commissioned in the CV-580
    a. Requirements definition started in 1979
    b. Installation was delayed by CAL problems in commissioning the Space Microwave high-power (64 kW) C-band transmitter.
34. 1986 Radar Data Development Program starts.
    a. Develop SAR applications science
    b. Develop SAR processing, analysis and information extraction technologies to support ERS-1 and RADARSAT SARs
    c. Use intensive airborne SAR acquisitions to provide development data that is coordinated with surface observations.
35. 1986 Start of the CCRS SAR calibration work and start of quantitative airborne SAR applications research in preparation for the ERS-1 SAR launch in 1991
36. 1986-1991 FG Bercha holds operator contract with CCRS
37. 1987 Alamaz T-2 launched
38. 1987 MDA X-band SAR was installed and commissioned in the CV-580
    a. Desired high power transmitter was refused by CCRS management and a 5 kW unit was acquired to save money.
        i. Attempts to replace the X band transmitter failed for funding reasons and the X-band system fell out of use because of low signal to noise. (estimated net savings < -$300K)
39. 1987 Intera STAR-2 X band radar commissioned
    a. Based on the MDA design for the CCRS SAR
    b. HH polarized waveguide array antennas
    c. Radar image output.
    d. Designed for operational use in ice monitoring
40. 1987 CV-580 SAR experiments in Europe in preparation for ERS-1
41. 1988 JPL AirSAR development, DC-8, PolSAR, TOPSAR and ATI extensions
42. 1988 X Band polarimeter investigations with the CCRS CV-580 SAR
        i. Single circulator Raytheon X-band switch testing and calibration Dec 1988
        ii. Flight tests Jan to Apr 1989
    b. Start C-band polarimeter design
    c. MPB tests of C-band antenna, radome combination (Oct 1988)
43. 1989 SIZEX experiment SVALBARD 13-Feb-1989 to 28-Feb-1989
44. 1989 ComDev C-Band Polarimeter switch development
    a. 1989 UK flights (5-Aug-1989 to 24-Sep-1989)
    b. Start design of interferometer upgrades to the CV-580 C-band SAR for single-pass interferometry.
        i. Side mount antenna,
        ii. InSAR interface
        iii. Processing software

45. 1989 RADARSAT International (RSI) starts operation to prepare markets for RADARSAT-1
46. 1990 Start design of a side radome for interferometry
47. 1990 SPAR Aerospace contract to build RADARSAT-1
48. 1990 Airborne C-band SAR calibration
49. 1990 Airborne SAR repeat pass interferometry demonstrated at CCRS
    a. This was first pass to pass interferometry of any kind, airborne or satellite.
50. 1991 CV-580 SAR along-track and across track interferometer antenna and interface commissioned.
    a. The antenna was two weighted strip-line arrays mounted at a dihedral angle of 2° to cancel the weighting squint.
51. 1991 Ashtech GPS receiver installed (November?)
52. 1991 ERS-1 SAR launched. ERS-1 experiments with CV-580 C-band SAR start.
    a. CV-580 / ERS-1 cross calibration experiment
    b. Data reception at the Gatineau and Prince Albert receiving stations
53. 1991 Spar Aerospace contract for RADARSAT-1
54. 1992 CV-580 SAREX mission to Central and South America (1-Apr-1992 to 2-May-1992)
    a. ESA funded program
55. 1992 Shirley's Bay calibration array installed
56. 1992 J-ERS-1 Launched 11-Feb-1992
57. 1992 CV-580 spatial (across-track) interferometer demonstrated at Kananaskis and Bylot Island
58. 1992 C-band polarimeter commissioned on the CV-580 SAR
59. 1993 GlobeSAR CV-580 Mission (8-Sep-1993 to 18-Dec-1993)
    a. Fred Campbell is the government organizer
    b. Asia, Africa, and Middle-East sites in 10 countries (China, Jordan, Kenya, Uganda, Tanzania, Malaysia, Morocco, Thailand, Tunisia and Vietnam.)
    c. Local ground support and training by CCRS to develop the capability to use data from RADARSAT-1
60. 1993 CV-580 polarimeter calibration
    a. Develop polarimetric SAR calibration approach that has become a standard.
61. 1993 High-power (64 kW transmitter replaced by medium power 16 kW transmitter for C-band
62. 1993 Bay of Fundy current maps using CV-580 ATI. Uncharted sea bottom dune field discovered.
63. 1994 Bay of Fundy CV-580 Along Track Iinterferometry demonstration
64. 1994 SIR-C Altona under-flights by the CV-580 SAR to support remote sensing applications development.
65. 1995 C and X band HDDTs are replaced by a cartridge type Helical Scan Recorder (HSR) (February)
66. 1995 Resolute Bay polarimetry flown by the CCV-580 Dar system as part of SIMMS project (April, May). Bylot Island InSAR flight is part of this deployment
67. 1995 MARCOT experiment (May) polarimetry for ship detection
68. 1995 ERS-2 Launched
69. 1995 RADARSAT-1 launched
    a. Single polarization wave guide antenna
    b. TWT transmitter
    c. Multiple modes
    d. ScanSAR experimental mode
    e. The system design supports commercial SAR operation
70. 1995 Intera moves to the USA as Intermap
71. 1996 CCRS moves SAR research focus to the exploitation of RADARSAT-1 data and other commercial satellites. Sensor development activities terminate.
72. 1996 CV-580 transferred from CCRS to Environment Canada
73. 1996 CCRS reorganized. Limebank Rd facility closed. No further sensor development.
74. 1996 CCRS high throughput polarimetric SAR processor completed

75. 1997 GlobeSAR 2 in south America
    a. CV-580 and RADARSAT-1 data
    b. Combined government, industry and academia effort
    c. Program designed to ready users for RADARSAT-2 data
76. 1997 Intera STAR 3i interferometric SAR
    a. Radar design by ERIM
    b. Design based on CCRS interferometry work
    c. Commercial High resolution, high precision DEM generation
77. 1998 MDA design for RADARSAT-2 polarimetry is based on CCRS polarimetric SAR studies
    a. RADARSAT-2 GMTI mode defined by DND was based on the proposed two channel design
    b. CV580 ATI mode is used from 1998 until 2010 to develop SAR GMTI theory and to validate RADARSAT-2 GMTI observations (post 2008)
78. 1999 DRDC SAR GMTI research starts with Petawawa flights using the CV-580 ATI mode and calibrated ground targets
79. 1999 DRDC GMTI specification for RADARSAT-2
80. 2000 CV-580 GMTI trial 2 at Petawawa with calibrated ground targets
81. 2000 CV-580 GMTI trial with calibrated targets Ottawa
82. 2000 SRTM mission
83. 2002 Air-to-air bistatic SAR experiment CV-580 and US BAC 111 at Petawawa
84. 2001 DRDC proposal to DND rebuild the CV-580 SAR system
85. 2001 CV-580 ATI radome phase calibration
86. 2002 ENVISAT Launch 1-March-2002
87. 2002 Repeat pass polarimetric interferometry (Sept) with CV-580
88. 2003 Maritime target GMTI flight trials Halifax
89. 2004 HSR repair and upgrade
90. 2004 Maritime target GMTI flight trials Halifax
91. 2004 Maritime GMTI target and GMTI high relief terrain trials (west coast)
92. 2004 Start the design of a disk recording system to replace the HSR
93. 2004 CV-580 polarimetric mode is used to generate application specific data sets for RADARSAT-2 polarimetric mode use training and familiarization
94. 2006 ALOS-PALSAR launch 24-Jun-2006. Uses CCRS polarimeter switching architecture
95. 2006 DLR F-SAR development (Germany)
96. 2006 CV580 Newfoundland GMTI trials
97. 2007 TerraSAR-X launch (Germany) 15-Jun-2007. The GMTI mode of TerraSAR-X was triggered by DRDC GMTI research and the planned RADARSAT-2 GMTI capability.
98. 2007 GMTI pre-processor developed for RADARSAT-2 GMTI modes
99. 2008 RADARSAT-2 launched
        i. Satellite uses programmable active-array antenna
        ii. Solid-state recorder
        iii. GMTI experimental mode
            1. Design elements used to add this capability have allowed this radar to be used as an on-orbit programmable device to test a range of experimental modes.
                a. EG high resolution wide swath
            2. Split antenna architecture allows the use of spotlight modes
100. 2008 DRDC GMTI processor for RADARSAT-2 GMTI (first version)
101. 2008 Joint CV580 RADARSAT-2 GMTI trials in Ottawa
102. 2008 Joint CV-580 RADARSAT-2 GMTI trials in Victoria
    a. Initial test of the CV-580 disk recording system
103. 2008 to 2016 293 RADARSAT-2 SAR GMTI scenes to support mode and theory development
104. 2009 ONEIRA SEITHI SAR (France)

105.2009 CV-580 disk recorder commissioning flight
106.2009 CV-580 used to test fly the new radar developed for The DND Aurora patrol aircraft
107.2009 RADARSAT Constellation mission (RCM) requirements review
108.2010 Tandem X mission (Germany)
109.2010 COSMOS-SkyMED constellation (Italy)
110.2010 Environment Canada decides to terminate CV-580 support
111.2011 Operational DRDC GMTI processor distributed in DND
112.2014 Sentinel-1A launched (European union) 3-Apr-2014
113.2014 ALOS-2 (DAICHI-2) launched 24-May-2014
114.2014 RADARSAT-2 GMTI / high resolution wide swath mode demonstrated
115.2015 CV-580 transferred to (arrives at) the Canadian Aviation museum
116.2016 Sentinel-1B launched (European union)
117.2017 Operational GMTI processor upgrade
118.2018 RADARSAT Constellation

Appendix C: Acronyms

The Canada Centre for Remote Sensing (CCRS) worked in the area of space and technology where acronyms were in common use. At one point RESORS maintained a list of these acronyms as well as a glossary of terminology. In some cases we have used the Government of Canada's terminology and linguistic data bank web page to provide the meaning of some of the acronyms not familiar to the authors/editor. See http://www.btb.termiumplus.gc.ca/tpv2alpha/alpha-eng.html?lang=eng&i=1&index=frw&codom2nd_wet=1 It should be noted that some of the acronyms used in the CACRS reports are not in this data bank and remain unclear as to their meaning

AARS – Asian Association on Remote Sensing
ACRS – Asian Conference on Remote Sensing
ADM – Assistant Deputy Minister
ADS – Applications Development Section, Applications Division, CCRS
AES – Atmospheric Environment Service, Environment Canada
AgRISTARS – Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing
APPU – Air Photo Production Unit
AQT – L'Association Québécois de Télédétection
BACEE – Bureau of Assistance for Central and Eastern Europe
BOREAS Boreal Ecosystem – Atmosphere Study
AVHRR – Advanced Very High Resolution Radiometer
CACRS – Canadian Advisory Committee on Remote Sensing
CANVAS – Canadian Vegetation Assessment System
CASI – Canadian Aeronautics and Space Institute
casi – Compact Airborne Spectrographic Imager
CCAP – Canadian Crop Assessment Program
CCEI – Climate Change and Ecosystem Impact
CCMEO – Canada Centre for Mapping and Earth Observation
CCRS – Canada Centre for Remote Sensing
CCT – Computer compatible tape
CFASU – Canadian Forces Airborne Sensing Unit
CGCP – Canadian Global Change Program
CGIS – Canada Geographic Information System
CIDA – Canadian International Development Agency
CIG – Canadian Institute of Geomatics
CIRS – Canadian Ice Reconnaissance Service
CIR – Colour Image Recorder
CIS – Crop Information System <u>and</u> Canada Ice Service
CJRS – Canadian Journal of Remote Sensing
CLI – Canada Land Inventory
CNES – Centre national d'études spatiales (French Space agency)
COSPAR – Committee on Space Research
CQCT – Centre Québécois de Coordination de la Télédétection
CRSS – Canadian Remote Sensing Society
CSA – Canadian Space Agency
CZCS – Coastal Zone Color Scanner
DAD – Data Acquisition Division (of CCRS)
DEM – Digital Elevation Model
DG – Director General – a senior executive-level position in Government
DICS – Digital Image Correction System
DND – Department of National Defence

DOCLS – Daily Observation of Canada's Landmass from Satellites
DoD – Department of Defence, USA
DRA – Defence Research Agency, Ministry of Defence, UK
DRB – Defence Research Board (the Canadian Government's military research arm)
DRDC – Defence Research and Development Canada
DSS – Department of Supply and Services
EBR – Electron Beam Image Recorder
ECV – Essential Climate Variable
EM – Electromagnetic Wave
EMR – Energy Mines and Resources (Federal Ministry)
EMS – Environmental Monitoring Section
EOADP – Earth Observation Application Development Program (CSA)
ERIM – Environmental Research Institute of Michigan
EROS – Earth Resources Orbiting Satellite (a proposed US satellite – not the Israeli satellite)
ERTS – Earth Resources Technology Satellite
ESA – European Space Agency
FLI – Fluorescence Line Imager
GCPs – Ground Control Points
GIS – Geographic Information System
GMS – Global Monitoring Section
GSD – Geodetic Survey Division
HISS – Holographic Ice Surveying System
IACRS – Interagency Advisory Committee on Remote Sensing
ICS – Interdepartmental Committee on Space
IDRC – International Development Research Centre
IFOV – Instantaneous Field of View
IGBP International Geosphere- Biosphere Programme
IJC – International Joint Commission
IPTASC – Interprovincial/Territorial Advisory Sub-Committee of CACRS
ISIS – International Satellites for Ionospheric Studies
ISY –International Space Year
IT – Information Technology
LACIE – Large Area Crop Inventory Experiment
LBIR – Laser Beam Image Recorder
LGSOWG – Landsat Ground Station Operators Working Group
LDIAS – Landsat D Image Analysis System
LTSP – Long Term Space Plan
LTWG – Landsat Technical Working Group
MAC – Management Advisory Committee, CCRS
MDA – MacDonald Dettwiller & Associates
MEIS – Multi-detector Electro-optical Imaging Sensor
MOSAICS – Multi-Observational Satellite Image Correction System
MOU – Memorandum of Understanding
MRSC – Manitoba Remote Sensing Centre, Govt of Manitoba
MSS – Multi-Spectral Scanner (a generic term often used to refer to the MSS on Landsat satellites)
MTPE – Mission to Planet Earth
NAPL – National Air Photo Library
NASA – National Aeronautics and Space Administration (of the USA)
NASDA – National Space Development Agency of Japan
NBIOME – Northern Biosphere Observation and Modeling Experiment
NESZ – Noise-Equivalent Sigma Zero
NOAA - National Oceanic and Atmospheric Administration, U.S. Department of Commerce

NRC – National Research Council (of Canada)
NRCan – Natural Resources Canada (Federal Ministry – was EMR)
NSERC – Natural Sciences and Engineering Research Council
OARS – Ontario Association of Remote Sensing
OMNR – Ontario Ministry of Natural Resources
PASS – Prince Albert Satellite Station
PDF – Post Doctoral Fellow
PNFRI – Petawawa National Forest Research Institute
PORSEC - Pacific Ocean Remote Sensing Society
PPEU – Program Planning and Evaluation Unit, CCRS
PPI – Plan Position Indicator (a common type of radar display)
PSRC – Project Selection and Review Committee
PWS – Polarimetric Workstation
R&D – Research and Development
RAF – Royal Air Force
RBV – Return-Beam Vidicon (Camera on Landsat satellites)
RDDP – Radar Data Development Program
RES – Research Scientist - a job classification in the Government of Canada
RESORS – Remote Sensing, On-Line Retrieval System
RFP – Request for Proposal
RPO – RADARSAT Project Office
RSI – RADARSAT International (a corporation)
RSTG Remote Sensing Technical Group
SAR – Synthetic Aperture Radar
SPOT – Satellites Pour l'Observation de la Terre
TEP – Technology Enhancement Program
TT – Technology Transfer
UAMU – User Assistance and Marketing Unit, Applications Division
UETI – User Education and Training Initiative
UN – United Nations
US (or U.S.) – United States
USGS – United States Geological Survey
UTM – Universal Trans Mercator
WRS – Worldwide Reference System

Appendix D: Geomatics Canada Scientists' Response to the Lortie Task Force's 1989 Attitudinal Study of Scientists in the Federal Public Service

Some Comments on Research at the Canada Centre for Remote Sensing[267]

Robert A. Ryerson, Ph.D., P.Ag.
CCRS, EMR

These comments summarize my views on research at CCRS and on the presentation which I was asked to attend some months ago on the attitudinal study of scientists in the federal Public Service. While I am a Section Head responsible for marketing and much of my agency's external face, I still publish in recognized journals and still consider myself to be a scientist. The opinions expressed here are my own and a synthesis of those from my colleagues gathered on September 13, the day I was asked to attend the meeting on September 15.

Comments on the Report

In general, the report on scientists' attitudes presented at the ISTC Boardroom some months ago summarized the attitudes of a group that seemed to be demoralized, unsure of where they were heading or what their mandate was. Furthermore, they seemed to be doing work that was not being compared to the world's best. Indeed, their viewpoints often seemed somewhat parochial.

Of important in viewing the results is that there always seemed to be some responses out in the "tails" of the distribution. There were always scientists who were happy, who were doing challenging work with interesting people and reasonable managers. While the situation at CCRS is not perfect, my opinion and that of the majority of my colleagues is that we do world-class work with a generally enlightened management team. Our leaders have, for the most part, done good research of their own before taking on managerial positions. We would welcome peer review by the best in the world – although for commercial reasons, we would like to limit the countries and agencies from which one might draw those who would do a review.

Comments on CCRS

CCRS does not just measure itself against other remote sensing groups in Canada. It quite unabashedly compares itself not to just to other labs, but to the best in the world in each of the fields in which it operates. While CCRS is far from perfect, it has developed a culture of confidence and support for scientists that has resulted in excellence virtually across the board. As CCRS scientists we are expected to succeed, are generally given the resources to succeed and we therefore do succeed. Our success enables us to attract and keep the brightest and best scientists at the entry and senior levels.

In the past three years the 40 scientists at CCRS have won three individual Government of Canada Merit Awards, and a further thirteen Group Merit Awards. Seven of these were given Government-wide Awards of Excellence. Fully 40% of all of our scientists have won such awards, more than 1 in 3 over the three years. Over three years across government as a whole, such awards are granted at a rate of less than 1 in 300.

Staff have also received a number of prizes for having the best, or among the best, papers at symposia. Several years ago, a paper published as a CCRS Report was selected as the best paper in the English

[267] Note to the Reader: This document was presented to the Task Force in 1989. Several of the recommendations were eventually implemented: CCRS Directors were classified in the EX category and CCRS was allowed to have a higher than average number of scientists at the RES 3, 4 and 5 levels. However, many of the concerns persisted and some of the successful approaches were subsequently abandoned.

language in remote sensing image interpretation. CCRS staff currently serve as editors or co-editors of most of the major Journals in the field. CCRS staff review papers for all of the major journals in the field and regularly contribute to all of them. The bench-mark ***Manual of Remote Sensing*** had two chapters contributed to by a CCRS staff member (Co-editor and Co-author), while CCRS has contributed one chapter and the CCRS library provided most of the bibliographic searching to the new Manual of Photographic Interpretation. A CCRS staff member currently serves as the elected Vice-Chairman of the Canadian Remote Sensing Society, while others serve or have served a number of international societies in a variety of leadership positions including elected leader of the 3500 member Remote Sensing Applications Division of the American Society for Photogrammetry and Remote Sensing.

Staff scientists are routinely asked to serve on national and international advisory boards and frequently take leaves of absence to work in the private and academic sectors at senior positions. Some of the staff return to CCRS (better for the experience), while others have chosen to remain in the private sector. Others have been subsidized to further their education at the Doctoral level. This flexible approach to personnel and movement of staff makes staff human resource management difficult, but demonstrates a care for the individual that is repaid by organizational loyalty and results. As well, the approach is an excellent form of technology transfer and shows a commitment to the growth of the whole sector, even if at times it may be to the short term detriment of the organization.

Contracting out as practiced by CCRS is good for the industry and usually benefits the research scientist. The private sector works with the best scientists in the field, while the scientists gain a commercial perspective from the private sector. The only drawback is found when the bulk of the creative work is done outside of the government lab. In such cases the scientist can become little more than a contract manager, and will soon lose his or her value as a respected scientist. The ideal sees the method or technology conceived by the scientist (often at the request of the private sector or other client), perfected with industry and then commercialized by industry. This process frees the scientist from the less attractive (scientifically) final commercialization phase to move on to attack another exciting problem on which more research and publishing can be done. In this model the industry gains the benefit of good science, an association with a world class lab, and the freedom to commercialize the work with the marketplace in mind. In some cases entrepreneurial scientists have gone with their work to further commercialize it – some have returned to CCRS and some have not. A corollary benefit is that a scientists can usually work on more than one problem, magnifying the benefits of his or her work.

In my opinion and that or most of my scientist colleagues, CCRS is a good place to work. But for some units, this also explains the relative length of service. To my knowledge only two scientists have taken a lateral transfer to leave CCRS in sixteen years. Virtually all of the others who have left have been actively recruited by the private or academic sectors.

Concerns of Scientific Staff

While the situation is generally good compared to most other government laboratories, there are either real or potential problems. In almost all cases they relate to the general framework of government science.

Contracting out is a useful means of moving our work to industry. However, there are concerns that there will be a tampering with the generally successful model of CCRS. Given the world class stature of our group, we are all very mobile. If staff were expected to be contract administrators rather than scientists, we expect that would trigger a serious erosion of morale and mass exodus of the best people. A core of research must be kept at CCRS to continue to be successful and world class. We are close to this line in some areas, and perhaps over it in others, such as sensor development.

Research as defined by the Treasury Board and other central agencies is not necessarily the idea scientists have of research.

Science is over-managed. The central agencies and departmental management seem to require a needless amount of paper work and overhead before any work is done. The CCRS project management system (or one like it) should be all that is required.
A second corollary is that there are too many poorly run meetings and committees with ill-defined agendas. A tremendous amount of time is wasted in unfocused and rambling meetings of questionable utility. This is a universal complaint.

A third corollary is that the central authorities, and our planners, program auditors, administrators, financial people, and personnel people often seem to lose sight of the fact that their sole purpose in life is (or should be) to support our job of doing the best possible research for the general benefit of Canada. We the scientists have not been placed here to frustrate them and their rules. Neither should we be expected to understand each and every rule. Their job should be to facilitate research, not frustrate it. They would help by interpreting the rules and regulations in a sensible fashion and, where rules do not make sense, they should help get them changed or waived. This too is a universal complaint.

CCRS staff have become frustrated with the RES-2 bottleneck. This is especially so in that we have gone beyond the normal quota for the higher levels, leaving those behind quite certain that they must await either death or resignation for promotion. Our management has done a good job securing advancement, based on the simple but true statement that we should have more RES-3/4 than normal because we are so strong. That possibility is fading for the rest who seek to either move into the RES category, or who seek promotion within it.

There is some frustration with the lack of commitment to long term endeavours. Without long term commitments, the deeper questions and most thorough work is not possible. Our colleagues in Japan have taken the long term view – we must as well to be successful in the long term. In short, science cannot be turned off and on like a tap. This, however seems to be the perspective of the non-scientists involved in policy.

Dealing with DSS has been a particular irritant to several of our scientists. “You are guilty of an infraction until proven innocent.” It may be that courses may lead to a better understanding of the system, and of science by the system.

The RES appraisal system is too competitive. It tends to promote those who are most often first authors, who publish the most, etc. This situation is, of course, no different than the university environment. A co-operative and sharing environment, as one often finds in an industry team, is not encouraged. Similarly there should be an opportunity to work in a proprietary fashion with, for example, the oil or mineral industry. Government scientists are expected to publish to get promoted, but such is not possible if one is doing proprietary work that is commercially sensitive. We lose valuable experience, and industry does not get access to our pool of talent.

Related to this is the concern that those promoted to the section head level to manage a section of their peers can use this position to improve their chances for further promotion to improve their chances for further promotion by involving themselves in much of the work and publications of the section. This is very hard to argue against since the same section head may well be in a position to control the staff scientist’s appraisal, assign unpleasant (or at least unrewarding) duties, and decide who will go to which conference. A system of rotating appointments at this level would help reduce this concern, while broadening the experience of the scientists, preparing them for the position of Director.

Directors. The concept of Senior Manager as someone who can manage anything is ludicrous. Science cannot be managed by anyone. While science can be managed by those who have not done science, individuals who can manage science without having worked at the bench are rare. (Those who can, usually have training as engineers or worked in a related milieu.

A corollary is that the SM category should not be placed above scientists. It is silly to have a manager who earns thousands of dollars less per year than his staff. Our Directors, for example, should likely be in the EX category.

Conferences and travel. It is too difficult for junior and intermediate staff to get approvals to go to a conference or international meeting – even when the trip is paid for by another organization. Too many trips seem to be rewards for senior people, as opposed to opportunities for advancement for the younger scientist. The rules limiting the number of people going to a conference (to one per department) should be revised. Those going to conferences should be required to prepare an in-depth trip report for distribution to those who could not go, and place conference proceedings in their agency's library. I have never seen any of the current forms used by anyone, and have no idea where they go and I have been dutifully completing them for sixteen years.

Appendix E: A Simple Explanation of Polarimetry for the Non-Scientist

Lori White

Radar polarimetry (*Polar*: polarization, *Metry:* measure) can be defined as "the science of acquiring, processing and analyzing the polarization state of an electromagnetic field" [Boerner, 2003]. Within the electromagnetic field a wave can be horizontally or vertically polarized (Figure 1), and the electric and magnetic fields are positioned at 90º angles from each other. The polarization of a monochromatic electromagnetic plane wave describes the shape and locus of the electric vector end point in a plane orthogonal to the direction of wave propagation[268]. (Born and Wolf, 1959)

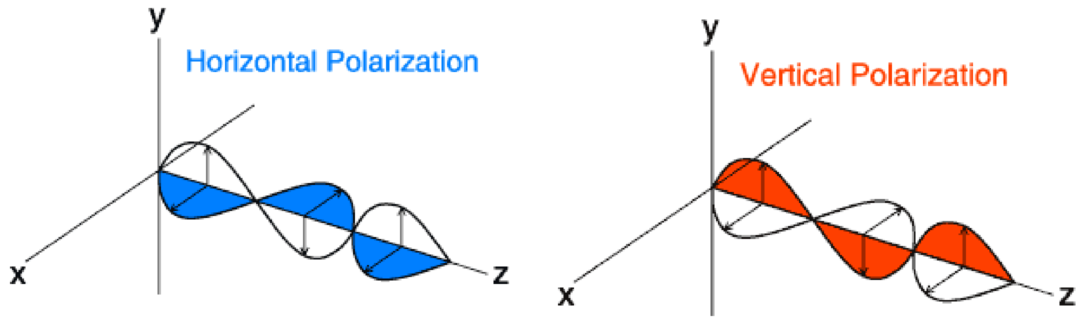


Figure 1: Schematic diagrams illustrating examples of a horizontally and vertically polarized wave. ©NOAA

Polarimetric radars allow the user to measure the scattering properties of features on the earth's surface by sending out an incident wave and recording the portion of the returned scattered wave to the satellite antenna. The characteristics of the features on the earth's surface such as shape, geometrical structure, roughness, orientation and reflectivity affect the amount of backscatter returned to the satellite and provide information to help classify the ground targets.

Most of the early synthetic aperture radar satellites (e.g. Radarsat-1, SIR-A, SIR-B, ERS-1/2) were single polarized SAR systems. Within these systems both the transmitted and received energy sent from the satellite were within the same plane, either horizontal or vertical to the SAR look direction. The next generation of SAR satellites were dual polarized (e.g. ENVISAR-ASAR, RISAT-1) or quad polarized (egg. Radarsat-2, TerraSAR-X, ALOS-PALSAR, Cosmo-SkyMed, ALOS). Dual-polarized SAR satellites have the ability to send and receive microwave energy as co-polarized (HH or VV) or cross-polarized (HV or VH). A fully-polarimetric, quad-polarized SAR system can transmit and receive the SAR signal in all four planes (HH, VV, HV, and VH) (Born& Wolf 1959, Brisco, 2011). Utilizing the full polarimetric information allows for the measurement of the amplitude (strength of the signal) and the phase (measures the time it take for the radar signal to be sent, interact with the ground target, and received) (Sletten & Mc Laughlin, 2005). Having polarimetric SAR data allows the decomposition of the scattering matrix or the covariance matrix into different scattering types, which allows the user to extract more information about the ground targets. Some commonly used SAR polarimetric decompositions include the Freeman-Durden decomposition (Freeman and Durden, 1998), the Cloude-Pottier decomposition (Cloude and Pottier, 1996), the Touzi decomposition (Touzi, 2007), and the Yamaguchi decomposition (Yamaguch, 1995). The additional information provided by polarimetric decompositions

[268] Editor's Note: This explanation is scientifically correct, but perhaps more complex than a layperson will be able to easily understand. Here we have opted for scientifically correct wording and if this is too complex for the reader we suggest that the reader will be able to move on through the remainder of the explanation to get a feeling for polarimetry

are often used as input into classification models and have been shown to improve class separability in many cases.

The Freeman-Durden decomposition is commonly used because it only has three components, surface, volume and double-bounce scattering, which makes it easy for users to interpret (Yang *et al*. 2015, Figure 2). Surface scattering results in a single-bounce return to the SAR system for targets such as ground surfaces with little or no vegetation, or rough water. Volume scattering, occurs from targets that scatter the SAR signal in multiple directions, such as vegetation canopies. The third component is double-bounce scattering, which results when two smooth surfaces create a right-angle and in turn the SAR signal to be deflected off of both surfaces and the majority of the signal being returned to the SAR. An example of a double-bounce scattering is when the emitted SAR signal hits the ground and then bounces off of a tree trunk (Hess *et al*., 2003; Lane *et al*., 2010; Brisco *et al*., 2011, 2013; Wdowinski *et al*., 2008).

The Touzi decomposition is more complex, but provides the user with more information about target scatterers compared to the Freeman-Durden. The Touzi decomposition provides an in-depth analysis of the three single scattering eigenvalues (surface, volume, and double-bounce). This allows for the eigenvalues to be expressed as 5 roll invariant and independent scattering parameters (α_{si}, $\phi_{\alpha si}$, m, τ_i, λ). The symmetric scattering type magnitude (α_{si}) describes the type (surface, volume, or double-bounce scattering) and strength of the radar backscatter. The symmetric scattering type phase ($\phi_{\alpha si}$), measures the amount of offset in the phase between odd (single, or multiple scattering) and even bounce scattering (double-bounce scattering). The Kennaugh-Huynen maximum polarization return (m) provides a measure of the maximum power. The Kennaugh-Huynen maximum polarization (helicity, τ_i) calculates the amount of symmetry of the ground targets. The normalized eigenvalues (λ) give a relative measure of power for each eigenvalue. In addition, the Touzi decomposition includes the Kennaugh-Huynen maximum polarization orientation angle (ψ_i), which quantifies the orientation angle of the ground targets (Touzi, 2007, Touzi, 2009).

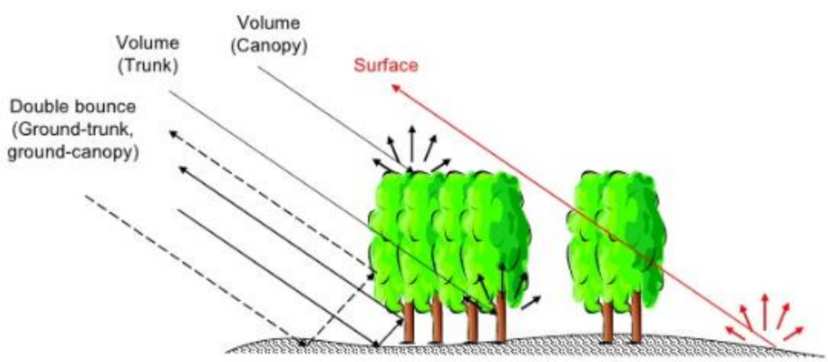
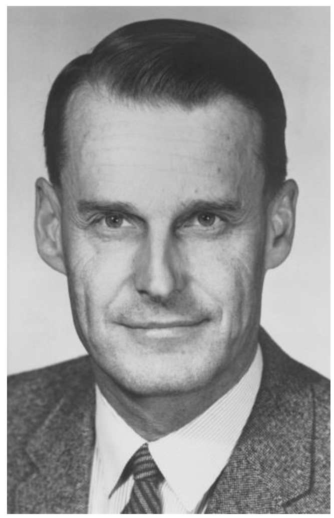


Figure 2: Schematic diagram demonstrating common backscatter responses (surface scattering, volume scattering, and double-bounce scattering) from ground targets to polarimetric radars. ©NASA

Appendix F: Tribute to Larry Morley A Legacy of Excellence in Canadian Remote Sensing

Presentation at the Banquet of the 34th Canadian Symposium on Remote Sensing, Victoria, British Columbia, August 2013

Bob Ryerson, Bob O'Neil, Florian Guertin, Edryd Shaw, and Les Whitney[1]



Abstract

Dr. Larry Morley was the founding Director General of the Canada Centre for Remote Sensing. Dr. Morley passed away April 22nd, at the age of 93. He was active right to the very last days of a life that has inspired the authors of this presentation. Dr. Morley's work as a leading geophysicist made him realize early-on the potential of remote sensing. His approach to remote sensing can be described in just a few words: he was a patriotic Canadian dedicated to excellence. That excellence was manifested in his management style, approach to research, and how he responded to issues important to the country. He foresaw that the linkages between science, national policy making and ultimately service to Canadians would be strengthened by the consistent data sets provided by Earth observation. His understanding of the importance of industry and the development of an advisory structure embracing government at the federal and provincial levels, industry and academe set the stage for a program that has grown to be regarded as a national treasure. He promoted national and international partnerships that have become a hallmark of remote sensing world-wide to this day. Through his efforts Canada came to be recognized as a world leader in a field that has been of growing importance to the study of our environment, natural resources, and development. This presentation will detail these achievements as seen through the eyes of some of those who were directly involved, with closing remarks on how these lessons may be applicable today.

[1]The authors held a number of positions at CCRS including Scientist, Section Chief, Director and Director General spanning the period from 1973 to 2006. The authors appreciated input and comments offered by Keith Raney, Lee Godby, Derek Peddle, Doug Bancroft and, most importantly, Beverly Morley.

The Speech

Tomorrow Keith Raney will give a more formal presentation on the technical contributions in remote sensing of Larry Morley, the founder of remote sensing in Canada, including CCRS, the Canadian Remote Sensing Society that is sponsoring this symposium, and this series of symposia. Larry was also the individual who did more than anyone to make the world's remote sensing community a global village based on cooperation and sharing.

Those of you at the conference last year will recall Larry saying a few words at the banquet and asking his usual intelligent, polite and yet penetrating questions during the technical sessions. Larry passed away at the age of 93 this past April. He was active right to the very last days of a life that has inspired the authors of this presentation and, I know, many of the people in this room.

At the outset every new discipline or organization benefits greatly from having a leader who is at the same time a visionary, mentor, wise counselor, with a strong moral compass and a bedrock of principles. Along with these attributes this person should have the ability to build consensus to achieve his vision. Larry owned all of these attributes – attributes usually assigned to a statesman. We have thought long and hard about how best to describe this wonderful, inspirational person. The best we could come up with was that he was an intelligent, thoughtful, kind, patriotic Canadian of genius and integrity dedicated to excellence. And we all loved working with him. And we should note you worked WITH Larry, not for him.

Larry was a true visionary who was able to articulate a vision for remote sensing and Earth observation in Canada. Moreover, he was the right person at the right time to realize the vision. By the "right person" we can cite his expertise in geophysics – a rather small and rarified discipline but, at the time, well developed in Canada – especially airborne. This expertise in geophysics gave him an understanding of what the view from above could yield. That grounding led him to see the potential for Earth observation, especially from satellite. Satellite data provides large area and repeat coverage, and observation of otherwise inaccessible locations and events. In addition Larry knew the right Canadians needed to make it happen (particularly in the National Aeronautic Establishment, industry and universities). He then was able to attract them to join CCRS or he involved them in CCRS projects and programs. Along with these strengths he possessed the attribute of integrity: indeed Larry was a "poster-boy" for integrity – he expected it of others in professional activities as well as personal interactions.

Another hallmark of Larry's contribution was international cooperation. He knew the limitations of Canada's budgets – we were not going to have our own satellites in those early days, and we needed access to the data from others, so he sought out partnerships. The most important of these was the involvement in what began as the ERTS Program and became the Landsat Program. Reducing it to rather simplistic terms, the relationship with the US was seen as symbiotic – our interest gave them credibility just as their acceptance of our involvement gave us credibility. Perhaps Larry's most important contribution was that he showed the way for the international sharing of data and resources, a characteristic that we all accept today. Later partnerships involved ESA, NOAA, and other remote sensing organizations.

Along with this long list of attributes Larry possessed one that set him apart from most of those in government – both before and since – his willingness to take risks. The most significant we can recall (as bureaucratic public servants) may have been the purchase of the CV-580 aircraft – an opportunity that was not part of the budget - until after the fact. The expertise gained in Canada with airborne radar imagery led to the definition and approval of the RADARSAT-1 Satellite Program and helped ESA in the definition and proof of concept for the European ERS satellite program.

His dedication to excellence is manifest in why and how he championed remote sensing, his management style, his links to industry, how he obtained external advice, his approach to research, and how he responded to issues important to the country.

While it was his unique range of attributes and intelligence that allowed him to accomplish great things, Larry has left us with a number of lessons that are as widely applicable today as they were in the 1960s and 1970s.

Lesson # 1: Larry championed remote sensing because it was important and useful to his country. He was not an advocate and champion of remote sensing because it was new and sexy. He did not continue his interest and support because he had been “doing” remote sensing for years, or because he was instrumental in getting Canada engaged. I think that is the first lesson we should take away.

There are a number of lessons in management – as relevant today as when we first saw them being implemented.

Lesson # 2: Surround yourself with extremely capable people and then listen to their advice. For the older people in the crowd who may know of the comic strip L’il Abner, Larry was the “outside guy” in the skunk works called CCRS and Lee Godby was the inside guy. And he brought in people with experience in airborne, applications, satellite data reception, and computer technology.

Lesson # 3: Deals with how you attract interest, support, and the good people you need to succeed. If you have something to say, get out and say it, but say it well and say it with passion. Larry gave what he called “Dog and Pony Shows” all over Canada to generate interest in remote sensing. These inspirational speeches were attended by many of us who were in grad school at the time – people like Josef Cihlar, Tom Alfoldi, Mike Kirby, myself, and many others. Remember that CCRS started at a time when all of us in grad school got a number of permanent job offers even before we began to write a thesis. Such was his pull that even with that many jobs available, 400 people applied for eight positions. THAT is inspiration! Everyone wanted to work for Larry.

Lesson # 4: Manage with respect for the entire team. Each and every person, from the clerks operating the stores and mail room to the computer operators and scientists, were treated as colleagues and valued team members. This was perhaps best seen in the cafeteria at the CCRS headquarters where it was a common sight to see people from all levels within CCRS sitting down for lunch at the same table. The famous CCRS pot-luck lunches were born from that spirit of camaraderie. Bob O'Neil and I still argue over whether that tradition started at Limebank Road or Belfast Road!

Lesson # 5: Give employees enough rope to succeed, but never enough to hang themselves. Today this might be called empowering your employees. Then it was unique. But if we did get in trouble, and we were in trouble for trying hard to achieve the goals of the organization, he backed us up. But woe betide anyone who proved to be incompetent or who was not striving for excellence.

There were a number of other lessons one could take away from studying how Larry Morley did things.

Lesson # 6: There is an important and symbiotic relationship between government and industry – especially in an organization and field such as CCRS dealt with. Early-on Larry suggested that the national remote sensing program could in part be paid for by the taxes levied on those exporting the remote sensing technology we developed in Canada. In addition there were benefits that came from better information. As a result there was a focus on working with industry to develop and export expertise as well as an effort to measure the impact of our programs. MDA, Optech, PCI are among the best known, but there were many others. Several of us became expert in measuring impacts and benefits – and that expertise came in handy time and again when justifying our programs and seeking new funding.

Lesson # 7: Engaging stakeholders in a meaningful way can provide good advice and support. Internal to the federal government there was the senior level Interagency Committee on Remote Sensing (IACRS – pronounced EEYACKERS) to coordinate remote sensing in the federal government. More broadly the Canadian Advisory Committee on Remote Sensing (CACRS – pronounced KACKERS) was established to bring together different levels of government, academe, and industry. It was recognized that everyone wants to be involved in providing advice to a national program – so the intent was involve as many people as possible, including those whose ideas and perspectives may be quite different.

There were a number of sub-committees dealing with the important applications and technology issues of the day. The sub-committees met on a regular basis and reported to an annual meeting which had 60 or more participants from outside CCRS. The bear-pit plenary sessions provided constructive criticism and advice. Many of the new programs developed came from CACRS. And CACRS participants became ambassadors for our program at CCRS.

Lesson # 8: As the Canada Centre for Remote Sensing, the Government of Canada's agency responsible for the acquisition, dissemination and research in remote sensing, CCRS would respond only to issues important to Canada. The issues were identified through statements of the government of the day. At the beginning this included areas like crop forecasting, support for Arctic oil exploration, landslide assessment, and a number of environmental files. Over time industry development was also seen as an important activity. These files crossed departmental boundaries and this led to the next lesson.

Lesson # 9: Research such as CCRS was doing should have a purpose, should involve the ultimate users, and should be focused on issues where remote sensing could make a difference.

Applications scientists were expected to work simultaneously with a number of users to foster the development of new uses of remote sensing that addressed issues that were important to the country. At the beginning none of the scientists in Applications Development were Research Scientists – they were not expected to publish, although we all did. We were expected to develop operational applications with “real” users using methods developed by Dave Goodenough and his team.

Lesson # 10: Learn from what has gone before, build on it, but make it better. Larry did not want to see wheels re-invented or “me-too” research – doing what someone else had done to prove it did “work.” This led indirectly to the development of RESORS, the first searchable data base of remote sensing publications. And, for a long time, the only one anyone ever consulted. It was organized by some 1500 keywords – and every paper was read and weighted keywords assigned. Remember that this was before the Internet and decades before Google. RESORS was used by scientists across Canada and around the world to search what had been done. World-wide every scientist or expert in remote sensing wanted his or her research catalogued in RESORS so that it (and they) would gain exposure. And of course those of us in Canada benefited by being able to see what everyone else was doing – and we learned by their mistakes. I note in passing that it was the largest data base of publications in both English and French. By the time it shut down in the 1990s there were over 100,000 papers in it….and it is still being used.

If Larry was to hear this presentation I am sure that he would tilt his head to one side, give his famous smile, and say “well, you got most of it right, but you missed a couple really interesting points…” and he would hold your attention for the rest of the evening….

Speaking for my colleagues who have helped put this together, thank you Larry for giving us guidance, opportunity, and enough rope to succeed, and for being there for us through it all. Speaking for our whole community, thank you Larry for all you have done to build a strong foundation for remote sensing in Canada that has lasted through many upheavals and changes. We miss you, but your legacy will live on…