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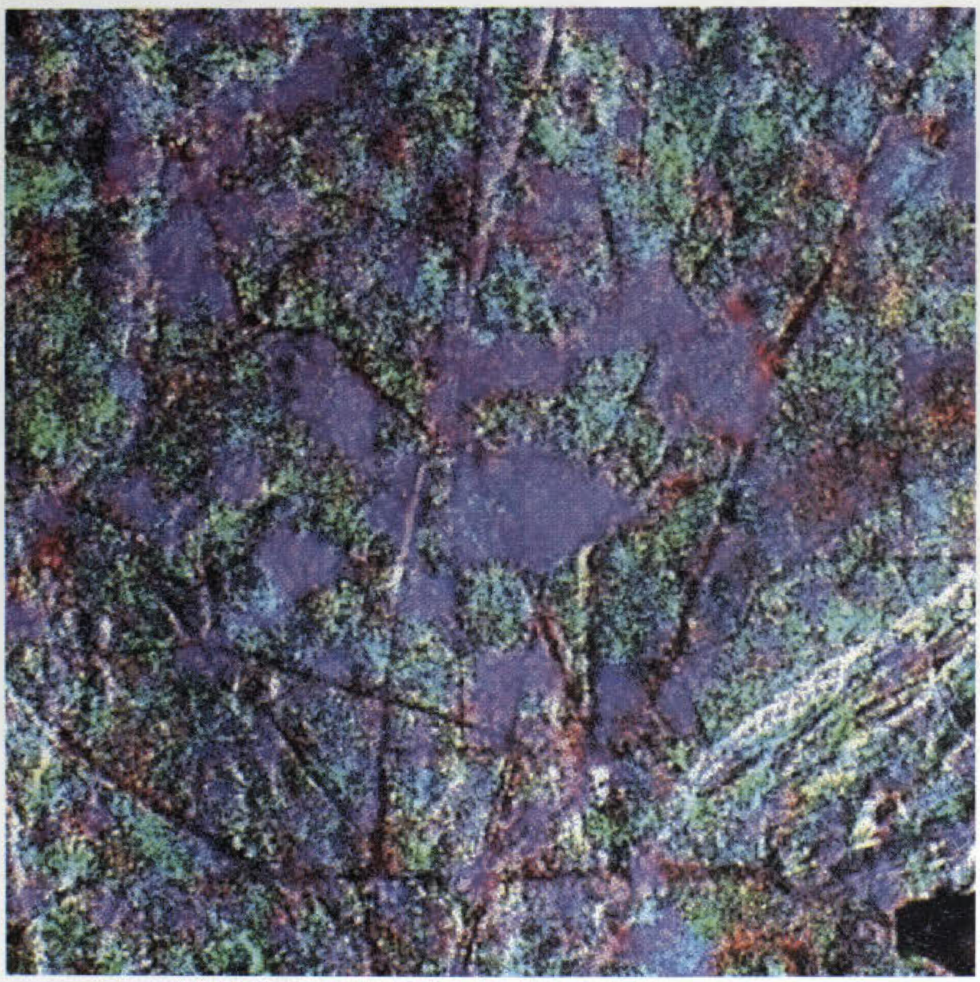
Canadian and ESA ERS-1 Announcements of Opportunity

SUMMARY REPORT



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Canadian and ESA ERS-1 Announcements of Opportunity

SUMMARY REPORT

prepared by the

Canadian ERS-1 AO Project Team Members

the

Canadian ESA ERS-1 AO Project Team Members

and the

Canada Centre for Remote Sensing / Geomatics Canada

Ottawa, 1996

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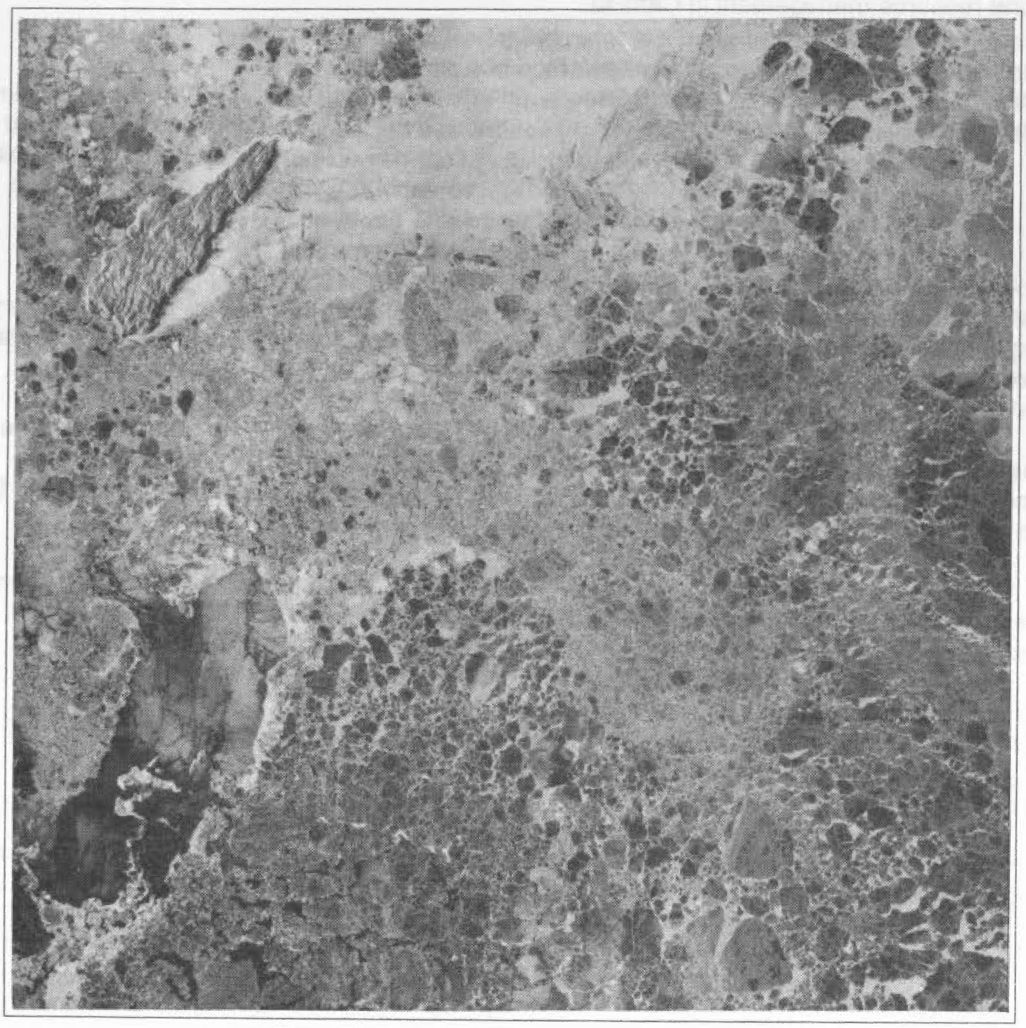
PART A:
INTRODUCTION



ERS-1 SAR image of Belle Isle, NFLD., 14/03/92, produced at CCRS / (c) ESA 1992

INTRODUCTION

In 1991, the first European Earth Resources Satellite mission, ERS-1 for short, was launched. This document contains a summary of activities under the Canadian ERS-1 Announcement of Opportunity (AO) which was issued in 1991, and the Canadian project work related to the European Space Agency (ESA) AO which was issued in 1986 . These activities were carried out by the Government of Canada, through the Canada Centre for Remote Sensing (CCRS), and the members of the Canadian ERS-1 Project Team and the Canadian component of the ESA ERS-1 AO Project Team. The Summary Report is integral part of an agreement between the Government of Canada and the European Space Agency (ESA) to promote research and development with regard to the reception, processing and analysis of ERS-1 synthetic aperture radar (SAR) data for environmental monitoring and natural resource management in Canada.

Organization of the Document

The Summary Report consists of four parts. PART 'A' provides a brief introduction to the ERS-1 satellite mission, the Canadian involvement in the ERS-1 project, the Canadian ERS-1 Announcement of Opportunity, the ESA ERS-1 Announcement of Opportunity, and an account of all the Canadian ERS-1 activities.

PART 'B' contains a listing of Canadian ERS-1 AO projects and a collection of more than 60 Project Summary Sheets. These summary sheets contain project title, study area, investigators, ERS-1 SAR data specifications, project objectives, results, and references.

PART 'C' contains a listing of Canadian projects conducted under the ESA ERS-1 AO and a collection of 22 Project Summary Sheets. These summary sheets contain project title, study area, investigators, ERS-1 SAR data specifications, project objectives, results, and references.

PART 'D' contains listings of ERS-1 SAR data specifications and scenes delivered to the Principal Investigators of both ERS-1 Project Teams. Also included is a collection of references related to ERS-1 AO work with particular emphasis on studies carried out in Canada.

The ERS-1 Mission

Mission Objectives

The first European Remote Sensing Satellite (ERS-1) is the forerunner of a new generation of civilian Earth observation satellites which promise to make a substantial contribution to scientific study of our environment from the vantage point of space. ERS-1 uses advanced microwave remote sensing techniques for global measurements and imaging to take place independent of cloud and sunlight conditions. The ERS-1 mission was designed to measure many environmental parameters not covered by other Earth observation satellite systems. These parameters include all-weather sea state, sea surface winds, ocean circulation and sea levels, Arctic / Antarctic ice sheet mass balance, coastal processes and pollution, and improved detection and management of land use change. ERS-1 has an important role to play in the study of oceanography, ocean/climate phenomena, climate change, geophysics, glaciology, geodesy.

Space Segment

The ERS-1 satellite carries five main instruments on-board.

- The C-band Active Microwave Instrument (AMI) consists of side-looking radar systems with three in-flight selectable modes: for high-resolution SAR imaging; for measurements relating to wave spectra (WAVE); and for wind scatterometry over the ocean surface (WIND). The AMI can operate in one of the three modes: IMAGE, WAVE or WIND. IMAGE mode is exclusive, but the WAVE and WIND modes can operate in tandem.
- The Ku-band Radar Altimeter is a nadir-looking instrument for altitude measurements and operates over ocean and ice. Over the ocean, it is used to determine the significant wave height, the wind speed and mesoscale sea surface topography. Over ice, it is used to determine the ice surface topography, ice type and sea/ice boundaries.
- The Along Track Scanning Radiometer (ATSR) is a passive instrument. It consists of an advanced four-channel infrared radiometer (IRR) and a microwave sounder (MWS), both of which can be operated at the same time. The IRR provides measurements of sea-surface and cloud-top temperatures more accurately than previous instruments. The MWS is a nadir-viewing passive radiometer providing measurements of the total water content of the atmosphere. The ATSR is an experimental package resulting from an ESA Announcement of Opportunity for a scientific add-on payload package. ERS-2 carries an enhanced version (ATSR-2) with three additional optical channels, two within the visible and one in the near infra-red range.
- The Precise Range and Range-rate Equipment (PRARE) is an all-weather microwave ranging system designed to perform high-precision two-way microwave range and range-rate measurements using ground-based transponder stations. These measurements are used for orbit determination and for geodetic applications. Unfortunately, the PRARE on ERS-1 suffered fatal damage to its Random Access Memory due to radiation after a few hours of operation. An improved version was designed for ERS-2.
- The Laser Retroreflector is a passive device operating in the infra-red. It is used as a target by ground based laser ranging stations for accurate determination of the satellite's height.

The satellite was launched with an ARIANE-4 rocket on July 17, 1991 from the Kourou Space Centre in French Guyana. It was positioned in a sun-synchronous orbit at an altitude of 785 km with a 98.5 deg. inclination. ERS-1 has been in various orbital configurations with repeat coverage cycles of 3, 35, 176 days. The satellite crosses the equator at 10:30 local standard time on descending orbit and at 22:00 local standard time on ascending orbits. ERS-1 has a minimum two-year mission life time which has already been exceeded; ESA expects to operate ERS-1 in tandem with ERS-2 until the end of the decade.

ERS-2 was successfully launched on April 20, 1995. ERS-2 has the same sensor configuration as ERS-1 except for the addition of a Global Ozone Monitoring Experiment (GOME). Once the orbits are adjusted, the ERS-1 and ERS-2 satellites will be 50 minutes apart in orbit. The close orbit will be helpful for generating digital terrain maps.

TABLE A.1: ERS-1 SAR Sensor Parameters (AMI image mode)

Frequency	5.25 GHz
Band (wavelength)	C (5.7 cm)
Antenna	waveguide
Size (length x height)	10 x 1 m
Polarization	*Vertical transmit*
	Vertical receive
Off-nadir angle	*23 degrees*
Resolution	
Range	26 m
Azimuth	28 m (6 looks)
Swath width	*100 km*
Pixel spacing	
(product dependent)	*12.5 m, 25 m*
Image scene size	*100 km x 100 km*

Ground Segments

The principal ground segment of the ERS-1 system resides in Frascati, Italy (ESRIN). The mission management and control centre is located at Darmstadt, Germany (ESOC). ESA ground stations include Gatineau and Prince Albert (Canada), Kiruna (Sweden), Fucino (Italy), Maspalomas (Canary Islands, Spain), Bangkok (Thailand), Fairbanks (Alaska, USA), Alice Springs (Australia), Tromso (Norway), Cuiaba (Brazil), Cotopaxi (Ecuador), Hatoyama and Kumamoto (Japan), Hyderabad (India), Pare-pare (Indonesia), West Freugh (UK), Beijing (China). Temporary stations include Syowa Station and O'Higgins (Antarctica) and Libreville (Gabon).

The Canadian ground segment is the responsibility of the Canada Centre for Remote Sensing (CCRS). Currently, data is acquired at the Prince Albert and Gatineau receiving stations. The Canadian SAR receiving and processing facilities were upgraded in order to accommodate ERS-1 SAR data reception and processing. The upgrade includes an additional 10 m tracking antenna at both stations and the construction of an annex at the Gatineau station to accommodate the Canadian SAR processing facility.

As a service to ESA, CCRS also receives and processes data from the non-imaging ERS-1 sensors, the low bit rate (LBR) data. These products are sent directly to ESA for worldwide distribution. In Canada, the

Atmospheric Environment Service of Environment Canada accesses the LBR fast delivery products from ESA for use in their weather and sea-state forecasting programs.

Sensor Performance

The C-band AMI SAR in imaging mode has been very stable and has operated within technical specifications over the duration of its mission.

SAR Image Quality

SAR image quality has been consistent. However, some variability has been noted in the Canadian SAR processor from time to time. First-order radiometrically calibrated products are not available from the Canadian processor. This necessitated the development of user software which will perform this function on standard SGF image products only (Noetix Research, 1992). First-order radiometrically calibrated products are available from some European processing facilities.

SAR Image Orientation

The orientation of the output image data varies from processor to processor. This affects the location of the first line and pixel in the output file. Canada processes all products with the first near-edge pixel on the 'right' and the first line of data received on the 'top' regardless of the satellite orientation during data reception. Data acquired from ascending orbits need to be rotated 180°. Other processors may output the first near-edge pixel on the 'left' and the first line of image data on the 'top' or bottom' depending on the orientation of the satellite during data reception, *i.e.* descending or ascending orbit. This results in horizontally and/or vertically 'mirrored' images, depending on image mode.

History of Canadian Involvement in ERS-1

SAR Technology Development

Canada joined ESA's Remote Sensing Preparatory Program in 1980 and subsequently became a full participant in the design, construction and operation of ERS-1. The Canadian government assumed a 6.26% share of the design and construction phases and a 7.30% share of the operating phase. In return, Canadian industry gained a proportionate share of contracts for the spacecraft and for the ESA-funded ground segment. Canada also gained the right to receive ERS-1 data in Canada for Canadian government approved purposes, subject to ESA allocation rules.

ERS-1 and RADARSAT

The cooperation between Canada and ESA with regard to the development of Synthetic Aperture Radar (SAR) has been mutually beneficial. Canada and ESA have a similar desire for advancing this technology into the field of natural resource management and environmental monitoring. ERS-1 is primarily a research and development tool, similar to the American SEASAT and Japan's JERS-1 missions. As such, the Canadian government, industry and academic institutions utilize ERS-1 to prepare for the operationalization of RADARSAT SAR data reception, processing and analysis.

Canadian ERS-1 Announcement of Opportunity

The conditions under which ERS-1 data is provided to participants in the Canadian ERS-1 AO are laid out in a legal document entitled *Canadian Announcement of an Opportunity to Acquire ERS-1 and J-ERS-1 Imagery*. The document is dated November, 1991. Details are provided below.

Background

To foster the development of SPOT satellite applications, CCRS offered zero-cost imagery to those in the private sector who had ideas for new commercial applications. Commercial groups were asked to make suggestions for new applications. Companies who presented ideas for new applications received an image for their research and evaluation where it was judged by CCRS that the potential for the application was unknown. The only commitment on the part of the company was to provide a brief report on the success or lack of it with regard to the stated application. One company involved has become the largest single purchaser of SPOT imagery in Canada.

The Opportunity

Companies, colleges, universities, government research agencies and resource management end-users are invited to identify potential applications which they would like to evaluate. Should the applications be judged to be "routine", or well recognized as radar applications (such as ice monitoring or water body mapping), they will not be accepted. Those proposals which are accepted may receive up to six ERS-1 and/or JERS-1 standard products (scenes) free of charge. The proposal should specify the nature of the application, the people to be involved, the market being addressed, and the potential size of the market for the imagery. In addition, if it can be specified at this time, the location of the required scenes and the window for the acquisition date.

Limitations

This offer is made only to Canadian organizations. The data offered is that which can be received at the Canadian ground stations. This data will be processed to standard products on the Canadian ground systems.CCRS is unable to provide financial assistance in support of proposals responding to this announcement.This offer is not being made to permit research groups to expand the data sets allocated by ESA under ERS-1 Announcement of Opportunity.

Reporting

The recipient of data shall prepare a report of no more than ten pages on the application success, including accuracies achieved. The report shall be due within 1 year of the delivery of the data set. For teaching applications, the nature of ground data to be collected must be specified and an undertaking must be made to publish the data set or make it available to other Canadian education institutions at nominal cost. Should a company not decide to prepare a report (because of the potential commercial market), the company may buy its way out of the agreement by purchasing the imagery supplied at full cost.

Corporate Commitment

Proposals must be accompanied by a letter, signed by an appropriate officer of the organization, committing the organization to analyze the data provided by CCRS and to report the results within 1 year after the delivery of the data set.

Evaluation of Proposals

Proposals shall be evaluated by a small team consisting of the Chief of Industrial Cooperation and the discipline coordinators of the Radar Data Development Program. Proposals shall be treated as proprietary. The general nature of successful proposals to which CCRS agrees to contribute data shall not be proprietary. The reports submitted at the conclusion of each project shall be generally available.

TABLE A.2: Canadian ERS-1 AO Projects

Application	*Projects*	*Scenes*	*Project Status: Complete (other)**
Agriculture	7	38	7
Education	1	1	1
Environment (BOREAS)	1	~6	1
Forestry	6	26	4 (2)
Geology	18	48	15 (3)
Glaciology	1	6	(1)
Habitat	1	2	(1)
Hydrology	8	32	5 (3)
Ice	2	~600	1 (1)
Mapping	9	126	7 (2)
Oceans/ Coastal	6	~33	5 (1)
Other	2	4	1 (1)
Total	62	~900	47 (15)

Project Summary

A summary of the Canadian ERS-1 AO projects is presented in Table 2. A total of 62 projects qualified, and approximately 900 scenes were distributed to project team members. Most of the image data was delivered to the investigators from 1992 through to 1995. Project reports were filed by 47projects teams; 42 projects are completed and five projects are still ongoing. Three project teams did not file a report because the work could not not be conducted as planned. In 12 cases, project work was either not done or not reported on. A cummulative list of references is provided in the Appendix. Project specific references are contained in the individual summary sheets in PART B.

Applications

The application with the largest number of individual projects was Geology, followed by Mapping, Hydrology, Agriculture,Oceans and Forestry, and Ice. The remaining applications all had one project each.

Data Volume

A very large number of scenes (~600) were processed under arrangement with the Ice Centre of the Atmospheric Environment Service (AES), Environment Canada, for operational algorithm development and testing in preparation for RADARSAT. A large number of scenes was also required for two large-area mapping and mosaicking projects over British Columbia;one project received 53 scenes, the other required 16 scenes. In some cases the amount of data delivered was not accounted

TABLE A.3: Canadian ERS-1 AO Project Coverage by Province

Province (area)	*ERS-1 Scenes*	*No. of Projects*
British Columbia	106	12 (2)*
Yukon	7	2 (1)
Northwest Territories	~21	4
Alberta	32	3 (2)
Saskatchewan	15	3 (1)
Manitoba	6	2 (3)
Ontario	20	6 (2)
Quebec	52	6(1)
New Brunswick	15	4
Prince Edward Island	12	1
Nova Scotia	21	4
Newfoundland	10	2 (3)
East Coast (off shore)	~600	2
USA	10	3

* Brackets indicate number of projects with coverage in another province.

for precisely. Therefore, Table 2 only identifies the estimated number of scenes delivered to the investigators. Table 3 identifies Canadian ERS-1 AO project coverage and number of projects on a province by province basis.

ESA ERS-1 Announcement of Opportunity

ESA AO Process

In 1986, the European Space Agency issued a scientific Announcement of Opportunity for use of data from the ERS-1 satellite in the scientific and application domain. Canada particpated successfully in this AO which resulted in approximately 260 experiments around the world. These projects were considered by a review committee composed of experts appointed by ESA and endorsed by the Programme Board of Eartrh Observation of ESA.

Support Mechanisms

ESA provided support to the selected projects by making available the necessary ERS-1 data products free of charge, as well as the relevant documentation concerning the mission, the instrumentation. The format and contents of the data products. ESA also organized meetings in order to exchange technical information. ESA also provided access to User Services which allowed for the submission of requests for data products and scheduling of data acquisition by the ERS-1 satellite.

Canadian Projects

In Canada, ESA ERS-1 AO project work was carried out under the leadership of the Canada Centre for Remote Sensing with Dr. Ron Brown as Principal Investigator. CCRS worked closely with other organizations to conduct a series of ESA ERS-1 AO projects in Canada. Studies were conducted in the area of renewable and non-renewable resource analysis, as well as oceanography and for sensor calibration purposes. The Ice Centre of Environment Canada's Atmospheric Environment Service used data for validation studies.

TABLE A.4: ESA ERS-1 AO Projects

Application	*Projects*	*Scenes*
Agriculture	7	~15
Calibration	1	~25
Forestry	2	15
Geology	3	3
Hydrology	3	25
Ice	2	~2800
Mapping	3	6
Oceans	1	12
Total	22	~2900

Summary

Table 4 contains a summary of applications, number of projects, and overall ERS-1 SAR data volume. A total of 22 individual projects were carried out under the Canadian ESA ERS-1 AO umbrella. Approximately 100 scenes were distributed to project team members for non-renewable and renewable resource analysis, wave and calibraion studies during the period of 1991 to 1995. A far greater nember was used for ice reconnaissance and validation studies. The application with the largest number of individual projects was Agriculture, followed by Geology, Hydrology, Mapping with three projects each, then Forestry and Ice with two projects each. The remaining application areas had one project each. A cummulative list of references is provided in the Appendix. Project specific references are contained in the individual summary sheets in PART C.

Summary of Important ERS-1 AO Events

1986:
ESA issues a scientific Announcement of Opportunity resulting in about 260 experiments, including Canadian projects

May, 1990:
ESA issues a call for applications oriented pilot projects, resulting in 23 applications projects in Europe

July, 1991:
ESA launches the ERS-1 satellite from the Kourou Space Centre in French Guyana.

Fall/Winter, 1991:
Testing and commissioning of Canadian ERS-1 SAR receiving stations in Prince Albert and Gatineau and processing facilities (Gatineau)

December, 1991:
ERS-1 Commissioning Phase begins in order to test and validate the ERS-1 sensor package.

November, 1991:
Government of Canada officially releases the Canadian ERS-1 Announcement of Opportunity.

November, 1992:
ESA holds a general meeting in Cannes, France, to present first results of ERS-1 data analyses, including those by Canadian investigations (ESA 1992).

October, 1993:
ESA holds the Second ERS-1 Symposium in Hamburg, Germany (ESA, 1993). Canadian investigators reported on progress of their projects.

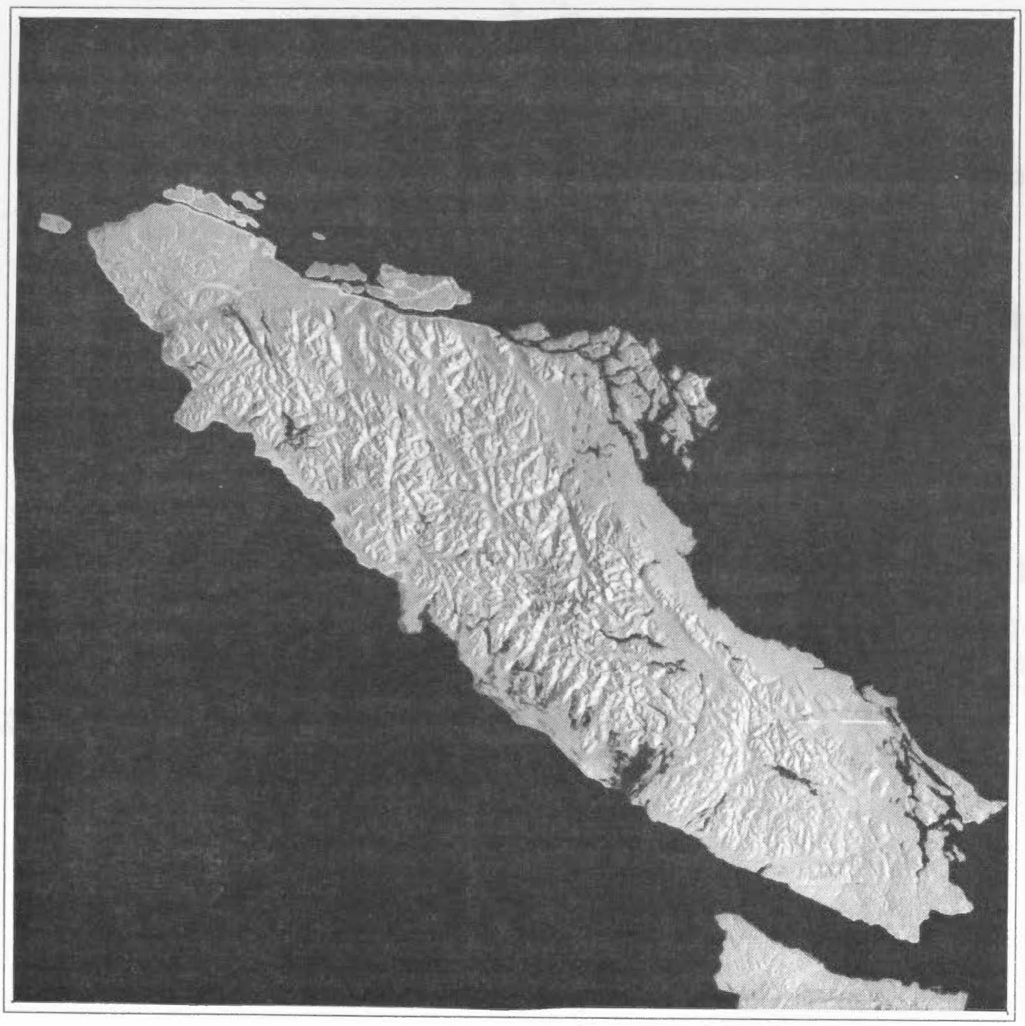
June, 1994:

ESA holds the First Workshop on ERS-1 Pilot Projects in Toledo, Spain, on July 22 to 24, 1994.

April, 1995:
ERS-2 successfully launched from the Kourou Space Centre in French Guyana.

March, 1996:
CCRS, in cooperation with the Canadian ERS-1 AO participants, releases a Summary Report of ERS-1 AO activities in Canada.

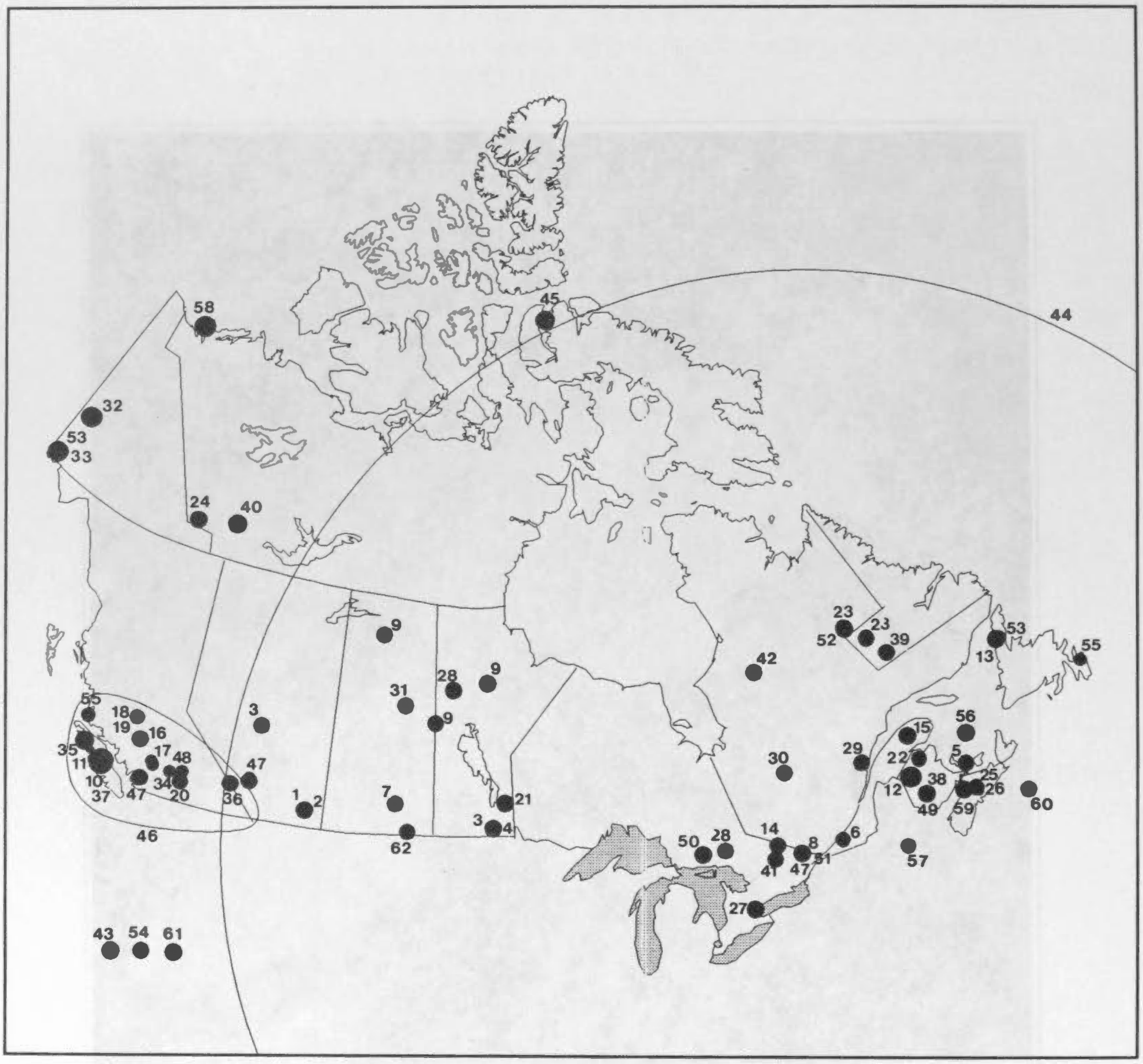
PART B:
CANADIAN ERS-1 AO PROJECTS



ERS-1 SAR mosaic of Vancouver Island, produced at CCRS / © ESA 1993

CANADIAN ERS-1 AO PROJECTS

PART 'B' contains details regarding all Canadian ERS-1 AO projects. A list of these projects is presented in TABLE B.1. The geographic distribution of the projects is presented in MAP B.1. This is followed by 62 Project Summary Sheets. Note that actual project numbers are cross-referenced so that project numbers mentioned in TABLE B.1 correspond to location numbers in MAP B.1 and Project Summary Sheet numbers.



MAP B.1: Regional Distribution of Canadian ERS-1 AO Projects in Canada

TABLE B.1: List of Canadian ERS-1 A/O Projects

No.	*Application*	*Area*	*P.I.*
1	Agriculture	Southeast Alberta	D. Major
2	Agricutlure	Southern Alberta	D. Major
3	Agriculture	Central Alberta and Southern Manitoba	T. Huffman
4	Agriculture	Altona, Manitoba	R. Dixon
5	Agriculture	Summerside, Prince Edward Island	K. Korporal
6	Agriculture	Ste.-Leonard D'Aston, Quebec	M. Hinse
7	Agriculture	Melville Saskatchewan	C. Chen
8	Education	Ottawa, Ontario	R. Saper
9	Environment	Northern Manitoba and Saskatchewan	J. Cihlar
10	Forestry	Vancouver Island, British Columbia	D. Goodenough
11	Forestry	Vancouver Island, British Columbia	D. Jaques
12	Forestry	Northwestern New Brunswick	S. Franklin
13	Forestry	Western Newfoundland	S. Franklin
14	Forestry	Petawawa, Ontario	T. Amano
15	Forestry	Gaspe, Quebec	M. Hinse
16	Geology	Fraser Plateau, British Columbia	B. Broster
17	Geology	Lillooet, British Columbia	K. Campbell
18	Geology	Quesnel, British Columbia	K. Campbell
19	Geology	Quesnel, British Columbia	K. Campbell
20	Geology	Revelstoke, British Columbia	P. Dong
21	Geology	Whiteshell, Manitoba	A. Brown
22	Geology	Northern New Brunswick	T. Mersereau
23	Geology	Shefferville, Que., Labrador City, NFLD	J. Harris
24	Geology	Nahanni, Northwest Territories	W. Moon
25	Geology	Truro, Nova Scotia	M. Akhavi
26	Geology	Central Nova Scotia	M. Akhavi
27	Geology	Southern Ontario	A. Rutty
28	Geology	Sudbury, Ontario / Snow Lake, Manitoba	W. Moon
29	Geology	Charlevoix, Quebec	R. Desjardins

TABLE B.1: List of Canadian ERS-1 A/O Projects, Continued

No.	*Application*	*Area*	*P.I.*
30	Geology	Demaraisville, Quebec	A. Moreau
31	Geology	South-Eastern & Northern Sashatchewan	J. Shaner
32	Geology	Dawson Creek, Yukon	S. Franklin
33	Geology	St. Elias Mountains, Yukon	G. McDermid
34	Glaciology	Central British Columbia	M. Brugman
35	Habitat	Vancouver Island, British Columbia	D. Jaques
36	Hydrology	Banff, Alberta	A. Maxfield
37	Hydrology	Vancouver Island, British Columbia	D. Jaques
38	Hydrology	Central New Brunswick	P. Tang
39	Hydrology	Churchill Falls, Newfoundland	D. Bajzak
40	Hydrology	Fort Simpson, Northwest Territories	R. Soulis
41	Hydrology	Algonquin Park, Ontario	R. Ducan
42	Hydrology	Riviere La Grand (LG4), Quebec	J-P. Fortin
43	Hydrology	Northern California, USA	R. Saper
44	Ice	East Coast (off shore)	B. Ramsay
45	Ice	Bent Horn, Northwest Territories	R. Gorman
46	Mapping	Southern British Columbia	B. Guindon
47	Mapping	S. British Columbia, Alberta, Ontario	B. Mercer
48	Mapping	Vernon, British Columbia	M. Seymour
49	Mapping	Gagetown, New Brunswick	E. Derenyi
50	Mapping	Northern Ontario	U. Nielson
51	Mapping	Ottawa, Ontario	H. Moore
52	Mapping	Shefferville, Quebec	P. Vachon
53	Mapping	Yukon / Western Newfoundland	S. Franklin
54	Mapping	Lander, California, USA	L. Gray
55	Oceans	British Columbia & Newfoundland	R. McKenna
56	Oceans/Coastal	Isle-de-la-Madeleine, Quebec	G. Drapeau
57	Oceans	Gulf of Maine	M. Collins
58	Oceans/Coastal	Beaufort Shore, Northwest Territories	C. Bjerkelund

TABLE B.1: List of Canadian ERS-1 A/O Projects, Continued

No.	*Application*	*Area*	*P.I.*
59	Oceans/Coastal	Central Nova Scotia	D. Werle
60	Oceans	Sable Island, Nova Scotia	A. Thomas
61	Software Development	Orange County, California, USA	T. Wilson
62		Estevan, Saskatchewan	D. Thomson

A. *Project Title:* **Remote Sensing of Mixed Prairie Range Condition**

B. *Study Area:* South Eastern Alberta

C. *ERS-1 Data:* 2 scenes (13 Aug 1991, 20 Aug 1992)

D. *Principal Investigator(s):*

Name: Dr. David Major
Affiliation: Agriculture and Agri-Food Canada
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E. *Co-Investigator(s):*

Dr. A. Smith (Agriculture Canada)

F. *Study Objectives & Methodology:*

The study objective was to use satellite SAR and visible infrared (VIR) imagery as tools in rangeland monitoring. Data from Landsat Thematic Mapper (TM) and SPOT satellites were compared with data from airborne and ERS-1 satellite synthetic aperture radar (SAR) sensors to determine similarities and contrasts in assessing rangeland at the Agriculture and Agri-Food Canada, Onefour Research Substation.

G. *Results & Recommendations:*

The TM and SPOT sensor bands were highly correlated with each other and the radar sensors were correlated with each other to a lesser degree. Correlations between SAR and VIR were not high. Russian wildrye pastures had high SAR and high VIR returns while native range had low SAR and low VIR. Crested wheatgrass had high SAR and low VIR return. Other features such as sedimentary Cretaceous softrock, had high SAR and VIR returns while intermittent water bodies or shallow depressions, characterized by high clay content and strong micro-topography, had high SAR and low VIR. More information can be obtained from a combination of both types of sensor than from either alone.

H. *References:*

Major D. J., A.M. Smith, (1994) *Report: Canadian ERS-1 / JERS-1 Announcement of Opportunity*; Agriculture Canada; Submitted to the Canada Centre for Remote Sensing, 92 p.

Smith A. M., D.J. Major, B. Brisco, R.J. Brown, (1993) Complementarity of Radar and Visible-Infrared Sensors in Assessing Rangeland Condition, *Proceedings 16th Canadian Symposium on Remote Sensing*, Sherbrooke, Que, pp 331-336.

Smith A. M., D.J. Major, B. Brisco, R.J. Brown, (1993) Complementarity of Radar and Visible-Infrared Sensors in Assessing Rangeland Condition; *Cdn. J. of Rem. Sensing*, (pre-print).

Smith A. M., D.J. Major, R.L. McNeil, W.D. Willms, B. Brisco, R.J. Brown, (1995) Complementarity of Radar and Visible-Infrared Sensors in Assessing Rangeland Condition. *Remote Sensing Environment*, Vol. 52, pp.173-180.

Smith A. M., R.J. McNeil, D.J. Major, W.D. Willms, (1995) Rangeland Monitoring by Visible-Infrared and Radar Sensors. *Abstracts Fifth International Rangeland Congress*, Salt Lake City, Utah. 23-28 July, 1995. p.64.

Willms, W. D., D.J. Major, M.J. Hill, B. Brisco, R.J. Brown, (1993) Remote Sensing and Geographic Information Systems for Range Assessment in Southern Alberta, *Proceedings XVII Int. Grassland Congress*, Lincolin, NZ, Feb. 15-16, pp 1608-1609.

A. *Project Title:* **Complementarity of Radar and VIR for Processing Soil Erodability**

B. *Study Area:* Southeast Alberta

C. *ERS-1 Data:* 10 scenes (17 July 1992, 4 Nov 1992, 13 Jan 1993, 28 April 1993, 2 July 1993, 7 Aug 1993, 11 Aug 1993, 17 Nov 1993, 19 Nov 1993, 11 May 1994)

D. *Principal Investigator(s):*

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E-mail: major@abrsle.agr.ca

E. *Co-Investigator(s):*

Dr. A. Smith (Agriculture Canada)

F. *Study Objectives & Methodology:*

The study objective was to use satellite SAR and VIR imagery combined in a GIS to assess erodability of fields in southern Alberta. Ground-based VIR and radar backscatter experiments have clearly demonstrated that VIR reflectance is capable of classifying fields with respect to the amount of crop residue and radar is capable of identifying fields that have been cultivated. The intent was to assess the ability to identify cultivation practice using ERS-1 and JERS-1 radar data and compare the information content from the two sensors.

G. *Results & Recommendations:*

In the original proposal we had asked for radar imagery for 1992 and 1993 to coincide with the VIR satellite data we acquired for four test sites that were ground-truthed. No JERS-1 imagery was available for the fall and the three scenes we did receive were found to be of areas other than the test sites.

ERS-1 data were acquired for the fall of 1992, the spring, summer and fall of 1993. The data was processed and analyzed for the ability to differentiate cultivation practices. The direction of cultivation and the high degree of within-field variability and speckle confounded the identification of tillage practice. The results of airborne synthetic aperture radar and ground-based scatterometer data suggest that the incidence angle of ERS-1 (23 degrees) is sub-optimal for the identification of tillage induced surface roughness.

The areas in the JERS-1 images did not overlie those in the ERS-1 images and consequently at this time no results or recommendations are available with respect to a comparison between these two sensors. RADARSAT with its multiple incidence angle capability should be evaluated with respect to identifying cultivation and therefore conservation farming practices.

H. References:

Major D. J., A.M. Smith, (1994) *Report: Canadian ERS-1 / JERS-1 Announcement of Opportunity*; Agriculture Canada, Submitted to the Canada Centre for Remote Sensing,, 92 pages.

Smith, A. M., D.J. Major, C.W. Lindwall, (1994) *Annual Report of the PARI Program 2: Monitoring Conservation Preactices in Three Soil Types in Southern Alberta*, March 25, 1994, 30 p.

Smith, A. M., D.J. Major, C.W. Lindwall, (1993) Monitoring Soil Conservation Practices in souther Alberta Using Remote Sensing, *Proceedings 16th Canadian Symposium on Remote Sensing*, Sherbrooke, Que, , pp 909-913.

Smith A.M. & D.J. Major, (1994) Assessing Soil Conservation Practices with Remote Sensing, *Proceedings Annual Meetings Canadian Society of Agronomy*, Regina, SK. July 10-14, 1994.

Smith A.M., D.J. Major, C.W. Lindwall, (1994) Monitoring Soil Conservation Practices Using Remote Sensing, *Agronomy Abstracts*, Seattle, Washington, November 13-18, 1994. p. 357.

Smith A.M. & D.J. Major, (1995) Remote Sensing and Soil Conservation in Southern Alberta, *Proceedings 1995 Conservation Workshop and Farm Progress Days Trad Show and the Alberta Conservation Tillage Society 17th Annual Meeting*, Red Deer, AB. Feb. 23-25, 1995. p.191.

Smith A.M., D.J. Major, C.W. Lindwall, (1995) Monitoring Agricultural Practices Using Remote Sensing, *Proceedings 17th Canadian Symposium on Remote Sensing, Saskatoon*, SK. 13-15 June 1995. Vol. 1, pp.375-380.

Smith A.M., D.J. Major, C.W. Lindwall, R.J. Brown, (1995) Multi-Temporal, Multi-Sensor Remote Sensing for Monitoring Soil Conservation Farming, *Cdn. J. Rem. Sensing*, 21, pp.177-184.

A. *Project Title:* **Land Use & Land Cover Monitoring in the Canadian Prairies**

B. *Study Area:* Central Alberta and southern Manitoba

C. *ERS-1 Data:* 9 scenes (2 June 1993 (2), 10 June 1993, 15 July 1993, 19 Aug 1993, 23 Sept 1993, 20 Oct 1993 (2), 28 Oct 1993)

D. *Principal Investigator(s):*

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E. *Co-Investigator(s):*

E. Unrau, Geomatics Consultant.

F. *Study Objectives & Methodology:*

The study objective was to evaluate the feasibility and cost of using ERS-1 imagery as an alternative to Landsat TM imagery in crop rotation mapping. The evaluation was conducted by calculating classification accuracies using different combinations of radar images from within one growing season in a conventional multi-temporal classification scheme and comparing those results with the accuracy obtained using one TM scene.

G. *Results & Recommendations:*

Results of this study indicate that a series of ERS-1 images spaced approximately one month apart throughout the growing season can provide adequate crop classification accuracies. However, in order to achieve an accuracy equivalent to a single, 3-band TM image from mid-July, six radar images (April, May, June, July, August, September) were required. Using the ERS-1 imagery required six times as much processing and would cost approximately three times as much.

The implications are that multi-temporal ERS-1 imagery can be used to replace Landsat TM imagery in agricultural land cover classifications, thus adding a degree of certainty to time frames for projects involving remote sensing. However, the time and cost requirements of using multi-temporal radar imagery dictate that such use may only be warranted for critical projects when no cloud-free VIR imagery is available or for relatively small areas.

H. *References:* None.

A. *Project Title:* **ERS-1 for Crop Identification in the Altona Region**

B. *Study Area:* Altona Manitoba.

C. *ERS-1 Data:* 1 scene (24 July 1992)

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E. *Co-Investigator(s):*

None.

F. *Study Objectives & Methodology:*

The study objective was to evaluate the usefulness of ERS-1 single date data for crop seperability in the Red River valley of southern Manitoba. A digital image anaylsis procedure was conducted in two phases. Phase one consisted of image pre-processing. A radiometric correction was applied to the scene followed by a median filter to reduce speckle. A linear contrast stretch was then applied to the median filtered image. The second phase involved the generation of training area polygons for every field within the study area using ground survey data to define the agricultural classes. A feature selection algorithm was used to determine discrimination between agricultural classes.

G. *Results & Recommendations:*

The algorithm used to assess crop seperability provided the divergence and transformed divergence between eight crop classes. Cereals were consistently separable from the broad-leafed crops (corn, sunflower, canola, sugar beets, peas, and lentils) as indicated by the transformed divergence values. These results appear consistent with previous findings (Brown et al., 1993). Sunflower had the brightest backscatter values within the broad-leafed crops and therefore was separable from all crops with the exception of sugar beets. Further work is planned for this project and as yet to be completed.

H. *References:*

Brown, R.J., B. Brisco, R. Leconte, D.J. Major, J.A. Fischer, G. Reichert, K.D. Korporal, P.R. Bullock, H. Pokrant, J. Culley, (1993) Potential Applicationa of RADARSAT Data to Agriculture and Hydrology, *Cdn. J. of Rem. Sensing*, Vol. 19(4), pp. 317-329.

A. *Project Title:* **Potato Crop Monitoring in Prince Edward Island**

B. *Study Area:* Summerside-Kensington, P.E.I.

C. *ERS-1 Data:* 12 scenes (17, 18 June 1992; 7, 8 August 1992; 23, 24 August 1992; 3, 18 June 1993; 8, 23 July 1993; 27, 28 Aug 1993)

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E. *Co-Investigator(s):*

Dr. R. Brown (CCRS), Dr. B. Brisco (Intera).

F. *Study Objectives & Methodology:*

The main objectives were to evaluate ERS-1 SAR imagery for operational potato crop monitoring in PEI, and as a potential replacement and/or complementary source of digital satellite imagery for Landsat TM and SPOT XS imagery. The research was divide into two phases.

Phase I methodology consisted of the development of images analysis and GIS procedures in order to compare the accuracy of potato classifications generated from single-date and multi-temporal ERS-1 data sets. The classifications from the 1992 data set were compared with results obtained from Landsat TM and SPOT XS imagery. Extensive ground truth data was collected during mid-July throughout the study region, and captured in a GIS. The GIS was used to generate confusion matrices to assess classification accuracies.

Phase II methodology consisted of conducting image data analysis on the 1993 data set. The ERS-1 SAR data was radiometrically corrected, adjusted for speckle, and registered to the UTM map projection. Transform divergence statistics were computed for all major crops using single-data and multi-temporal data. These statistics were compared with results obtained from analysis of the SPOT XS data.

G. *Results & Recommendations:*

Phase I:

Potato classification accuracy obtained by digital analysis of the multi-date (early & late season) ERS-1 SAR imagery were marginally better than results obtained using single-date SPOT XS and/or Landsat TM. The research demonstrated that potato crop row direction significantly affects radar return and subsequent potato classification accuracy. The best potato classifications were obtained using multi-date ERS-1 descending mode imagery under dry conditions. This research demonstrated the potential for incorporating ERS-1 SAR data as a complementary data source for operational potato crop monitoring. The usefulness of ERS-1 SAR as a data source to overcome localized cloud-cover problems was illustrated. Preliminary results indicated the potential for preparation of early-season potato area estimates and potato crop mapping using a combination of SAR and VIR satellite imagery. Nonetheless, the findings in Phase I were inconclusive because of the lack of ERS-1 data collected during the optimum acquisition window during July (due to a temporary satellite malfunction). Based on these results, a broader research study was planned under Phase II to address ERS-1 information content for operational crop monitoring.

Phase II:

It was determined that single-date ERS-1 imagery cannot meet the accuracy demands of operational crop classification in PEI. Multi-date ERS-1 imagery might meet the accuracy demands, but additional imagery costs question the operational cost-effectiveness. Single-date ERS-1 data provides complementary information for SPOT by enhancing the information content and accuracy. Descending mode SAR data are preferred over ascending mode imagery, and environmental effects on the data must be considered in image acquisition strategy.

The research indicated that the information content of ERS-1 and SPOT XS data is complementary, but requires extra analysis to address issues of crop row direction relative to the orbit track of ERS-1. This is not a factor for the SPOT data. Additional processing resources, data costs, and analysis complexity make this a questionable operational scenario. The July ERS-1 imagery is best for both ascending and descending modes. Multi-temporal ERS-1 combinations using early, mid and late-season imagery meets operational accuracy, but not cost-effectiveness. This research also confirmed previous findings that row direction in potatoes becomes as issue in all SAR image dates, particularly in early and late-season. Also, row direction effects can be seen equally in both ascending and descending SAR imagery. This work confirmed previous findings which indicate improved crop separability using ERS-1 imagery acquired during dry conditions.

H. References:

Dobbins, R., P. Nixon & K. Korporal, (1992) Comparison of ERS-1 and VIR Digital Data for Potato Crop Monitoring, presentation at the 2nd Radar Data Development Program Workshop, 26-28 January , 1993, Gananoque, Ontario.

Dobbins, R., P. Nixon & K. Korporal, (1995) Comparison of ERS-1 and VIR Digital Data for Potato Crop Monitoring, presentation at the 17th Canadian Symposium on Remote Sensing, Saskatoon, Sask, 13-015 June, 1995

A. *Project Title:* **Suivi des Pratiques Agricoles de Conservation et Mesurage des Parcelles**

B. *Study Area:* Saint-Léonard D'Aston, Quebec

C. *ERS-1 Data:* 4 scenes (25 July 1992, 28 July 1992, 16 Aug 1992, 13 Sept 1992)

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E. *Co-Investigator(s):*

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F. *Study Objectives & Methodology:*

Les objectifs de l'étude portaient sur (1) l'identification de pratiques agricoles dans une perspective de conservation des sols sur les images RSO aéroportées et satellitaires ERS-1, et (2) sur une évaluation des images radars pour l'identification et la mesure de parcelles agricoles. Suite à une campagne de terrain qui a permis de recenser et d'identifier diverses pratiques agricoles, une interprétation visuelle et une analyse statistique des données radars a été realisée afin de discriminer et de cartographier les pratiques agricoles de conservation des sols. Les mesures de parcelles agricoles ont consisté en une comparaison des résultats obtenus par méthode traditionnelle et ceux obtenus avec les images radars.

G. *Results & Recommendations:*

Même si plusieurs points n'ont pu être éclaircis de façon déterminante, cette étude démontre qu'au niveau des pratiques de conservation des sols, il a été possible de discriminer, sur les images RSO aéroportées, les surfaces à plus fort risque d'érosion de celles à plus faible risque, ainsi que les surfaces de sols nus hersées par rapport aux surfaces plus rugueuses de labour ou de chisel. Cependant, la confusion entre les surfaces à plus fort risque d'érosion, qui dépendent fortement de la quantité, plus ou moins grande, de résidus laissés au sol, demeure élevée. Une des sources importantes de cette confusion est attribuable aux conditions de gel au sol qui règnait lors de l'acquisition des images radar. Ce facteur a modifié considérablement la constante diélectrique relié a l'humidité des sols, ce qui a eu pour effet de masquer l'information reliée aux résidus de surface. Il demeure donc essentiel d'acquérir des images radar qui répondent au créneau des pratiques de conservation et qui soient prises dans des conditions optimum de surfaces de sols secs.

Sur le plan du mesurage des parcelles agricoles, l'étude démontre que la précision des mesures sur l'image RSO aéroportée est comparable à celle obtenue à partir de la photographie aérienne. Cependant, l'image radar n'a pas fait ressortir tel qu'espéré les limites plus subtiles entre les parcelles de même culture permettant une délimitation nette entre ces dernières. Il reste encore beaucoup de développement à faire dans le domaine des images radar pour maîtriser les données à l'intérieur d'une méthode opérationnelle.

En regard des objectifs de cette étude et du paysage agricole québécois, constitué de parcelles fortement morcellées, les caractéristiques des images ERS-1 n'ont représenté aucun intérêt, notamment en terme de résolution spatiale et d'angle d'incidence. Il semble donc que les applications des images ERS-1 dans ce domaine demeurent très limitées et peu propices à des progrès notables.

H. References:

Hinse, M., M. Carigan, (1993) *Utilisation D'Images Radar Aéroportées pour l'Étude des Pratique Agricoles de Conservation des Sols et la Mesure de Parcelles*, Report No H9305R01 Submitted to the Canada Centre for Remote Sensing.

A. *Project Title:* **Satellite SAR Application Development for Agriculture**

B. *Study Area:* Melville Saskatchewan

C. *ERS-1 Data:* 4 scenes (16 June 1993, 21 July 1993, 25 Aug 1993, 5 Sept 1993,)

D. *Principal Investigator(s):*

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E. *Co-Investigator(s):* None.

F. *Study Objectives & Methodology:*

The objectives of this study were to investigate the extent to which SAR images could be used to identify crop types and to differentiate between crops and forage. Four ERS-1 SAR images were used. Both single date and multi-temporal images were examined in terms of classification accuracy over an area of 60 square kilometres. An image segmentation technique was developed and tested on a smaller area (12.8 km) to extract and classify homogeneous segments of SAR images. This procedure is referred to as per-field classification.

G. *Results & Recommendations:*

Single-date C-VV SAR imagery can be used to distinguish grain and peas from summer fallow and forage with a high degree of accuracy (85.7% for grain and 91.2% for peas) in the middle to late crop growing season (20-25 July) in the study area. June and August multi-date classification can be used to distinguish forage from crops. Because of confusion between crops and summer fallow in the early growing season, and among crops in the late ripen season, and between fallow and forage in the middle growing season, the overall classification accuracy for the multi-temporal data was 59% - 64%, while the single date image classification accuracy was 40.4% - 53%.

The image segmentation technique improved the classification of canola, field peas and summer-fallow by 19%, 15% and 17.8% respectively. The overall classification improved by at least 12%. Results of segmentation (per-field classification) applied on multi-temporal imagery provided better classification results and higher accuracy than traditional per-pixel classification.

H. *References:*

Chen, C., (1995) *RADARSAT Technology Transfer Phase II - Agriculture Application*, Internal Report, Devel-Tech Inc., Saskatoon, SK.

Chen, C., (1995) *RADARSAT Technology Transfer Phase II (for value-added component)*, Interim Report, Devel-Tech Inc., Saskatoon, SK.

A. *Project Title:* **To Evaluate Educational Applications of ERS-1 and JERS-1 Data**

B. *Study Area:* Kanata, Ontario

C. *ERS-1 Data:* 1 scene (22 May 1993)

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E. *Co-Investigator(s):*

None.

F. *Study Objectives & Methodology:*

The study objective was to produce prototype educational materials in various media aimed at helping to increase the proficiency of the learner to interpret SAR image data.

G. *Results & Recommendations:*

The results of this study were non-commercial prototype components of electronic tutorials which combined images, text and diagrams in an interactive point-and-click format. These prototypes were the precursors of the RADARSAT Tutor, The Electronic Version of the ERS-1 Canadian User's Guide, the RADARSAT Mission, and Understanding Synthetic Aperture Radar Images.

H. *References:*

Canada Centre for Remote Sensing, (1992) *The Electronic Version of the ERS-1 Canadian User's Guide*, Natural Resources Canada.

Canadian Space Agency, (1993) *The RADARSAT Mission.*

Vantage Point International Inc., (1991) *RADARSAT Tutor.*

Vantage Point International Inc., (1994) *Understanding Synthetic Aperture Radar Images.*

A. *Project Title:* **Boreal Ecosystem Atmosphere Study (BOREAS)**

B. *Study Area:* Northern Manitoba and Saskatchewan

C. *ERS-1 Data:* ~6 scenes.

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F. *Study Objectives & Methodology:*

The objectives of this project are twofold. The first is to map forest structural properties in the boreal forest of Canada using JERS-1 and ERS-1 data with optical image data sets. Longer wavelength L-band SAR data penetrates into forest canopies better than shorter wavelengths and thus can provide more direct inferences about canopy vertical structure. This information can then be used to develop algorithms for estimating forest structure variables such as standing biomass density and forest type. Examination of these variables across the landscape with JERS-1 can reveal horizontal structure information related to ecosystem processes. Co-registered optical satellite data such as Landsat TM will be used to enhance the classification of forest types.

The second objective is to map various levels of regeneration using multi-temporal JERS-1 data over the boreal forest, especially in areas of recent fires. The sensitivity of the JERS-1 signal to forest biomass values less than 100 tons/ha will be suitable for monitoring forest successional stages which are in turn related to the net primary production in young forests. By studying the relationship between the JERS-1 backscatter signal and existing information over experimental sites in the boreal forest of Canada and Alaska, we intend to develop a simple algorithm that can map various stages of regrowth. Preliminary examination of images from other areas suggests that the algorithm should be sensitive to regrowth during the first 10-15 years after fire or longer. In order to complete this study we require data sets from four seasons and at least over a two-year period.

G. *Results & Recommendations:*

The study is in progress. Field data have been collected and processed. Some satellite data processing has been completed. Further JERS-1 and ERS-1 satellite data will be required.

H. *References:* None.

A. Project Title: **SEIDAM: System of Experts for Intelligent Data Management - Forest Changes Through ERS-1 and JERS-1 Data Fusion**

B. Study Area: Parson, Sooke, Clayoquot Sound, Victoria British Columbia

C. ERS-1 Data: 5 scenes (21 July 1994, 24 July 1994, 3 Aug 1994, 7 Aug 1994, 13 Aug 1994)

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E. Co-Investigator(s):

None.

F. Study Objectives & Methodology:

A report was not submitted for this project.

G. Results & Recommendations:

None.

H. References:

None.

A. Project Title: **Monitor and Map Slope Stability Problems and Reforestation Efforts**

B. Study Area: West coast of Vancouver Island, B.C.

C. ERS-1 Data: 2 scenes (11 July 1992, 15 Aug 1992)

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E. Co-Investigator(s):

None

F. Study Objectives & Methodology:

A report was not submitted for this project.

G. Results & Recommendations:

None

H. References:

None

A. Project Title: **ERS-1 Estimation of Forest Parameters in Northwestern New Brunswick**

B. Study Area: Northwestern New Brunswick

C. ERS-1 Data: 1 scene (1 Aug 1993)

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F. Study Objectives & Methodology:

The objective of this study is to examine the spatial (textural) and spectral relationships between ERS-1 satellite SAR data and forest biophysical properties in a sample of stands of conifer-dominant second-growth in western New Brunswick. Image processing techniques applied to the single-band, single-date SAR observations are explored to reveal the conditions under which forest biophysical properties, such as woody biomass, may be estimated.

In another study from western Newfoundland (Franklin et al. 1994) (project # 13 in this report), relationships were found between SAR tone and balsam fir stand structure following the application of topographic corrections and adaptive algorithms. The overall goal is a model of Net Primary Production (NPP) that can be initialized with remote sensing input, and that can respond to temperature and moisture variations over time based on physiological principles.

We hypothesize that the ratio of respiration to photosynthesis can be predicted from the ratio of woody biomass to Leaf Area Index (LAI), which in turn can be predicted from the ratio of SAR backscatter to optical/near-infrared remote sensing observations. This research is part of a larger effort to determine the role of SAR imagery in this and other forest applications.

G. Results & Recommendations:

In general, significant relationships exist between LAI and vertically polarized power backscatter, which may decrease with decreased stem density or clumping. In this study, the largely deciduous stand had the lowest mean SAR tone response and the highest response was found in the coniferous stand. Conifers tend to have more 'horizontal' branching patterns which may tend to increase corner reflection patterns. The SAR backscatter will also vary as a function of the composition of the individual trees within a stand.

This study followed the trend of the Newfoundland study with the highest correlation between

SAR and Landsat TM data being in the TM infrared bands (TM4, 5, 7). The TM relationships were also generally stronger with the leaf based measures of foliage weight per hectare and LAI, than with the bole/branch measures.

An exploratory analysis of ERS-1 SAR imagery acquired over Newfoundland (Franklin et al. 1994) has been confirmed with the New Brunswick study. The forestry information content of these images is low, but their utility can be improved significantly through image processing (texture algorithms, particularly those with an adaptive technique). Field variables were regressed on the SAR observations following the interpretation of a number of individual correlations. Although these results are encouraging, the small sample sizes and the large standard error in some instances requires further testing of the principles explored in the study with larger data sets.

H. *References:*

Wulder, M.A., M.B. Lavigne, S.E. Franklin, (1995) Empirical Relations Between Forest Stand Parameters and ERS-1 SAR Imagery in Northwestern New Brunswick, *Proceedings, 17th Candian Symposium on Remote Sensing*, Saskatoon, Saskatchewan, 13-15 June, 1995, Canadian Remote Sensing Society, Ottawa, Ontario, pp. 663-668.

A. *Project Title:* **ERS-1 Radar Remote Sensing of Net Assimilation Rate in Western Newfoundland**

B. *Study Area:* Western Newfoundland

C. *ERS-1 Data:* 2 scenes (29 July 1992, 18 Sept 1992)

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F. *Study Objectives & Methodology:*

In this study the spatial (textural) and spectral relationships are examined between satellite SAR data and forest biophysical properties in 25 stands of second-growth balsam fir. Image processing techniques applied to single-band, single-date SAR observations are explored to reveal the conditions under which forest biophysical properties, such as woody biomass, may be estimated. Potential improvements in the analysis are revealed that may be available through one of the several possible remote sensing or image processing strategies.

The study is based on raw and corrected multi-look precision-coded ERS-1 SAR imagery. Landsat TM imagery is correlated with LAI, crown closure, and canopy height. The radar data is integrated with a DEM and the TM derived estimate of foliar biomass to study the possibility of driving forest growth models solely with remotely sensed data. Linear regression was selected as the method for testing ERS-1 SAR for dependency on local incidence angle, correlation with forest biomass parameters, complementary with TM image data, and integration with TM and DEM to characterize forest ecosystems.

The selected forest stands were surveyed late in the growing season and during the fall of 1992. They were chosen to obtain a wide range of woody biomass through age-class distributions from 10 to 60 years old, as well as large variations in stem density per hectare.

The ERS-1 SAR imagery was co-registered and re-sampled to a common 30m grid after processing to facilitate stand sampling. The TM data were adjusted for radiometric and atmospheric effects using the regression intersection method (Crippen, 1987). An additional correction, using mean crown length, was used to approximate canopy attenuation of the SAR data together with an estimate of incidence for local topographic effects.

Image texture analysis was based on first-order grey level statistics over a window size of 5 by 5 in the original resolution ERS-1 data for the point texture estimates and a power-domain shape parameter for the stand-level texture estimates.

G. *Results & Recommendations:*

The exploratory analysis of ERS-1 SAR data has shown that the forestry information content of these data is low, but that their utility can be improved significantly through image processing. Field variables were regressed on the SAR observations after corrections for incidence values were applied and canopy depth estimates used to isolate that portion of the SAR signal resulting from the double bounce.

Image texture and spatial statistics were used with the original SAR values, and showed some potential for improving estimates of stand conditions together with the co-registered TM optical data. However, this analysis confirmed empirically that the ERS-1 sensor measurements were dominated by the properties of the crown layer consisting of foliage and branches. This finding gives rise to the notion that useful allometric equations may be derived to yield estimates of other forest structure conditions such as stem biomass.

H. *References:*

Franklin, S. E., M.B. Lavigne, B.A. Wilson, E.R. Hunt Jr., (1994) Empirical Relations Between Balsam Fir (*Abies balsamea*) Forest Stand Conditions and ERS-1 SAR Data in Western Newfoundland; Special Symposium Issue, *Cdn. J.of Rem. Sensing*, Vol 20, No. 2, Ottawa, Ontario, pp. 124-130.

Franklin, S. E., M.B. Lavigne, B.A. Wilson, E.R. Hunt Jr., (1993) Empirical Relations Between Balsam Fir (*Abies balsamea*) Forest Stand Conditions and ERS-1 SAR Data in Western Newfoundland, *Proceedings of the 16th Canadian Symposium on Remote Sensing*, Sherbrooke, Canada, CCRS, Ottawa, Canada, pp. 295-300.

A. *Project Title:* **Data Fusion Analysis for ERS-1 and JERS-1**

B. *Study Area:* Petawawa, Ontario

C. *ERS-1 Data:* 3 scenes (28 Feb 1993, 13 June 1993, 2 July 1993)

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F. *Study Objectives & Methodology:*

Investigating forest classification improvement by data fusion and co-registration of ERS-1 and JERS-1.

G. *Results & Recommendations:*

Project is underway and the co-registration is complete. Further analysis is in progress.

H. *References:*

None.

A. *Project Title:* **Suivi des Changements en Forêt et des Coupes avec des Données Radar**

B. *Study Area:* Gaspe Penninsula, Quebec

C. *ERS-1 Data:* 5 scenes (25 July 1992, 28 July 1992, 16 Aug 1992, 8 Oct 1992, 21 Oct 1992)

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E. *Co-Investigator(s):*

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F. *Study Objectives & Methodology:*

Les objectifs poursuivis par ce project d'application d'images radar sont: (1) évaluer le potentiel des images radar aéroportées et d'une image satellitaire ERS-1 pour la mise à jour annuelle de l'information sur les interventions forestières; (2) évaluer le contenu de l'information forestière des images radar aéroportées prises seules et en hybridation avec des images optiques satellitaires; (3) évaluer la précision de la superficie des aires de coupes obtenues avec les images radar aéroportées en comparasion avec la méthode traditionnelle ainsi qu'avec les images SPOT et Landsat-TM.

La méthodologie employée se résume en quatre volets: (1) correction géométrique des images radar et des images optiques satellitaires et production d'ortho-images à l'aide d'un modèle numérique d'élévation; (2) interprétation et cartographie des couped forestières à l'aide de l'imagerie radar (aéroportées et satellitaire ERS-1); (3) évaluation quantitative de la superficie des aire de coupes répertoriées à l'aide de l'imagerie radar et comparaison par rapport à la carte forestière 1991 et aux images optiques satellitaires SPOT at Landsat-TM; (4) évaluation qualitative des interventions forestières sur les images radar aéroportées et satellitaires ERS-1.

G. *Results & Recommendations:*

Après une correction géométrique rigoureuse avec un modèle numérique d'élévation (MNE), les images radar aéroportées acquises par le capteur ROS C/X du centre canadien de télédétection se sont montrées un outil performant pour l'interprétation et la mise à jour des interventions récentes. Toutefois, l'utilisation d'images d'hiver (avec un couvert total de neige au sol) est un élément essentiel pour délimiter précisément le contour des coupes. Utilisées conjointement avec des données provenant des satellites Landsat et SPOT, les données radar apportent une information différente et intéressante quant à la nature et au contenu des paysages forestiers.

L'image ERS-1 du mois d'août n'a présenté aucun intérêt pour la cartographie at la mise à jour des coupes récentes. La mauvaise performance de cette image s'expliquerait en grande partie par son faible angle d'incidence, sa faible dynamique de niveau de gris et aussi par la période d'acquisition de cette image.

Si les résultats de cette étude sont transposables à l'utilisation des images satellitaires de haute résolution de RADARSAT (à 10 m de résolution), ce type d'image pourra représenter un apport considérable dans le processus de la mise à jour de la carte écoforestière.

H. *References:*

Coulombe A., M. Hinse, (1994) *Évaluation Des Images Radar Aéroportées Pour la Mise a Jour Des Interventions Forestières; Ministère des Ressources Naturelles*, Le Service des Technologies à Référence Spatiale (MRN-Terres), Governement of Quebec Report No. H940R03, Submitted to the Canada Centre for Remote Sensing, 35 p.

A. *Project Title:* **Terrain Mapping and Quaternary History: Taseko Lakes Area, British Columbia**

B. *Study Area:* Fraser Plateau, B.C.

C. *ERS-1 Data:* 3 scenes (8 Aug 1993, 1 Sept 1993, 12 Sept 1993)

D. *Principal Investigator(s):*

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None.

F. *Study Objectives & Methodology:*

An ERS-1 image was evaluated as an aid to surficial mapping in the Taseko Lakes map area, British Columbia. The study area consisted of montane, plateau and valley physiographic regions. Landforms and sediment cover reflected the interaction between glacial and post-glacial processes and complex physiography. Each physiographic region was associated with a distinctive landform and sediment component.

G. *Results & Recommendations:*

The use of radar imagery enabled mapping to be extended into areas where aerial photographic coverage was not available, or restricted by cloud and vegetation cover. Glacial deposits and landforms were distinguished according to variations in surface texture and reflectivity. Feature identification was limited to landforms larger than 9 meters. The mapping of low-relief features was difficult due to the steep incidence angle (23 deg.) for the SAR.

Terrain analysis using ERS-1 SAR is effective when applied to an area with bench-mark control. The image data complimented an earlier surface mapping study, and has significantly improved the working knowledge of the Quaternary history of the Taseko Lakes area.

H. *References:*

Huntley, D. H., B.E. Broster, (1994) *Terrain Mapping and Interpretation Using ERS-1 Data in an Area of Variable Relief: Taseko Lakes Map Area, British Columbia*, Report submitted to the Quaternary and Environmental Studies Laboratory, Dept. of Geology, University of New Brunswick, and to the Canada Centre for Remote Sensing, 15 p.

A. *Project Title:* **Neotectonics of The Fraser Fault System**

B. *Study Area:* Lillooet, British Columbia

C. *ERS-1 Data:* 2 scenes (summer of 1992)

D. *Principal Investigator(s):*

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F. *Study Objectives & Methodology:*

The purpose of this study was to evaluate the usefulness of ERS-1 SAR imagery in the identification of Tertiary and younger faults associated with the Fraser Fault System in south central British Columbia. The procedure was a combination of image processing and interpretation. The findings were compared and evaluated with field observations and studies using Landsat TM imagery.

G. *Results & Recommendations:*

In valley bottoms and plateau areas the ERS-1 data was able to identify very subtle geomorphic breaks in glacial drift covered areas that mark fault scarplets. The SAR imagery was also successful in delineating transverse fracture corridors. It made a great contribution to the project and will be used in a routine fashion in succeeding projects.

H. *References:*

None.

A. *Project Title:* **Application of Radar to Surficial Materials Mapping and Glacial Transport**

B. *Study Area:* Quesnel, British Columbia

C. *ERS-1 Data:* 1 scene (summer of 1992)

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F. *Study Objectives & Methodology:*

The purpose of this study was to evaluate the usefulness of ERS-1 SAR imagery in the mapping of surficial materials. The procedure was a combination of image processing and interpretation. The findings were evaluated in light of previous field work in the area, similar studies with Landsat TM, SEASAT SAR, conventional air photos and JERS-1 SAR.

G. *Results & Recommendations:*

The relatively flat terrain permitted rectification to a satisfactory level. A wealth of geomorphic details is evident in the imagery, far beyond what could be discerned on TM data. Drumlins and glacial frooves are clearly expressed. ERS-1 data proved an excellent tool in surficial mapping in the area.

H. *References:*

None.

A. *Project Title:* **Synthesis of Radar with Aeromagnetics**

B. *Study Area:* Quesnel, British Columbia

C. *ERS-1 Data:* 1 scene (18 May 1992)

D. *Principal Investigator(s):*

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F. *Study Objectives & Methodology:*

The work was a trial to test the practicality and effectiveness of merging aeromagnetics with SAR imagery in a glacialed plateau region of the Intermontain Belt.

G. *Results & Recommendations:*

The product used was SGF. The relatively flat terrain permitted acceptable SAR rectification to a degree suitable for fusing with 200 meter gridded magnetics. The fused product is colourful but is not equal to the sum of its parts, ie; interpretation of magnetics alone and SAR alone provide more insight to the geology than the fused product. The latter does serve a function as a presentation aid. The SAR image provided a great deal of structural information far beyond what conventional air photos or TM imagery were able to achieve.

H. *References:*

None.

A. *Project Title:* **Mapping Rock Type and Structures within the Monashee Mountains South of Revelstoke, B.C.**

B. *Study Area:* Revelstoke, B.C.

C. *ERS-1 Data:* 1 scene (6 May 1992)

D. *Principal Investigator(s):*

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E. *Co-Investigator(s):*

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F. *Study Objectives & Methodology:*

The aim of the study is to attempt the delineation of geological structures and major rock types through the integration of ERS-1 SAR and Landsat TM imagery.

G. *Results & Recommendations:*

In this mountainous area of British Columbia, radar layover, foreshortening and shadowing greatly influence the ability to interpret the ERS-1 SAR images. Although the geometric distortions in the image can be corrected using a digital terrain model (DTM), the information in the layover and shadow areas is still absent. Also the snow, ice and vegetation cover (as a function of change in elevation) created great difficulties in determining rock types. Curved linear features, anticipated to be fold structures, in fact turned out to be large snow banks.

Thus far our sole recommendation is that radar images should be selected with caution, particularly in mountainous environments.

H. *References:*

None.

A. Project Title: **Characterizing the Structural and Geological Features of Plutonic Rock Areas of the Canadian Shield for Evaluating Potential Nuclear Fuel Waste Disposal Sites**

B. Study Area: Whiteshell research area, Manitoba

C. ERS-1 Data: 2 scenes (16 June 1992, 12 Jan 1993)

D. Principal Investigator(s):

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E. Co-Investigator(s):

None.

F. Study Objectives & Methodology:

Project objectives included the manipulation and analysis of ERS-1 SAR imagery to determine the potential usefulness of the data for structural interpretation in the Canadian Shield for geological site characterization. Two image analysis systems were used for image manipulation and enhancement. After geo-correction, numerous filtering techniques were investigated and employed in an attempt to reduce speckle and enhance any subtle linear features of geologic significance. The SAR data were combined with both Landsat TM and airborne geophysics to assess any benefits from this form of data integration. After repeated attempts at lineament enhancement, the images were utilized in a lineament analysis and subsequently compared with linear features extracted from the TM imagery.

G. Results & Recommendations:

Visual inspections, after the data was geo-referenced, revealed a lack of structural information over the study area in comparison to features extracted from the TM data. Both the January and June ERS-1 scenes expressed less structural information than what was expected from SAR data. However, detailed examinations of the ERS-1 images did indicate some linears that were not clearly expressed in the TM data. Combining the SAR data with airborne geophysics did not improve the detection of topographic features, but integrating the SAR data with TM did provide some further enhancement of these features.

In general, both images poorly illustrated terrain features. The study area has relatively low relief which was expressed by fairly homogenous texture in the June image, with a slightly improved response in the January scene. The reduction in canopy cover and the snow-pack appeared to smooth the surface roughness thus allowing for greater lineament expression in the winter image. This was more evident in the areas of the image corresponding with greater relief. Low relief and the steep imaging angle of ERS-1 seemed to be responsible for the poor lineament expression over the study area.

In comparing the ERS-1 with airborne SAR data, the effect of shallow look angle is more apparent. The airborne SAR imagery detected much more subtle terrain features than the ERS-1 SAR. Other factors contributed to the improved feature detection as well, such as look direction and polarization.

It is recommended that ERS-1 be re-considered for linear feature detection on areas of low relief. The degree to which ERS-1 data may contribute to any site characterization is considered variable, depending on the amount of relief within the target area.

H. References:

None.

A. Project Title: **An Assessment of ERS-1 Radar Data as an Aid to Mineral Exploration in Northern New Brunswick**

B. Study Area: Northern New Brunswick

C. ERS-1 Data: 5 scenes (9 July 1992, 13 Aug 1992, 21 Feb 1993, 28 Mar 1993, 6 June 1993)

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F. Study Objectives & Methodology:

The objective of the study was to determine the potential of ERS-1 SAR data for mineral exploration.

The study was conducted on a scale of 1:50,000 covering the NTS map sheet 21O/8. The SAR data was geo-referenced, clipped to the NST map extent, and filtered to remove speckle. The data was then integrated with relevant geological information, such as airborne magnetics and stream sediment geo-chemistry.

G. Results & Recommendations:

As a stand-alone product, the ERS-1 SAR imagery clearly indicated the existence of geological faults in the vicinity of known mineral occurrences. When combined with airborne magnetic data, it was possible to determine where the magnetic 'highs' are dissected by the faulting. Similarly, it was possible to correlate the geo-chemistry 'highs' with the faulting shown in the ERS-1 scene.

When ERS-1 SAR data is combined with other data types used for exploration, it proves to be a useful tool. It assists in narrowing down the zones where more detailed exploration should be conducted on the ground. This potential can help in finding new discoveries or increase the interest level in existing mineral occurrences.

H. References:

None.

A. Project Title: **Mineral Review**

B. Study Area: Schefferville, Que., Labrador City, Newfoundland

C. ERS-1 Data: 4 scenes (6 Sept 1991 (2), 20 Mar 1992 (2))

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None.

F. Study Objectives & Methodology:

A report was not submitted for this project.

G. Results & Recommendations:

None.

H. References:

None.

A. *Project Title:* **Nahanni Earthquake Tectonic Investigation Using ERS-1 and JERS-1**

B. *Study Area:* Nahanni, Northwest Territory

C. *JERS-1 Data:* 6 scenes (October 1993 - Jan. 1994)

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F. *Study Objectives & Methodology:*

The study consisted of the following objectives. Firstly, to map large scale tectonic features related to local earthquakes; secondly, to evaluate the usefulness of space-borne L-Band SAR system; and thirdly, to test spatial digital data fusion techniques for earthquake tectonics.

G. *Results & Recommendations:*

The geological tectonic mapping was a great success, revealing several new fault systems which appear directly related to the frequent local earthquakes. One major discovery includes the much shorter extension of the Iverson Thrust Fault, which was mapped to extend throughout the study area. It appears the new E-W tending faults play important roles in the local earthquake processes.

Based on the limited experiment, the space-borne L-Band SAR system is an excellent earthquake tectonic mapping tool.

H. *References:*

Moon, W.M., B. Li, V. Singhroy, C.S. So, and Y. Yamaguchi (1994) Data Characteristics of JERS-1 SAR data for Geological Remote Sensing, *Cdn. J. of Rem. Sensing*, 20, pp. 329-333.

Moon, W.M., V. Singhroy, Y. Yamaguchi, and R. Kuoda, (1995) Tectonic Investigation of Nahanni Earthquake Area, Northwest Territories (Canada) Using JERS-1 and ERS-1 SAR Data, *IEEE IGARSS'95 Proceedings*, pp. 2197-2200.

Moon, W.M., V. Singhroy, B. Li, Y. Yamaguchi, (1995) Integrated JERS-1 SAR Investigation of Nahanni Earthquake Area, NWT, Canada, *Proceedings, of the 2nd JERS-1 PI's Conference*, Tokyo, Japan, 24 pages. (in press).

Moon, W.M. (1993) *Preliminary Results of the JERS-1 Science Verification Project (Nahanni Earthquake Area, NWT, Canada)*, JERS-1 Science Verification Meeting, Tokyo, Japan, 7 p.

Won, J.S., W.M. Moon, and H.R. Yoo, (1993) Integration of airborne and space-borne SAR image using wavelet transform, *IGARSS'93 Extended Proceedings*, pp. 1230 - 1236.

A. *Project Title:* **Multi-Temporal Analysis of the Truro Area**

B. *Study Area:* Truro, Nova Scotia

C. *ERS-1 Data:* 8 scenes (10 May 1992 (2), 29 May 1992 (2), 18 June 1992 (2), 8 Aug 1992 (2))

D. *Principal Investigator(s):*

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E. *Co-Investigator(s):*

L.M. Tighe and A. Hudgins (College of Geographic Sciences).

F. *Study Objectives & Methodology:*

The objectives of the study were to perform structural lineament mapping using ERS-1 data, and to use GIS modelling techniques on order to generate gold suitability target maps.

G. *Results & Recommendations:*

A section of the Chedabucto Fault Zone, in central Nova Scotia, was chosen to generate proper mineral exploration models. This area was selected because of its geologic similarities to the well known Carlin-type deposit. Structural lineaments were mapped utilizing ERS-1 and Landsat TM data. A lineament map was prepared containing the location of known fault zones as well as linears depicted on ERS-1 data. This map was integrated with airborne geophysical data, digital ground sampled geochemical data, geological and topographic maps. Spatial modelling of the above data sets, within a GIS, provided necessary information to generate gold suitability target maps.

These works have provided ample technical expertise in radar remote sensing to take advantage of Canadian RADARSAT data which will become available early in 1996.

H. *References:*

Tighe, L.M., M.S. Akhavi, A. Hudgins, (1995) Application of Synthetic Aperture Radar (SAR) to Gold Exploration in Central nova Scotia, *Proceedings, 17th Canadian Symposium on Remote Sensing*, Canadian Remote Sensing Society, Ottawa, pp. 721-726.

A. *Project Title:*

The Utility of ERS-1 Mosaic and SPOT Datasets for Lineament Analysis: An Integrated RS/GIS Approach

B. *Study Area:* Central Nova Scotia and Cobequid Highlands

C. *ERS-1 Data:* 4 scenes.

D. *Principal Investigator(s):*

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F. *Study Objectives & Methodology:*

The first objective was to prepare a seamless mosaic of ERS-1 data; second was to integrate digital geological and radiometric data with ERS-1 mosaic to detect regional structural features and modelling for exploration targets; and third was to perform lineament mapping in Cobequid Highlands using both ascending and descending ERS-1 data.

G. *Results & Recommendations:*

Four ERS-1 scenes, covering central Nova Scotia, were used to prepare a seamless radar mosaic. This mosaic was integrated with digital geological and radiometric data in order to detect regional features and review the occurrence, area extent, and contact relationships of plutonic rock bodies.

Lineament mapping was conducted for both ascending and descending ERS-1 data in the Cobequid Highlands. It was concluded that the number and length of linears depicted on these modes are fairly similar. However, backscatter properties of various structural and geomorphic features differed considerably on these modes because of their difference in look direction. Also, lineament analysis of SPOT-2 satellite data was compared with similar data derived from ERS-1 imagery. It was noticed that the length and number of linears depicted on the former data set were about one-half of the latter one. A lineament map was prepared for the study site.

H. *References:*

Jackson, S.J.E. & M.S. Akhavi, (1995) The Utility of ERS-1 Mosaic and SPOT Datasets for Lineament Analysis: An Integrated RS/GIS Approach, *Proceedings, 17th Canadian Symposium on Remote Sensing*, Canadian Remote Sensing Society, Ottawa, pp. 769-774.

A. *Project Title:* **Analysis of Neotectonic Activity in Southern Ontario from Radar Remote Sensing and Ground Studies**

B. *Study Area:* Southern Ontario

C. *ERS-1 Data:* 3 scenes (8 May 1992 (3))

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E. *Co-Investigator(s):*

Mr. P. Stefanoff (U of Toronto).

F. *Study Objectives & Methodology:*

The objectives of the project were to evaluate the usefulness of ERS-1 SAR imagery for the detection of subtle geomorphic lineaments in glaciated terrain of low relief. In the Palaeozoic platform rocks and the Quaternary cover of southern Ontario such lineaments can potentially be related to faults and related structures (e.g. joints) in the bedrock. The study area was chosen to coincide with the trace of a known NNE-tending basement fault (Niagara-Pickering Linear Zone) which, from geophysical data, is known to occur in the subsurface between Pickering and Kashagawigamog Lake. This structure has been the object of much recent speculation on the possibility of post-glacial faulting in southern Ontario. It was also the focus of an earlier investigation by Rutty & Cruden using Landsat TM data.

Methods to be employed were standard image processing and photo-geological techniques combined with field observation and comparison to other image types.

G. *Results & Recommendations:*

ERS-1 data was found to image subtle linear terrain features such as low-relief escarpments and drumlins well. Such features were often found to have a clearer expression on the radar images than on the equivalent Landsat TM scene. One unique advantage of the ERS-1 data is its ability to differentiate between symmetric and asymmetric terrain features. This allows for more confident interpretation of features such as drumlins and escarpments. The ERS-1 data also images surfaces quite differently than multi-spectral imagery and, for the area examined, is far less sensitive to high frequency cultural clutter. This proved to be useful in differentiating between areas underlain by Precambrian and Palaeozoic rock. Relief in the area was sufficiently low to minimize radar-specific geometric distortions such as foreshortening and layover.

Although the ERS-1 data was useful for the detection of lineaments related to bedrock structure, the age and origin of such features could not be determined. As with all other forms of remote sensing data, further ground studies are required to resolve these problems.

The ERS-1 imagery has also been incorporated into undergraduate course material and is currently being used for a graduate student research project in which it will be combined digitally with aeromagnetic data and Landsat TM data. Work on the ERS-1 data formed the basis for defining continued research in the area using RADARSAT SAR imagery.

H. References:

Cruden, A.R., A.L. Rutty, & P. Stefanoff, (1994) *Application of Landsat TM and ERS-1 Satellite Imagery for Mapping Fracture Patterns in Southern Ontario*, Geological Association of Canada, Waterloo' 94, Program with Abstracts vol. 19, A24.

Cruden, A.R., D. Armstrong, P. Barnett, & M. Easton, (1995) *Structural Geology of South Central Ontario*, Radarsat ADRO research proposal #64, 15 p.

Stefanoff, P.S. (1993) *ERS-1 Radar Imagery of the Pickering-Kashagawigamog Lake Area, Ontario: Data Transfer, Image Processing and Preliminary Photogeological Interpretation*, BSc thesis, Dept. of Geology, University of Toronto, 76 p.

A. Project Title: **Geological / Geophysical Application Development of ERS-1 and JERS-1 SAR Data For Non-Renewable Resource Exploration**

B. Study Area: Sudbury, Ontario; Snow Lake, Manitoba

C. ERS-1 Data: ~ 6 scenes.

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F. Study Objectives & Methodology:

The study objectives were fourfold. The first was to evaluate usefulness of a space-borne SAR system for mineral resources and geological mapping; the second was to compare L-Band and C-Band SAR systems for mineral exploration tasks; the third was to test multiple sensor, integrated exploration techniques and their relative usefulness of space-borne remote sensing (SAR) systems; and the fourth was to map local geological (and tectonic) features related to local mineral deposits.

G. Results & Recommendations:

Space-borne SAR systems, particularly L-Band SAR, provide an excellent structural geological mapping tools for regional studies as well as for mineral exploration. In the case of Sudbury area, C-Band airborne SAR system performs as well as the L-Band space-borne SAR system. However, the ERS-1 (C-Band space-borne SAR system) data are less effective than the above two.

In both study areas, space-borne and airborne SAR data provide the local investigators with an excellent overall regional picture of Geology. The SAR data proved to be very effective for tracing and correcting errors made during the surface geological mapping projects.

Space-borne SAR system provides an excellent digital image base for more sophisticated GIS based integrated resource exploration.

A digital data fusion technique using Wavelet Transform was developed in this research. This new Wavelet Transform technique has proved to be considerably more accurate and effective for integrating more than one layer of SAR data than the conventional techniques such as PCA.

H. References:

An, P., W.M. Moon, and G. Bonham-Carter (1995) An Objective Oriented Knowledge Representation Structure for Exploration Data Integration (Snow Lake Area, Manitoba), *Nonrenewable Resources*, 4, (*In press*).

An, P., W.M. Moon, and G. Bonham-Carter (1993) Uncertainty Management in Integration of Exploration Geophysics Data using Belief Function, *Nonrenewable Resources*, 3, pp. 60-71.

Moon, W.M. (1993) Mathematical Basis for Geophysical Information Representatio and Integration, *Cdn. J. Rem. Sensing*, 19, pp. 63-67.

Moon, W.M. and C.S. So (1995) Information Representation and Integration of Multiple Sets of Spatial Geoscience Data, *IEEE IGARSS'95 Proceedings*, pp. 2141-2145.

Moon, W.M., J.S. Won, V. Singhroy, P.D. Lowman Jr. (1994) ERS-1 and CCRS C-SAR Data Integration for Look Direction Bias Correction using Wavelet Transform, *Cdn. J. Rem. Sensing*, 20, pp. 280-286.

Singh, V., W.M. Moon, H. Miller, and C.S. So, (1994) Interpretation of gamma ray spectrometer data from Sudbury, Ontario, *CIM Bulletin*, 87, pp. 31-35.

Singh, V., W.M. Moon, V. Singhroy, and R.V. Slaney (1993) Preliminary Result Integrating Multi-Sensor Airborne Geophysical Data Over Sudbury, *Cdn. J. Rem.Sensing*, 19, pp. 160-169.

Won, J.S., W.M. Moon, and H.R. Yoo, (1993) Integration of Airborne and Space-Borne SAR Image Using Wavelet Transform, *IGARSS'93 Extended Proceedings*, pp. 1230 - 1236.

Won, J.S. and W.M. Moon, (1991) Inversion and Image Formation of SAR Wavefiel from Surface Scattering, *Geophysical Journal (International)*, 108, pp. 423-432.

A. *Project Title:* **Structural Geomorphology. Analysis of the Charlevoix Astroblème with Remote Sensing Techniques**

B. *Study Area:* Charlevoix, Québec

C. *ERS-1 Data:* 3 scenes (2 Feb 1992, 9 May 1992, 22 Aug 1992)

D. *Principal Investigator(s):*

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E. *Co-Investigator(s):*

None.

F. *Study Objectives & Methodology:*

The purpose of the study was to evaluate ERS-1 data for understanding the structural geomorphology of the impact crater at Charlevoix, Quebec. The specific objectives were to determine the most appropriate time for data acquisition; the evaluation of the results derived from ERS-1 compared to those from conventional methods and techniques; and to determine the usefulness of ERS-1 data when integrated with multi-source information.

G. *Results & Recommendations:*

It was possible to map approximately two-thirds of all the lineaments in the area with ERS-1. The estimation was based on the comparison between the ERS-1 results and the base map produced at a scale of 1:20,000 with conventional methods. ERS-1 confirmed the general orientation of the different families of lineaments in the crater area. Surface deposits and land use prevented mapping of lineaments in the crater itself.

The integration of ERS-1, Landsat TM and a DEM suggested a new grouping of lineaments in the surrounding area. Landsat data provided information in areas where ERS-1 data was lacking due to terrain effects (shadowing, and overlay). The DEM provided information on lineaments in a parallel orientation to the SAR orbital path.

H. *References:*

Desjardins, R., (1994) *Rapport de Recherche: Géomorphologie Structurale. Analyses de l'Astroblème de Charlevoix par Teledetection*, Submitted to the Canada Centre for Remote Sensing.

De Seve, D., R. Desjardins, T. Toutin, (1994) Contribution des Donnees Radar d'ERS-1 dans l'Apprehension de l'Organisation des Lineaments. Le Cas de l'Astroblème de Charlevoix, *Cdn. J. of Rem. Sensing*, Vol 20, No 3, pp 233-244.

De Seve, D., T. Toutin, R. Desjardins, (*in submission*). Evaluation de Deux Methodes de Correction Géometrique d'Images Landsat TM et ERS-1 RAS dans une Etude de Lineaments Géologiques; *International Journal of Remote Sensing.*

A. *Project Title:* **Remote Sensing Applied to Mineral Exploration of the Desmaraisville Area, Quebec, Canada from ERS-1 Radar Data**

B. *Study Area:* Desmaraisville, Quebec

C. *ERS-1 Data:* 3 scenes (5 Aug 1992, 15 Aug 1992, 6 Sept 1992)

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E. *Co-Investigator(s):*

None.

F. *Study Objectives & Methodology:*

The main objectives of this study were (1) to demonstrate the usefulness of the ERS-1 imagery for the recognition of geological features in a complex environment (complex geology covered by an equally complex overburden); and (2) to compare the results of the ERS-1 imagery with Landsat-TM data; and (3) to evaluate the technical quality of the data.

G. *Results & Recommendations:*

The main results of the study indicated that (1) ERS-1 data is an effective tool for the mapping of complex geological structures even in a thick overburden terrain; (2) geological structures of interest were identified in swamps and shallow lakes and streams (e.g. the Freewest discovery); (3) ERS-1 data gave more geological information of the area in comparison to the Landsat-TM data; (4) the overall quality of the data is quite poor. Discrepancies of about 200 meters were observed in the position of absolute objects. This is a severe limitation when precise work is required.

The main recommendations of the study are (1) that ERS-1 data should be used for regional mapping work (at 1:100,000 scale or more); and (2) the results of this study should be compared with the coming RADARSAT data in order to determine if more precise results can be obtained.

H. *References:*

DOZ Inc. (1993) *ERS-1 Imagery Work Pertaining to the Desmaraisville Area*, Internal document (with posters and images).

A. *Project Title:* **Satellite SAR Application Development for Geology**

B. *Study Area:* Central & Northern Saskatchewan

C. *ERS-1 Data:* 7 scenes (16 June 1993, 21 July 1993, 25 Aug 1993, 5 Sept 1993, 29 Sept 1993, 15 Oct 1993, 3 Nov 1993)

D. *Principal Investigator(s):*

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E. *Co-Investigator(s):*

None.

F. *Study Objectives & Methodology:*

The objective of this study was to evaluate ERS-1 and JERS-1 SAR imagery for geological resource management. The SAR imagery would be integrated with Landsat TM, magnetic and other geological data.

G. *Results & Recommendations:*

The southern study area did not prove very successful. The effect of agricultural landuse on the radar backscatter made the mapping of surficial landforms very difficult. Some linear trends were noticeable, but the textural variance between crops eliminated the effectiveness of edge detection algorithms. Surficial features were more easily distinguished near the Souis River Basin due to the natural marsh environment and a lack of agriculture in this area. The difficulty in mapping surficial features was compounded by having only one look direction available in the data set (ascending mode). Data imaged from at least two look directions are required for effective mapping of linear features.

If further studies are to be performed in this region, a data set with more than one look direction should be acquired to properly map surficial landforms. A winter scene could prove more effective because the SAR backscatter would be less affected by crop boundaries, allowing high pass edge detection filters to be applied to the data.

The northern study region indicated more promise in the use of SAR imagery for mapping surficial landforms. Lineament features such as faults, shear zones and folds were identifiable in the ERS-1 imagery. The ability of ERS-1 imagery to detect linear features provided an update for the existing lineament maps.

Colour composite images were produced using the SAR data, the available Landsat TM scene and helicopter magnetic data. The integration of SAR imagery and magnetic anomalies in an Intensity, Hue and Saturation transformation has proved beneficial for mapping linear features in gold prospecting of Nova Scotia.

The use of SAR imagery for classifying lithological units was not successful. Few studies have been completed in this area with little success. Variations in texture may be related to different rock types, but to test such a theory would require several different SAR images. This would be an area for further study.

Overall, radar imagery shows great promise in the field of geological exploration within the Precambrian Shield regions . The ability of radar imagery and ancillary data such as Landsat TM and magnetics has been proven to be a valuable tool in the exploration of gold.

Within the central and southern regions of Saskatchewan, the benefits of using SAR imagery for surficial mapping are less clear. Agricultural landuse patterns has a profound impact on radar backscatter, reducing the effectiveness of edge detector algorithms. However, analysis of winter scenes warrants further study.

H. References:

Shaner, J. (1995) *RADARSAT Technology Transfer Phase II - Geology Application*, Internal Report, Devel-Tech Inc., Saskatoon, SK.

A. *Project Title:* **Geoscientific Comparison of ERS-1 and JERS-1 SAR Data of the Dawson Creek Region**

B. *Study Area:* Dawson Creek, Yukon

C. *ERS-1 Data:* 1 scene (3 June 1992)

D. *Principal Investigator(s):*

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E. *Co-Investigator(s):*

None.

F. *Study Objectives & Methodology:*

There was no work done on this project.

G. *Results & Recommendations:*

None.

H. *References:*

None.

A. *Project Title:* **Using Optical Imagery, Radar Imagery, and Digital Elevation Data to Model the Location of Debris Flow Systems, St. Elias Mountains, Southwest Yukon**

B. *Study Area:* St. Elias Mountains,Yukon

C. *ERS-1 Data:* 3 scenes (29 June 1992, 16 Aug 1992, 18 Aug 1992)

D. *Principal Investigator(s):*

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None.

F. *Study Objectives & Methodology:*

There was no work done on this project.

G. *Results & Recommendations:*

None.

H. *References:*

None.

A. *Project Title:* **Developing Algorithms for Glacier Mass Balance and Glacier Hydrologic Studies**

B. *Study Area:* Peyto Glacier, Sentinel/Place Glacier

C. *ERS-1 Data:* 6 scenes (3 from May 1992, 1 from spring 1993, 16 Sept 1993, 10 Oct 1993)

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None.

F. *Study Objectives & Methodology:*

A report was not submitted for this project.

G. *Results & Recommendations:*

None.

H. *References:*

None.

A. *Project Title:* **Summer Mapping of Vegetation Cover to Determine Prime Whooping Crane Nesting Habitat**

B. *Study Area:* West coast of Vancouver Island, B.C.

C. *ERS-1 Data:* 2 scenes (11 July 1992, 15 Aug 1992)

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None.

F. *Study Objectives & Methodology:*

A report was not submitted for this project.

G. *Results & Recommendations:*

None.

H. *References:*

None.

A. *Project Title:* **Mountain Runoff Forecasting**

B. *Study Area:* Banff, Alberta

C. *ERS-1 Data:* 6 scenes (25 April 1992, 14 May 1992, 30 May 1992, 18 June 1992, 4 July 1992, 12 Sept 1992)

D. *Principal Investigator(s):*

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E. *Co-Investigator(s):*

G. Kyte (NHRI), T. Pultz (CCRS).

F. *Study Objectives & Methodology:*

The objectives of this study were to develop procedures for high-resolution monitoring of mountain basin snowmelt on a continuous basis for flood forecasting. These included the demonstration of satellite radar measurements of snowmelt lines in forest openings and alpine areas of the Rocky Mountains; and the integration of the SAR data from the snowmelt with runoff forecast techniques. This was done in the ERS-1 Brewster Creek Experiment near Banff, Alberta. The above supplied SAR images constituted part of the 26 ERS-1 images acquired for this study over 1992-3. The experiment utilized the ERS-1 SAR data for the detection of wet snow. The ground data consisted of the Banff area avalanche network and NHRI Sunshine Alpine observations. SPOT and Landsat data were used for comparison.

The analysis method consisted of co-registration of sub-images from the 1992-3 SAR data set. The multi-temporal imagery was then ratioed to a standard cold winter composite scene in order to obtain the power ratio on a pixel-by-pixel basis. The fraction of each pixel not affected by wet snow was interpreted as equal to the power ratio. This simple procedure allowed for straight forward analysis and exception handling over the rugged mountain terrain.

G. *Results & Recommendations:*

The examination of the geo-coded multi-year imagery near Banff indicated that geo-coded SAR imagery allows for the construction of radar wet-snow area maps which quantitatively indicate snowmelt area-fraction in relation to elevation, slope and aspect. These maps are applicable to areas above the tree-line or along avalanche tracks at any elevation. Masks are required for areas with radar overlay and areas affected by wet snow surface scattering events. The latter occurred on slopes of less than 10 degrees during an April thaw-freeze event in alpine meadows and during a May night-time melt event on the above slope with local incidence angles of less than 22 degrees.

The examination of spring radar backscatter minima from mountain talus slopes demonstrated their relationship to spring snowmelt phenomena. The date of minimum backscatter was positively correlated with talus elevation, highly significant at the 1% level. The minimum backscatter date residual was delayed for slopes with more northerly directions, the correlation is significant at the 5% level. Radar systems stability was tested using naturally stable targets, indicating a gain consistency of +/- 1 dB.

In general, the simple wet-snow algorithm was successful in mapping snow areas in non-forested areas, but further research is required to better define periods and areas prone to snow surface scattering which can invalidate the algorithm. Additionally, research is required to define standard comparison images, in addition to the cold winter scenes used in this study, for applications to mountains with a warmer climate regime.

H. *References:*

Maxfield, A., (*in press*) Rocky Mountain Snowmelt on Talus Slopes by Radar Satellite, *Can. J. Rem. Sensing.*

Maxfield, A., (*in press*) Rocky Mountain Snowmelt - Multi-Year Radar Satellite Observations, Application of Remote Sensing in Hydrology, National Hydrology Institute Symposium, Saskatoon, Canada.

Maxfield, A., (1994) Radar Satellite Snowmelt Detection in the Canadian Rocky Mountains, Proceedings, IGARSS '94, Pasadena, USA, pp. 2974-2077.

A. *Project Title:* **Defining and Mapping Snow and Ice Conditions**

B. *Study Area:* West coast of Vancouver Island, B.C.

C. *ERS-1 Data:* 2 scenes (11 July 1992, 15 Aug 1992)

D. *Principal Investigator(s):*

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None.

F. *Study Objectives & Methodology:*

A report was not submitted for this project.

G. *Results & Recommendations:*

None.

H. *References:*

None.

A. Project Title: **To Investigate the Use of ERS-1 SAR Data in Support of Flood Damage Reduction Efforts in New Brunswick**

B. Study Area: Central New Brunswick

C. ERS-1 Data: 4 scenes (29 Nov 1992. 30 Jan 1993. 14 Mar 1993, 30 Mar 1993)

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E. Co-Investigator(s):

T. Perrott (CCRS).

F. Study Objectives & Methodology:

The specific objectives of the study included as assessment of the SAR's ability to depict snow cover, ice cover, and flood extent. The study also served as a familiarization and training exercise for provincial resource managers to remote sensing technology.

Analysis of the image data consisted of three steps: preprocessing, enhancement, and visual interpretation. Subsequently, portions of the imagery were sampled to obtain a quantitative description of the image statistics.

G. Results & Recommendations:

The inability to clearly discriminate land from open water proved to be a major disappointment. Many stretches of the river appear quite bright and similar in tone and texture to forested areas. Registration of the ERS-1 data proved to be more difficult than expected. Cultural features were poorly depicted on the imagery making it impossible to identify control points.

The study has shown that image analysis requires time, trained personnel, and resources. Hydrologists should understand the advantages and limitations of SAR data.

H. References:

Tang, P., B. Burrell, T. Perrott, (1993) Hydrologic Applications of ERS-1 SAR Imagery, Saint John River, N.B. -- Preliminary Results; Canadian Society for Civil Engineering Annual Conference, *Proceedings 11th Canadian Hydrotechnical Conference*, June 8-11, 1993, Fredericton, N.B., pp 11-20.

A. *Project Title:* **Snow Hydrology by SAR Churchill Falls Labrador**

B. *Study Area:* Churchill Falls, Newfoundland

C. *ERS-1 Data:* 3 scenes (1 Sept 1992, 6 Oct 1992, 19 Jan 1993)

D. *Principal Investigator(s):*

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E. *Co-Investigator(s):*

B. A. Roberts (Natural Resources Canada)

F. *Study Objectives & Methodology:*

The study objective was to obtain relative snow-water equivalent information in test sites using multi-temporal ERS-1 SAR data.

Within the frame work of a CCRS RADAR Development Project airborne SAR data and simultaneous ground observations were obtained in selected sites. This data gave information on snow distribution and on ground cover types without snow. Digital Numbers (DN) of ERS-1 SAR, obtained in September (no frost or snow), in October (frost but no snow) and in January (deep snow), are to be analyzed simultaneously to correlate DN-s (and their combination) with snow depth and density. The difference between the three sets of data should give indication on snow conditions.

G. *Results & Recommendations:*

The airborne SAR and the ground data are being analyzed at the present time. The analysis of the ERS-1 data is not complete. Work will first concentrate on the airborne SAR analysis, then the ERS-1 SAR data analysis. The airborne SAR data should provide some useful information on snow depth, and SAR backscatter relative to ground cover (water, ice, vegetation, etc.).

H. *References:*

None.

A. *Project Title:* **The Mapping of Partial Snow Cover During Melt Season Using ERS-1 Imagery**

B. *Study Area:* Fort Simpson, NWT

C. *ERS-1 Data:* 2 scenes (5 May 1992, 8 May 1992)

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E. *Co-Investigator(s):*

None.

F. *Study Objectives & Methodology:*

There was no work done on this project. A second data set required for background comparison was not supplied due to a change in ERS-1 orbit parameters. This prevented data acquisition over the study site.

G. *Results & Recommendations:*

None.

H. *References:*

None.

A. *Project Title:* **Classification of Wetlands in Algonquin Park**

B. *Study Area:* Algonquin Park, Ontario

C. *ERS-1 Data:* 4 scenes (5 May, 1992 (2), 8 May 1992 (2))

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None.

F. *Study Objectives & Methodology:*

A report was not submitted for this project.

G. *Results & Recommendations:*

None.

H. *References:*

None.

A. *Project Title:* **Estimation of the Snowpack Properties**

B. *Study Area:* Riviere La Grande (LG4), Québec

C. *ERS-1 Data:* 7 scenes (16 Aug 1993, 25 Oct 1993, 12 Feb 1994, 26 Mar 1994, 4 May 1994, 10 June 1994, 25 Sept 1994)

D. *Principal Investigator(s):*

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F. *Study Objectives & Methodology:*

Since 1988, a few studies have been conducted at INRS-Eau to assess the potential of airborne and satellite SAR data (C and X bands) for monitoring dry and wet snow cover. The main goal of these studies is to develop an operational methodology fro monitoring the snow cover with RADARSAT. More precisely, we would like to estimate the Snow Water Equivalent for a given watershed by merging information coming from SAR images, snow transects and a hydrological model. The objective of this particular study is to assess the potential of ERS-1 data for monitoring dry and wet snow cover in Northern Quebec on an hydro-electric basin.

The study area is located in the boreal forest on the Canadian shield. The five main types of land cover are lakes, wetlands, coniferous forest, burn and regenerated areas. Within this area, 28 test-sites were selected for study. A total of 7 scenes were acquired from August 1993 to September 1994. In conjunction with 4 of the 7 ERS-1 over-passes, field campaigns were conducted in order to measure the snow cover characteristics (depth, density, SWE and dielectric profiles) as well as the soil characteristics (dielectric constant, temperature, moisture). Those field data were then computerized, filtered and verified.

The sub-scenes were extracted after the calibration of the ERS-1 SAR data was done as suggested by the Canada Centre for Remote Sensing and the European Space Agency. The imagery were geo-coded using a digital terrain model and the methodology developed by T. Toutin at CCRS. The backscattering coefficient from the test sites were extracted from all the ERS-1 images.

To estimate the Snow Water Equivalent of a given snowpack, a model which links the scattering coefficient (σ°) to the physical parameters of the snow cover and the underlying soil has been developed (Bernier, *et al*, 1994a). The model is based on the ratio of the scattering coefficient of a field covered by snow (σ_w) to the scattering coefficient of a field without snow (σ_f). Volume scattering (σ_{sv}°) from a shallow dry snow cover (d <0.7 m) is undetectable with C-band, and the backscattering signal from that snow cover is dominated by the soil surface. Then, the ratio of the scattering coefficients ($\sigma^\circ_w / \sigma^\circ_f$) will decrease proportionally to the dielectric constant of the soil in winter (ϵ_{gw}). The latter varies according to its liquid water content determined by its temperature below freezing point. Because the temperature drop will be greater for the site with the smaller thermal resistance, the spatial distribution of the signal ratio ($\sigma^\circ_w / \sigma^\circ_f$) should depict the spatial distribution of the thermal resistance of the snow cover, given the spatially uniform climatological condition over the test area. Finally, since the signal ratio depends on the thermal resistance of the snowpack and that we have established a consistent relationship between the thermal resistance and the SWE for a given snowpack density, we are exploring the possibility to estimate the SWE from the signal ratio (Bernier, *et al*, 1994a).

G. *Results & Recommendations:*

The preliminary results indicate that the presence of wet snow (May) and frozen soil (October) is detected by a lower backscatter coefficient from the low density Black Spruce stands. In comparison with the October signal, we note for February and March a proportional increase of the backscattering with the increase of the snow depth and the SWE. This increase of backscattering is larger in forest burn areas or in regenerated areas than in the coniferous stands. We also obtained a typical signature for wet snow (a mean decrease of 3 dB), thus we should be able to map the extent of the wet snow cover on a spring scene and the extent of the frozen soil in the fall data.

However, more research needs to be done in order to establish validated models linking the signal ratio to the thermal resistance of the snowpack and the thermal resistance to the SWE. Specifically, we need to define the range of applicability of those models and the regionalized parameters.

H. *References:*

Fortin, J-P., M. Bernier, (1995) *Traitment D'Images ERS-1 pour la Prévision Hydrologique - Rapport D'Étape Rédigé pour Hydro-Québec*, Research Report No R-431 (Phase III), Submitted to Hydro-Québec, 29 p.

Fortin, J-P., M. Bernier, (1995) *Traitment D'Images ERS-1 pour la Prévision Hydrologique - Rapport D'Étape Rédigé pour Hydro-Québec*, Research Report No R-431 (Phase II), Submitted to Hydro-Québec, 44 p.

Fortin, J-P., M. Bernier, (1994) *Traitment D'Images ERS-1 pour la Prévision Hydrologique - Rapport D'Étape Rédigé pour Hydro-Québec*, Research Report No R-431 (Phase I), Submitted to Hydro-Québec, 21 p.

Bernier, M., J.-P. Fortin, Y. Gauthier, (1994a) Suivi du Convert Nival par le Satellite ERS-1: Résultats Préliminaires Obtenus dans l'est du Québec, *Can. J. of Rem. Sensing*, Vol. 20(2), pp. 138-149.

Bernier, M., J.-P. Fortin, Y. Gauthier, (1994b) The Potential and Limitations of ERS-1 SAR data to Estimate the Snow Water Equivalent, *2nd International Workshop: Applications of Remote Sensing in Hydrology*, October 18-20, Saskatoon, Canada, 10 p.

Bernier, M., J.-P. Fortin, (*submitted*) The Potential of Time Series of C-band SAR Data to Monitor Dry and Shallow Snow Cover, *IEEE Transactions on Geoscience and Remote Sensing.*

A. *Project Title:* **Flood Boundaries for Northern California Using Radar Images**

B. *Study Area:* Northern California, USA

C. *ERS-1 Data:* 4 scenes (12 July 1994, 26 July 1994, 10 Jan 1995, 11 Mar 1995)

D. *Principal Investigator(s):*

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E. *Co-Investigator(s):*

None.

F. *Study Objectives & Methodology:*

The study objective was to verify the suitability of spaceborne SAR for monitoring and mapping flood extent through a comparison of pre-flood data from data acquired during the flood event. ERS-1 was chosen as a the sensor for this study, but the primary interest is in RADARSAT.

G. *Results & Recommendations:*

The image showed that flood extent was detectable and could be extracted via visual interpretation. The contrast between water and land was not always high, precluding a simple density slicing approach for this ERS-1 data set. It is confirmed that spaceborne SAR can be used to map flood extent, and we anticipate that superior results will be achievable with RADARSAT. RADARSAT will have the benefits of excellent revisit performance, HH polarization, and larger typical incidence angles than ERS-1.

H. *References:*

None.

A. Project Title: **Operational Use of ERS-1 SAR for Ice Reconnaissance**

B. Study Area: Ice covered waters within Gatineau Station Mask

C. ERS-1 Data: ~600 scenes

D. Principal Investigator(s):

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E. Co-Investigator(s):

J. Falkingham (Environment Canada), M. Shokr (AES)

F. Study Objectives & Methodology:

To make use of fast delivery ERS-1 SAR imagery for operational ice reconnaissance in Canadian waters. Data received at the Gatineau station were processed and delivered to Ice Services Environment Canada (ISEC) through a dedicated T1 link. The SAR imagery was then visually analyzed in combination with other data sources (Intera STAR-2, NOAA-AVHRR, DMSP-SSM/I, meteorological data, ship reports, etc.) to produce daily ice analysis charts and ice forecasts. The use of ERS-1 was seen as a valuable opportunity to gain experience with satellite SAR imagery in preparation for RADARSAT.

G. Results & Recommendations:

As suggested by the volume of data used, ERS-1 SAR was determined to be a useful data source for operational ice reconnaissance. However, the limited swath width, changes in orbit phases, and the lack of programming control prevent ERS-1 from meeting full operational requirements. For this reason, ERS-1 was seen as a supplementary data source when available. In some regions (e.g., Great Lakes), ERS-1 was the only source of radar imagery and was used extensively for reconnaissance and ice motion studies.

H. References:

Ramsay, B R. & R. Duncan, R. (1992) Early Results on the Use of ERS 1 SAR Data for Real time Sea Ice Monitoring in Canadian Waters, *Proceedings of the European ISY Conference*, Munich, Germany, 30 March - 4 April, 1992.

Shokr, M., B. Ramsay, and J. Falkingham, (1992) Preliminary Evaluation of ERS I SAR for Operational Use in the Canadian Sea Ice Monitoring Program, *Proceedings of First ERS I Symposium - Space at the Service of our Environment*, Cannes, France 4-6 November, 1992.

Ramsay, B.R. & J. Marquis, (1993) Operational Integration ERS I Data into Sea Ice Products for Canadian Marine Activities, *Proceedings of the ISY/Polar Ice Extent Workshop*, Mombetsu, Hokkaldo, Japan, 1-5 February, 1993.

Ramsay, B.R., Z. Miller, and W. Jackson, (1993) Operational Use of ERS 1 Data for Ice Monitoring Along Canada's East Coast Winter 1992/3, *Proceedings of the International Symposium: Operationalization of Remote Sensing*, Enschede, the Netherlands, 17-23 April, 1993.

Carrierres, T. (1993) The Use of ERS I Within an Operational Ice monitoring Program, *Proceedings of Optics to Radar SPOT and ERS Applications Symposium*, Paris, France, 10-13 May, 1993.

Ramsay, B., M. Manore, K. Porter, T. Bretz, and K. Clark, (1994) RADARSAT Simulations of Sea Ice Monitoring Image Products, presented at Second Thematic Conference, Remote Sensing for Marine and Coastal Environments, New Orleans, U.S.A., 31 Jan. - 2 Feb., 1994.

Ramsay, B., T. Hirose, *et al* (1993) Potential of RADARSAT for Sea Ice Applications, *Cdn. J. of Rem. Sensing*, Vol. 19, No. 4, pp. 352 362.

Ramsay, B, T. Hirose, T., T. Heacock, and A. Walton (1994) Automatic Synthetic Extraction Algorithms for Sea Ice Appiications, presented at the International Geoscience and Remote Sensing Symposium IGARSS 94, Pasadena, C.A., 8-12 Aug, 1994

A. Project Title: **Commercial Demonstration of ERS-1 Imagery for Marine Navigation in Ice**

B. Study Area: Bent Horn, Admiralty Inlet, NWT

C. ERS-1 Data: 4 scenes (21 Jan 1992, 15 may 1992, 18 May 1992 (2))

D. Principal Investigator(s):

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E. Co-Investigator(s):

Mike Manore (CCRS)

F. Study Objectives & Methodology:

A report was not submitted for this project.

G. Results & Recommendations:

None.

H. References:

None.

A. *Project Title:* **Generation of Large Area Mosaics from ERS-1 SAR Imagery**

B. *Study Area:* Southern British Columbia, Vancouver Island

C. *ERS-1 Data:* 53 scenes (15 June - 31 Aug 1992)
16 scenes (1 Feb - 31 Mar 1993)

D. *Principal Investigator(s):*

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E. *Co-Investigator(s):* None.

F. *Study Objectives & Methodology:*

There is a growing demand for large area synoptic data sets which require the merging of partially overlapping scenes into a seamless mosaic. Because of the dominating influence of topographic relief on the radiometric and geometric characteristics of steep-viewing imaging radars, simulation-assisted approaches have been proposed as a viable method for scene analysis. The CCRS has spent significant effort on the development of practice simulation-based tools to assist in the analysis of SEASAT, ERS-1 and RADARSAT SAR imagery. This project extends the aforementioned initiative to the generation of large area seamless image mosaics.

G. *Results & Recommendations:*

Mosaic generation involves two steps: (1) geo-coding of individual scenes and (2) identification of optimal seams in the areas of overlap of neighbouring scenes. Radiometric normalization was achieved by employing the co-registered simulated scene in the SAR projection to normalize the real image response for level land targets. It has been shown that a minimum cost approach for seam path definition can be adopted for both SAR and VIR imagery. Two prototype mosaics have been generated for southern British Columbia using Level 1 DTED digital elevation models to correct for terrain-related parallax. One 53-scene mosaic covers the provincial mainland while another 16 scene product encompasses Vancouver Island.

H. *References:*

Guindon, B., (1994) Generation of Large Area Mosaics from ERS-1 SAR Imagery, *Cdn. J. of Rem. Sensing*, Vol. 20, pp. 317-318.

Guindon, B., (1995) Performance Evaluation of real-Simulated Image Matching Techniques in the Acquisition of Ground Control for ERS-1 Image Geocoding, *ISPRS Journal of Photogrammetry and Remote Sensing*, Vol. 50, pp. 2-11.

A. Project Title: **ERS-1 Roll / Tilt Mode (RTM) Data**

B. Study Area: Mission, B.C., Calgary/Banff, Ottawa

C. ERS-1 Data: 4 scenes (10 April 1992 (2), 16 April 1992 (2) for Ottawa)
5 scenes (11 April 1992 (3), 24 April 1992 (2) for Vancouver)
4 scenes (8 April 1992 (2), 14 April 1992 (2) for Calgary)

D. Principal Investigator(s):

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E. Co-Investigator(s):

None.

F. Study Objectives & Methodology:

In January 1994, Intera was awarded a contract under the auspices of the RADARSAT Data Development Program (RDDP), to demonstrate a simulated topographic mapping capability for RADARSAT using data from ESA's ERS-1 roll-tilt and multi-disciplinary phases. The topographic mapping products referred to are primarily Digital Elevation Models (DEMs) and ortho-rectified images.

Intera proposed to modify, for use with ERS-1 data, its proprietary, commercially unique process referred to as STARMAP, with which topographical mapping products are derived from stereo STAR-1 airborne SAR data. The objective of the program was to simulate RADARSAT-derived topographic products both for technical assessment and for marketing purposes. Assuming favourable results, a second phase would be required to create the actual RADARSAT operational topographical mapping system that will be used to service the needs of the market. The results of the program are contained in this report.

The approach was to use ERS-1 data to simulate that from RADARSAT. Because of orbital constraints, normal ERS-1 data swaths do not have adequate overlap for stereo mapping purposes. However, sets of data have been acquired in roll/tilt mode (RTM) giving satisfactory stereo overlap when combined with multi-disciplinary phase imagery. Three sets of RTM data acquired in Canada were available to Intera. However, due to time constraints and stereo acquisition problems (see text for details), only two project areas have been completely processed. These two sets are located near Ottawa, Ontario and Mission, British Columbia close to the west coast.

G. Results & Recommendations:

Digital Elevation Models (DEMs) have been generated for two of the three project areas. These two DEMs derived from the ERS-1 data have been compared to government-supplied

DEMs with positive results. These results indicate that in areas of low relief the system performs extremely well giving vertical errors consistent with airborne platforms (10 - 30m RMS). In areas of high relief the performance degrades by varying amounts. It has been shown that this degradation is correlated to the local relief such that an increase in relief within a local area generally increases the noise in the DEM. Control points have also been utilized in the assessment of the ERS-1 DEM's and are consistent with the DEM results in the vertical. Horizontal uncertainty is about 35m RMS. Examples of DEMs produced for the Ottawa and Mission areas are appended below.

Ortho-rectified images have also been generated for the Ottawa and Mission project areas. These have been checked for both internal and absolute accuracy. Internal errors are based on image to image comparison, while absolute accuracy is derived by locating the same control points used for the DEM check and comparing positional information. Absolute horizontal accuracy derived by comparing image to control points is about 35m RMS. Internal horizontal accuracy derived by comparing image to image is also about 35m RMS.

The results of this program suggest the feasibility of a DEM creation and ortho-rectification capability for RADARSAT data based on stereoscopic extraction subject to certain qualifications. Level 1 DTED results should be achievable with RADARSAT in moderate terrain. Improved image matching algorithms and optimum beam viewing geometry will be required to achieve similar results in steep terrain.

H. References:

Intera Information Technologies Corp. (1995) *Topographic Mapping from RADARSAT*, Report Prepared for Public Works and Services Canada, Contract # 23413-3-7164/01-SQ, Under Sponsorship of the RADARSAT Data Development Program (RDDP).

A. Project Title: **Application Development Using ERS-1 SAR**

B. Study Area: Vernon, British Columbia

C. ERS-1 Data: 4 scenes (5 Sept 1991, 15 Jan 1992, 8 Sept 1992, 11 Sept 1992)

D. Principal Investigator(s):

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E. Co-Investigator(s):

T. Scheuer (MDA)

F. Study Objectives & Methodology:

The study objective was to perform SAR interferometry (InSAR) for terrain height estimation. A comparison of the estimated terrain heights with a digital elevation model (DEM) derived using optical techniques was planned to determine the feasibility of commercializing the technique.

G. Results & Recommendations:

Unfortunately, there was no coherence between the overlapping SAR images which meant that estimation of terrain height was not possible.

H. References:

None.

A. Project Title: **Military Terrain Analysis Using Synthetic Apperture Radar (SAR) Imagery**

B. Study Area: CFB Gagetown, New Brunswick

C. ERS-1 Data: 5 scenes (13 Aug 1992, 22 Oct 1992, 4 Feb 1993, 20 May 1993, 11 Nov 1993)

D. Principal Investigator(s):

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E. Co-Investigator(s):

Capt. P. Beaulieu (DND)

F. Study Objectives & Methodology:

The purpose of the study was to determine the usefulness of multi-temporal ERS-1 SAR imagery, in comparison with Landsat TM imagery, for the planning of military operations.

Radiometric corrections were applied to both the SAR and optical imagery data set. Both data sets were geo-coded to existing map information.

G. Results & Recommendations:

It was found that ERS-1 images were more difficult to interpret than Landsat TM imagery. Thematic maps derived from the unsupervised classification of the four best multi-temporal ERS-1 images proved to be of little use because of speckle, multiple spectral response patterns of water and other land cover types as well as geometric effects. ERS-1 images were better in detecting some man-made features (large buildings, steel bridges) and enhancing the topography of the terrain (small creeks). However, Landsat TM images were much more reliable than ERS-1 images in the production of terrain analysis maps.

The use of single-date ERS-1 imagery should be avoided. They should be integrated with optical imagery. If this is not possible, multi-temporal ERS-1 images should be used to prevent mis-identification of significant features.

H. References:

Beaulieu, P. (1994) *Interpretation of Multi-Temporal ERS-1 SAR Images*, M. of Engineering Thesis, Submitted to the Dept. of Geodesy and Geomatics Engineering, UNB, Fredericton, N.B.

A. *Project Title:* **Updating Digital Files Using Satellite SAR Imagery**

B. *Study Area:* Northern Ontario

C. *ERS-1 Data:* 4 scenes (25 Mar 1992, 13 April 1992, 13 Aug 1992, 11 Mar 1993)

D. *Principal Investigator(s):*

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E. *Co-Investigator(s):*

None.

F. *Study Objectives & Methodology:*

To study the possibility of developing a marketable service using spaceborne SAR data for updating digital maps. SAR data and multi-date TM data were overlaid onto the digital forest inventory maps and change detections were performed.

G. *Results & Recommendations:*

Placement of cut-over boundaries did not meet accuracy requirements. Edge pixels confused change detection analyses. Accurate geometric correction using elevation data (production of ortho-image) is a pre-requisite to any further analyses for forest management purposes. A reasonable ortho-correction algorithm was not available to Dendron to continue the study.

H. *References:*

None.

A. *Project Title:* **SAR Mapping of Urbanization**

B. *Study Area:* Ottawa, Ontario

C. *ERS-1 Data:* 1 scene (14 Aug 1991)

D. *Principal Investigator(s):*

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E. *Co-Investigator(s):*

None.

F. *Study Objectives & Methodology:*

This project will assess the potential for mapping land use patterns associated with urbanization using satellite SAR data. There has been much success in mapping land use patterns with visual interpretation of electro-optical satellite data. This project will apply visual interpretation methods to ERS-1 SAR data and compare the results with the interpretation of optical data. The radar data will be assessed as a stand-alone data set and as part of an integrated data set with the optical imagery. The interpretation process will use the land use classification keys developed by Environment Canada for Urban Land Use.

G. *Results & Recommendations:*

In general, ERS-1 radar data can be used to separate urban and non-urban land cover. However, several things can affect the interpretations: Tall vegetation cover, developments on slopes, orientation of streets and houses to the satellite orbit track. Large industrial, commercial and institutional buildings are easily identified, along with rail-roads and bridges. Short grass parks and golf courses are detectable. Under certain conditions, areas of medium and high density residential land use is detectable. The combination of ERS-1 SAR and Landsat TM or topographic map information greatly improves the interpretation of the data.

H. *References:*

Gregory Geoscience Ltd, (1992) *Satellite SAR Data for Monitoring Rural to Urban Land Use Change*, Project 91-12 Report Submitted to the Canada Centre for Remote Sensing, Contract No. 23413-2-7000/01-OTT, 40 p.

A. Project Title: **Detection of Small Changes on the Earth's Surface**

B. Study Area: Shefferville. Quebec

C. ERS-1 Data: 22 scenes (3 from 1992, 2 from 1993, the rest from 5 Feb - 6 April 1994)

D. Principal Investigator(s):

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E. Co-Investigator(s):

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F. Study Objectives & Methodology:

The objectives of this study were to develop applications for satellite repeat pass interferometry using ERS-1 SAR data; to assess coherence as a function of time for a permafrost site; and to study and prepare for InSAR applications of RADARSAT. A series of SAR passes over the test site from the duration of the second ERS-1 ice phase were obtained, processed to SLC form on a workstation-based SAR processor (dtSAR), interferograms were formed and coherence was estimated. Temporal properties of scene coherence were examined. Opportunities for differential InSAR were sought. A comparative study of ERS-1 and RADARSAT for InSAR was carried out.

G. Results & Recommendations:

It was demonstrated that RADARSAT fine resolution mode should be well-suited to InSAR, provided that the site is chosen to preserve scene coherence. The scene coherence appears to map the distribution of snow cover. Additionally, we were able to demonstrate the capability of differential InSAR over lake ice.

H. References:

Vachon, P.W., D. Geudtner, and A.L. Gray, (1995) ERS-1 Repeat Pass InSAR Demonstration Scene, *Remote Sensing in Canada*, Vol. 23, No. 1, pp. 1-5.

Vachon, P.W., A.L. Gray, and D. Geudtner, (1995) ERS-1 SAR Repeat-Pass Interferometry: Temporal Coherence and Implications for RADARSAT, *Proc. 17th Canadian Symposium on Remote Sensing*, Saskatoon, Sask., 13-15 June, pp 803-808.

Vachon, P.W., D.Geudtner, A.L Gray, and R.Touzi, (*in press*) ERS-1 Synthetic Aperture Radar Repeat-Pass Interferometry Studies: Implications for RADARSAT, Cdn. J. Rem. Sensing.

A. *Project Title:* **Topographic Dependence of Synthetic ApertureRadar Imagery**

B. *Study Area:* Slims River, Aishihik Lake, Yukon; Model Forest, Newfoundland

C. *ERS-1 Data:* 3 scenes (29 June 1992, 16 August 1992, 18 August 1992) in the Yukon
1 scene (29 July 1992) in Newfoundland

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F. *Study Objectives & Methodology:*

While the visual interpretation of radar imagery may be assisted by the influence of topography, the digital use of the data in image processing and image models may be hindered by the difficulty in separating topographically-induced radiometric variance from the targets of interests. Four different study areas in Canada and three different types of SAR imagery are used to illustrate the topographic dependence, and the degree of accuracy that can be expected, following the removal of topographic effects. The basic idea is that the incidence angle and forest canopy interactions with the radar beam can be estimated using a digital elevation model and near-coincident observations in the red and near-infrared portions of the spectrum.

G. *Results & Recommendations:*

The topographic effect on aerial and satellite SAR imagery was quantified and corrected using software modified from an earlier normalized-cosine package written for use with optical/infrared remote sensing imagery. In general, the topographic effect composes 10-20% of the variability in SAR tone and texture measures in vegetated areas. The removal of the topographic effect through image corrections was demonstrated with a reduction of within-class variance in forest and geomorphic classes. The corrected SAR data may generate a small increase in classification accuracy, and yield greater precision in the estimation of physical variables. The corrections were implemented in software as part of a larger effort to develop methods to enable more precise use of satellite and aerial SAR imagery in earth science applications.

H. *References:*

Franklin, S.E., M.B. Lavigne, E.R. Hunt Jr., B.A. Wilson, D.R. Peddle, G.J. McDermid, P.T. Giles, (1995) Topographic Dependence of Synthetic Aperture Radar Imagery; *Computers & Geosciences*, Vol 21, No. 4, pp. 521-532.

A. *Project Title:* **Detection of Small Changes on the Earth's Surface**

B. *Study Area:* Landers, California, USA

C. *ERS-1 Data:* 4 scenes (24 April 1992, 30 June 1992, 3 July 1992, 4 Aug 1992)

D. *Principal Investigator(s):*

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E. *Co-Investigator(s):*

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F. *Study Objectives & Methodology:*

The objective of this study was to observe surface displacement due to an earthquake event by using differential interferometry.

This project was not realized since we were unable to process the ERS-1 data to phase-preserved SLC products at the time. Subsequently, other interferometry groups demonstrated the potential of the technique using the Landers data set.

G. *Results & Recommendations:*

Small displacements of the earth's surface (such as those due to earthquakes) may be measured using differential interferometry if scene coherence requirements are met.

H. *References:*

(relevant to the provided data set but not a result of this project work)

Massonnett, D., M. Rossi, C. Carmona, F. Adragna, G. Peltzer, K. Feigl, and T. Rabaute, (1993) The Displacement Field of the Landers Earthquake Mapped by Radar Interferometry, *Nature* (364), pp 138-142.

A. Project Title: **Mapping Ocean Waves in Coastal and Inshore Environments**

B. Study Area: Brooks Peninsula, B.C; St John's NFLD

C. ERS-1 Data: 3 scenes (26 Jan 1992, 15 Sept 1992, 30 Oct 1992)

D. Principal Investigator(s):

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E. Co-Investigator(s): None.

F. Study Objectives & Methodology:

The objectives of this study were to develop the software and analysis techniques for generating coastal zone wave information products, and to perform market studies for such products. Archival ERS-1 SAR images were selected representing a wide range of significant wave heights imaged under varying wind conditions. This would determine the most suitable environmental parameters for favourable wave imaging with this sensor.

G. Results & Recommendations:

Wave heights between 1.5 and 5 meters were reliably estimated in offshore regions. Estimates of wavelength were consistent with linear wave theory in shallow waters. Spatial and frequency domain enhancement techniques were developed in order to extract wave refraction patterns suitable for conversion to vector format. Two dimensional linear prediction techniques were identified as possible alternatives to the standard Fourier techniques of wave spectra estimation in the near-shore region.

H. References:

Fissel, D. & R. McKenna (1993). Preliminary Results: Applications of Synthetic Aperture Radar Data for Mapping Ocean Waves in the Coastal Zone, *Proceedings Radar Data Development Program Workshop*, Gananoque, Ontario, Jan. 26-28, 1993.

A. *Project Title:* **Coastal Sensitivity Detection at Iles-de-La-Madeleine (Magdelen Islands) Using Radar and Optical Imagery**

B. *Study Area:* Isle-de-la-Madeleine, Québec

C. *ERS-1 Data:* 6 scenes (30 June 1992, 16 July 1992, 17 July 1992, 4 Aug 1992, 8 Sept, 1992 13 Oct 1992)

D. *Principal Investigator(s):*

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E. *Co-Investigator(s):*

P. Larouche (Department of Fisheries and Oceans).

F. *Study Objectives & Methodology:*

Coastal evolution is determined by measuring advances and retreats of the shoreline. Satellite images can be used for coastal evolution studies either when changes are measured in tens of metres and/or when time intervals between data sets are long enough to measure differences that exceed pixel sizes. For this project, we examined what combinations of scales and time intervals are appropriate for coastal zone studies when using remote sensing data from satellites. Iles-de-la-Madeleine, a 70 km long island located in the centre of the Gulf of St. Lawrence, was chosen as the study area since erosion and sedimentation rates of the shoreline are well known. SPOT (PLA and MLA) and Landsat-TM images recorded between 1982 and 1992 and three types of synthetic aperture radar images (airborne, ERS-1 and RADARSAT simulations) were used to evaluate the capabilities and limits of these products to monitor coastal evolution. Profiles across the littoral zone were selected to analyze the response of the different satellite sensors.

G. *Results & Recommendations:*

Many features, inherent to synthetic aperture radar, such as incidence angle of swath and noise level, make coastline detection difficult. Eroding beaches were found to be difficult to identify systematically on ERS-1 SAR images because they appeared narrower than their actual width. This may be caused by signal ambiguity between land and water; on narrow beaches waves break too close to shore or adjacent sand dunes shadow the beach when incidence angles are low. Wet sand may also be interpreted as calm water since its dielectric constant is similar, especially with C-HH configuration. Also, on most ERS-1 scenes, when wind was present, capillary waves on shallow ponds would generate a backscatter similar to adjacent land vegetation, making their discrimination difficult.

To monitor coastal changes, ground control points (GCP) must be taken inland. When the study area comprises mainly bushes, vegetated sand dunes and ponds, GCP acquisition is not obvious. The only man-made visible structures in the study area were a wharf and a bridge. The only narrow road was ambiguous to detect and sparse habitations almost invisible.

If waves are shorter than radar detectability, the water surface becomes noisy due to velocity smearing (Rufenach et al., 1991). Radar could also be affected by atmospheric effects, making land and water differentiation difficult (Thomson et al, 1992). Werle (1994) and Koopmans et al (1993) suggested that in order to detect bathymetric features, optimum conditions would be low winds and strong tidal currents. Unfortunately, Iles-de-la-Madeleine has opposite conditions: strong winds and low tidal currents. But in the Grande-Entre lagoon, the dredge channel can be seen on some ERS-1 SAR images, especially on August 4, 1992 where the wind was blowing in the same direction as the flood tide entering the lagoon from the south.

Although SAR is an all-weather, day-and-night sensor, some coastal applications rely on specific sea state conditions for their detection. This study shows that SAR images have their limitations that are different from those of optical images. SAR images provides useful information in the study of wave characteristics in the near-shore zone, information which can be used to calculate littoral sediment transport rates. This study shows that SAR remains complementary to optical sensors. However, the RADARSAT simulations provided sufficient indication to demonstrate its potential to delineate the coastline and could be used to update marine charts. As for ERS-1, more studies are required since coastline detection was more susceptible to wind conditions. It appears that the SAR C-HH configuration should allow a better coastline discrimination than C-VV, making this a potential application for RADARSAT once launched.

H. References:

De Lisle, D.A. & G. Drapeau, (1994) Coastline and Nearshore Features Delineation Using Remote Sensing', *Proceedings Coastal Zone Canada '94 "Cooperation in the Coastal Zone*, Sept 20-23, 1994, Halifax, NS.,pp. 992-1004.

De Lisle, D.A. & G. Drapeau (1994) *Coastal Sensitivity Detection at Iles-de-la-Madeleine Using Radar and Optical Imagery*, Report for the Canada Centre for Remote Sensing, contract # 23413-2-8190/01-SR. 17 p. plus appendix.

De Lisle, D.A., G. Drapeau, P. Larouche, C. Bjerkelund, (1993) Coastal Evolution Monitoring Using Remote Sensing, *Proceedings, Technical Conference on Space Based Ocean Observation*, Bergen, Norway, Sept 5-10, 1993.

De Lisle, D.A., G. Drapeau, P. Larouche, C. Bjerkelund, (1993) Potentiel Radar Antenne Synthétique pour Caracteriser l' Evolution des Littoraux, *Actes, 16e Symposium Canadien de Télédétection*, Sherbrooke, 7-10 juin, 1993.

De Lisle, D.A., G. Drapeau, P. Larouche (1993) 'Phénomènes de Rugosité de Surface de l'Ocean sur les Images Radar, *Actes de la 61 i me conférence de l'ACFAS*, Rimouski, p.196, avec presentation orale.

Drapeau, G., D.A. De Lisle, R.P. Rasoaliana, (1993) Potentiel du Radar Antenne Synthétique pour Caracteriser l' Evolution des Littoraux, *Proceedings, Canadian Coastal Conference*, Vancouver, May 4-7, 1993.

A. Project Title: **Evidence of Internal Waves in ERS-1 SAR for Ocean Bio-Productivity**

B. Study Area: Gulf of Maine

C. ERS-1 Data: 6 scenes (8 Sept 1993, 10 Sept 1994 (3), 13 Sept 1994 (2))

D. Principal Investigator(s):

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E. Co-Investigator(s):

D. Townsend, N. Pettigrew (U of Maine)

F. Study Objectives & Methodology:

The purpose of this study it to address the role of internal waves in nutrient fluxes and bio-productivity, through an interdisciplinary approach that utilizes satellite SAR data and oceanographic field observations. In the Gulf of Maine, propagation of surface slicks associated with internal waves has been commonly observed visually and by SAR imagery. Where moored observations have been made, vigorous internal wave activity has been evident. This area is widely perceived as a region of unusually energetic surface and internal tides. We believe that it is also a region in which significant mixing due to energetic internal oscillations is likely to occur and produce significant biological manifestations.

The study will use SAR data to infer the existence and characteristics of internal waves as well as the location and evolution of wave breaking events and the associated increase in standing stocks of phytoplankton. Internal waves whose energy is sufficiently localized in time and space will produce linear patches of relatively smooth surface water. SAR images surface waves through a resonant interaction between the electromagnetic plus and the high-frequency capillary waves. The surface "slicks" produced by energetic internal waves have a lower density of capillary waves and thus have a lower signal backscatter relative to the surrounding water. The study will map the distributions of internal waves from their surface expression in the SAR imagery. We can infer the wavelength of the imaged internal waves by the separation of successive slicks or from the width of the surface slick and the depth and strength of the pycnocline. The remotely sensed internal waves will be compared to predictions from our modelling study and to our field observations

G. Results & Recommendations:

The study is still in its initial stages and there are no results to report as of yet.

H. References: None.

A. *Project Title:* **Beaufort Sea Coastal Zone Mapping**

B. *Study Area:* Beaufort shore, MacKenzie Delta, NWT

C. *ERS-1 Data:* 3 scenes (5 July 1992, 9 Aug 1992, 13 Sept 1992) (Beaufort shore)
~6 scenes (MacKenzie Delta)

D. *Principal Investigator(s):*

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E. *Co-Investigator(s):*

B. Tittley (AERDE Environmental. Research.), S. Solomon (Atlantic Geoscience Centre).

F. *Study Objectives & Methodology:*

The objectives of this study was to determine the potential of satellite SAR data for coastal mapping in the Canadian Arctic. As part of the research, Landsat TM and SPOT PLA were integrated with the SAR in order to provide further information on erosional and accretional features of shoreline classification.

G. *Results & Recommendations:*

Both accretional and erosional features could be detected using the data, but their identification was highly dependant on the water height at the time of imaging. The integration of the optical data with the SAR provided good information on the accretional coastal features but was not as successful with identifying the erosional features. It was found that detection was highly dependant on size and orientation of the feature to the satellite look direction. Further studies are recommended. The Atlantic Geoscience Centre has shown interest in this work, but has not followed on it to date.

H. *References:*

Tittley, B., S.M. Solomon, C. Bjerkelund, (1994) The Integration of Landsat TM, SPOT PLA, and ERS-1 C-Band SAR for Coastal Studies in the Mackenzie River Delta, NWT, Canada: A Preliminary Assessment, *Proceedings 2nd Thematic Conference on Remote Sensing for Marine and Coastal Environments*, ERIM, Ann Arbor, MI.

Tittley, B., S.M. Solomon, C. Bjerkelund, (1994) The Integration of Landsat TM, SPOT PLA, and ERS-1 C-Band SAR for Coastal Studies in the Mackenzie River Delta, NWT, Canada: A Preliminary Assessment, presentated at Coastal Zone Canada '94 "Cooperation in the Coastal Zone, Sept 20-23, 1994, Halifax, NS.

A. Project Title: **Monitoring Coastal Zone Environment in Nova Scotia with ERS-1 SAR**

B. Study Area: Central Nova Scotia

C. ERS-1 Data: 8 scenes (10 May 1992 (2), 29 May 1992 (2), 18 June 1992 (2), 8 Aug 1992 (2))

D. Principal Investigator(s):

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E. Co-Investigator(s):

R. Percy (Environment Canada)

F. Study Objectives & Methodology:

The main objective of the work was to examine the usefulness of ERS-1 SAR imagery for coastal zone sensitivity investigations using test sites in the Maritime region of Canada as study areas. Specific objectives were fourfold. The first was to produce high-quality ERS-1 radar imagery for visual analysis; the second was to develop a procedure to enhance and co-register the radar data using standard digital image analysis equipment; the third was to interpret the radar imagery in terms of criteria important to coastal zone sensitivity investigations; and the fourth was to evaluate and discuss the results of the SAR image analysis.

The ERS-1 data acquisition was designed to acquire 25 m resolution SAR imagery in a variety of coastal environmental settings under a variety of environmental and atmospheric conditions. Image analysis focused on land, inter-tidal, and ocean surface features. Results of the image analysis were compared to existing map information and to environmental data collected during the time of SAR data acquisition.

G. *Results & Recommendations:*

ERS-1 SAR image analysis of digitally processed and enhanced data sets of the various test areas was not successful in providing a full range of information on shoreline materials, shoreline forms, and shoreline processes. In regards to shoreline forms and materials, only limited success was achieved in identifying anthropogenic and topographic features. There was good success in the detection of shoreline processes. These included wind and wave regimes, ice, and tidal regimes under certain conditions. These conditions were related most frequently to wind/water interactions and wind speed relative to the ERS-1 SAR system and imaging parameters.

It was further discovered that the level of detail required for Environment Canada's Coastal Zone Sensitivity Mapping Program was not adequately matched by the resolution of the ERS-1 SAR data sets.

Based on these findings, it is not recommended that satellite SAR be used as a comprehensive source of information for shoreline mapping exercises. However, the positive evaluation in regards to shoreline process identification should be viewed as a potential for mapping wind and wave regimes, ice, and tidal regimes.

In order to maximize the usefulness of a variety of sensors and data sources for shoreline mapping and coastal zone sensitivity analysis, a hybrid approach should be considered for data collection. SAR data should be considered for specific tasks as a supplementary source of information as part of a multi-sensor data base. A data integration exercise should be carried out within an operational setting in order to assess the feasibility of this option.

H. *References:*

Werle, D., R. Percy, (1995) *Radar Remote Sensing and the Coastal Zone - A New Tool for Environmental Analysis and Monitoring*, Environment Canada, pp. 1-4

Werle, D., (1994) *Evaluation of Synthetic Aperture Radar (SAR): Review of Previous SAR Investigations and Assessment of ERS-1 SAR Data of Coastal Areas in the Maritime Region of Canada*, Report Submitted to the European Space Agency and the Canada Centre for Remote Sensing, 76 p.

A. Project Title: **ERS-1 Imagery of High Waves off Sable Island**

B. Study Area: Sable Island, Nova Scotia

C. ERS-1 Data: 1 scene (12 Aug 1992)

D. Principal Investigator(s):

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E. Co-Investigator(s):

None.

F. Study Objectives & Methodology:

The objective of this study was to demonstrate the quantitative large surface wave monitoring capability of spaceborne SAR. An attempt was made to obtain an ERS-1 SAR image for a time period during which large (over 10 m) surface waves were present on the Scotia Shelf. Unfortunately, the delivered image was outside the time frame of large wave presence. No quantitative analysis of large surface waves was possible. The scene was subsequently incorporated into a series of demonstration projects of the ACRSO Association, showcasing general marine remote sensing technologies and capabilities and the ability of ERS-1 SAR to show other ocean surface features.

G. Results & Recommendations:

The difficulty in obtaining ERS-1 SAR imagery co-incident in both time and place with specific environmental events, field work and instrument measurements was demonstrated. This is especially true in the marine environment where phenomena are extremely temporally ephemeral.

The image illustrated other ocean surface features, including swell patterns, swell diffraction at the ends of Sable Island and what appears to be a system of large internal waves. For this reason it was incorporated into the general ACRSO Association library of marine images used for demonstration and display.

H. References:

None.

A. Project Title: **Investigate and Test Radar Analysis Functions (Developed During the Course of IRAP Project)**

B. Study Area: Orange County, Califorina

C. ERS-1 Data: 2 scenes (17 June 1992, 19 July 1992) (all product types)

D. Principal Investigator(s):

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E. Co-Investigator(s):

None.

F. Study Objectives & Methodology:

One of the objectives of PCI's IRAP project (Advanced Image Analysis Software Development, CA 103-1-1655) was to enhance its Radar Analysis software package. PCI wanted to commercialize the SAR geo-coding algorithm developed by Dr. Bert Guindon at CCRS (called SARPLAN), which uses a simulated SAR image generated from a DEM and user-collected ground control points. PCI required ERS-1 data to test the software developed using the SARPLAN algorithm. Orange County was chosen since PCI already had DEM and TM data for this area and could test registering the ERS-1 image with this data.

G. Results & Recommendations:

The main results of the study were three new programs (SARSIM1, SARSIM2, and SARGEO) based on the SARPLAN algorithm. These programs were added to PCI's Radar Analysis package for EASI/PACE (Version 5.1) released in 1992. PCI's demo data set of Irvine, California (a subset of Orange County) now includes a geo-coded ERS-1 image created using the SAR geo-coding programs. Since 1992, these programs have been re-written in order to improve performance.

H. References:

PCI Inc., (1992) *PACE Radar Analysis Manual*, Version 5.1, PCI Inc, Toronto, Ontario.

A. Project Title: Not specified

B. Study Area: Estevan, Saskatchewan

C. ERS-1 Data: 1 scene (28 Jan 1992)

D. Principal Investigator(s):

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E. Co-Investigator(s):

None.

F. Study Objectives & Methodology:

A report was not submitted for this project.

G. Results & Recommendations:

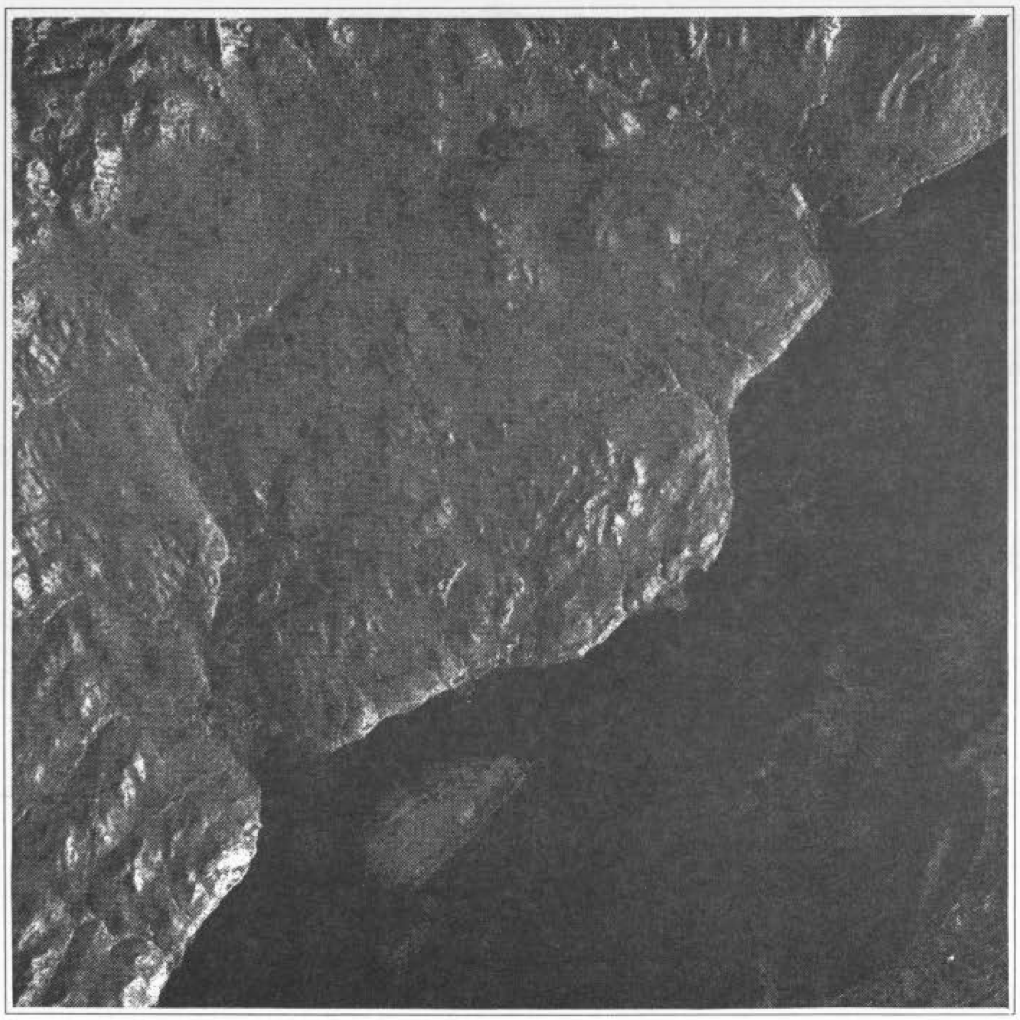
None.

H. References:

None.

PART C:

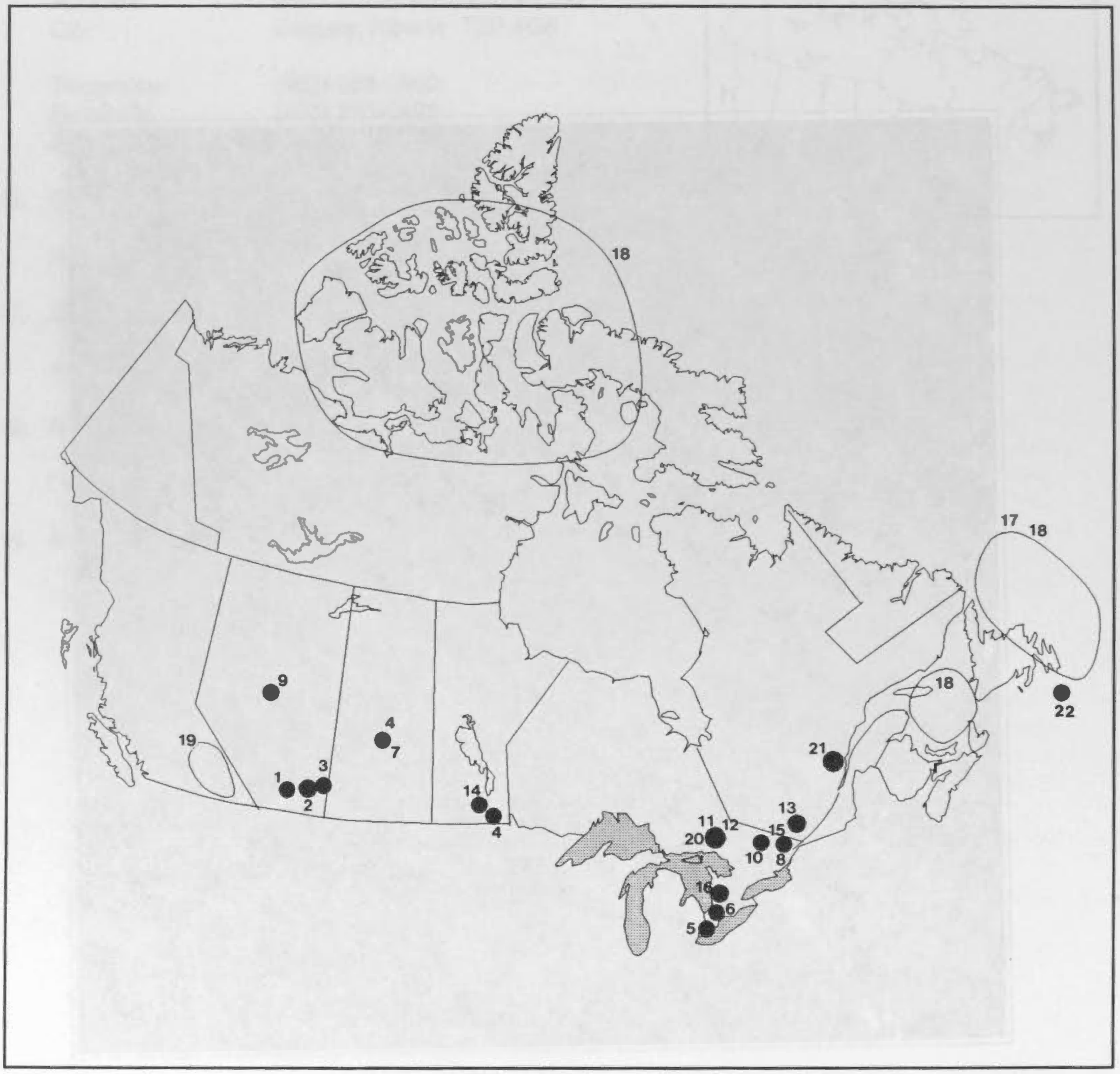
ESA ERS-1 AO PROJECTS



ERS-1 SAR image of Charlevoix, Que., 22/08/92, produced at CCRS / © ESA 1992

ESA ERS-1 AO PROJECTS

PART 'C' contains details regarding all ESA ERS-1 AO projects. A list of these projects is presented in TABLE C.1. The geographic distribution of the projects is presented in MAP C.1. This is followed by ?? Project Summary Sheets. Note that actual project numbers are cross-referenced so that project numbers mentioned in TABLE C.1 correspond to location numbers in MAP C.1 and Project Summary Sheet numbers.



MAP C.1: Regional Distribution of ESA ERS-1 AO Projects in Canada

TABLE C.1: List of ESA ERS-1 A/O Projects

No.	*Application*	*Area*	*P.I.*
1	Agriculture	Southern Alberta	R. Brown
2	Agricutlure	Southern Alberta	R. Brown
3	Agriculture	Medicine Hat, Alberta	R. Brown
4	Agriculture	Altona, Manitoba & Melfort Saskatchewan	R. Brown
5	Agriculture	Lake St. Clair Delta, Ontario	R. Brown
6	Agriculture	Oxford County, Ontario	R. Brown
7	Agriculture	Melfort, Saskatchewan	R. Brown
8	Calibration	Ottawa Ontario	T. Lukowski
9	Forestry	Whitecourt, Alberta	F. Ahern
10	Forestry	Petawawa, Ontario	S. Yatabe
11	Geology	Sudbury Basin, Ontario	V. Singroy
12	Geology	Geneva Lake, Ontario.	B. Rivard
13	Geology	Mont-Laurier, Quebec	B. Rivard
14	Hydrology	Assiniboine River, Manitoba	D. Barber
15	Hydrology	Carp River, Ontario	T. Pultz
16	Hydrology	Grand River, Ontario	E. Soulis
17	Ice	East Coast of Newfoundland	M. Manore
18	Ice	E. Coast NFLD, G. of St. Lawrence, Arctic	M. Manore
19	Mapping	Rocky Mountains, British Columbia	T. Toutin
20	Mapping	Sudbury Basin, Ontario.	T. Toutin
21	Mapping	Charlevoix, Québec	T. Toutin
22	Oceans	Grand Banks, Newfoundland	P. Vachon

A. *Project Title*: **Use of ERS-1 Data in Canadian Renewable Resource Applications: Rangeland Monitoring**

B. *Study Area:* Onefour Research Substation, Alberta

C. *ERS-1 Data:* August 10, 1991

D. *Principal Investigator(s):*

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E. *Co-Investigator(s):*

Smith, A.M., D.J. Major, R.L. McNeil. W.D. Willms, B. Brisco

F. *Study Objectives & Methodology:*

The objective of the project was to evaluate and compare the information content of SAR and VIR data for monitoring rangeland condition. The image data were evaluated alone and in various combinations using visual interpretation and statistical analysis techniques, after appropriate processing. The Onefour Substation contains a variety of rangeland conditions which were well documented using historical records and ground observations.

G. *Results & Recommendations*:

The study indicated that the SAR and VIR data were responding to different aspects of the rangeland environment and thus were complementary sources of data. The VIR responds mainly to the vegetation while the SAR responded to the geomorphology, micro-scale surface roughness, and soil moisture conditions. The two types of data used in combination thus provided very useful information for rangeland management.

H. *References:*

Smith, A.M., D.J. Major, R.L. McNeil. W.D. Willms, B. Brisco, and R.J. Brown, (1995) Complementarity of Radar and Visible-Infrared Sensors in Assessing Rangeland Condition, *Remote Sensing of Environment*, Vol. 52, pp. 173-180.

A. *Project Title:* **Use of ERS-1 Data in Canadian Renewable Resource Applications- Soil Conservation**

B. *Study Area:* Southern Alberta

C. *ERS-1 Data:* November 4, 1992

D. *Principal Investigator(s):*

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E. *Co-Investigator(s):*

Smith, A.M., D.J. Major, C.W. Lindwall

F. *Study Objectives & Methodology:*

The objective of the project was to evaluate the information content in integrated SAR and VIR data for identifying land cover classes pertinent to conservation farming. Landsat TM, airborne SAR, and ERS-1 data were compared for several test sites on different soil types using visual analysis and statistical techniques. The soil types chosen for comparison were from the Black, Dark Brown, and Brown soil zones of Southern Alberta.

G. *Results & Recommendations:*

The study found that multi-temporal, multi-sensor data could be used for the identification of farm management practices that affect soil erodability and sustainability. Timely VIR data could be used to separate vegetation and fallow categories, while differentiation between cereals and broadleaf crops, like canola, was dependent on the date of image acquisition. Radar data acquired in the fall provided additional information on tillage practices in both fallow and stubble classes. A hierarchical system was proposed for monitoring cropping practices over large areas.

H. *References:*

Smith, A.M., D.J. Major, C.W. Lindwall, and R.J. Brown, (1995) Multi-temporal, Multi-sensor Remote Sensing for Monitoring Soil Conservation Farming, *Cdn. J. of Rem. Sensing*, Vol. 21(2), pp. 177-184.

A. *Project Title:* **Use of ERS-1 Data in Canadian Renewable Resource Applications- Soil Salinity**

B. *Study Area:* Medicine Hat, Alberta

C. *ERS-1 Data:* August 7 and 13, 1991

D. *Principal Investigator(s):*

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E. *Co-Investigator(s):*

Brisco, B., D. Bedard, and J. Naunheimer

F. *Study Objectives & Methodology:*

The objective of the project was to evaluate the ability of ERS-1 data to detect soil salinity problems for remedial action and management. ERS-1 data were acquired before ("dry") and after a significant rain event ("wet") and visually compared to soil salinity maps and ground observations. A difference image (wet-dry) and a false colour composite (using the dry, wet, and difference images) were also evaluated.

G. *Results & Recommendations:*

In general the results were quite disappointing in that the salinized soil areas could not be reliably detected on any of the images or image products. It was concluded that vegetation, surface roughness, and soil moisture differences were the primary factors governing the radar response and that the variations in soil salinity had only a secondary effect on the image data. The false colour composite did demonstrate a useful change detection approach for mapping irrigation districts and identifying dryland farming regions from the irrigated fields. Fields being actively irrigated could also be identified.

H. *References:*

Brisco, B., R.J. Brown, D. Bedard, J. Naunheimer, (1992) Soil Salinity Evaluation with ERS-1 Data, *Proceedings of IGARSS'92*, Houston, Texas, May 26-29, 1992.

A. *Project Title:* **Use of ERS-1 Data in Canadian Renewable Resource Applications- Crop Type Identification**

B. *Study Area:* Altona, Manitoba & Melfort, Saskatchewan

C. *ERS-1 Data:* July 24, 1992 :Altona;
June 2, July 7, August 11, 1992: Melfort

D. *Principal Investigator(s):*

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E. *Co-Investigator(s):*

B. Brisco, F. Ahern. S. Yatabe and J. Drieman,
D. Bedard, J. Naunheimer

F. *Study Objectives & Methodology:*

The objective of the project was to evaluate the information content in single and multi-date ERS-1 for crop type classification. Test sites in Saskatchewan and Manitoba which had been used extensively during previous airborne SAR programs were used to facilitate results evaluation. Transformed divergence statistics were used to evaluate the crop separability.

G. *Results & Recommendations:*

In general the results support the conclusions of previous studies using airborne SAR. The single date imagery allowed identification of bare, grain, and broad-leafed classes but considerable confusion exists within these broad categories. The use of multi-date imagery significantly improves the separability within these classes, due to the variable crop phenology. It was also noted that environmental factors, such as rain, can have an important effect (often detrimental) on crop identification.

H. *References:*

Brown, R.J., B. Brisco, F. Ahern, S. Yatabe, J. Drieman, (1993) Preliminary ERS-1 Assessment for Canadian Agriculture and Forestry Applications, *Proceedings First ERS-1 Symposium*, Cannes, France, Nov. 4-6, pp. 611-616.

Brown, R.J., D. Bedard, B. Brisco, J. Naunheimer, (1994) Multi-temporal ERS-1 for Crop Discrimination, *Proceedings Second ERS-1 Symposium*, Hamburg, Germany, Oct. 11-14, pp. 57-62.

A. *Project Title:* **Use of ERS-1 Data in Canadian Renewable Resource Applications: Wetland Mapping and Monitoring**

B. *Study Area:* Lake St. Clair Delta, Ontario

C. *ERS-1 Data:* May 14, 1992 - April 29, 1993

D. *Principal Investigator(s):*

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E. *Co-Investigator(s):*

Li, C., B. Brisco, J. Wang, and J. McDonald

F. *Study Objectives & Methodology:*

The objective of the study was to evaluate SAR data alone and in combination with VIR data for wetland identification and monitoring. The single date SAR and TM false colour images were evaluated visually and compared to land-cover maps, air photos, and ground observations. Principal Components Analysis (PCA) was also used to reduce the dimensionality of the SAR image data set.

G. *Results & Recommendations:*

The multi-temporal ERS-1 sequence clearly demonstrated seasonal effects on wetland identification using SAR data. Optimum vegetation discrimination, including the wetland classes, was observed during peak vegetation growth in mid-summer. Freezing and very wet conditions produce low image contrast for the various land cover types. The SAR data combined synergistically with the VIR data resulting in improved class identification. The PCA was a useful technique to reduce the dimensionality of the multi-temporal SAR data as the first component was strongly correlated to the surface roughness while the second component was related to moisture differences in the scene. Combining these two components with the TM channels produced a very good false colour image for interpretation.

H. *References:*

Li, C., B. Brisco, R.J. Brown, J. Wang, J. McDonald, (1995) SAR/TM Wetland Identification in the Lake St. Clair Delta, *Proceedings of the 17th Canadian Symposium on Remote Sensing*, Saskatoon, Saskatchewan, June 13-15, 1995, pp. 60-64.

A. *Project Title:* **Use of ERS-1 Data in Canadian Renewable Resource Applications: Soil Moisture**

B. *Study Area:* Oxford County, Ontario

C. *ERS-1 Data:* May 27, October 14, 1992

D. *Principal Investigator(s):*

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E. *Co-Investigator(s):*

B. Brisco, F. Ahern. S. Yatabe and J. Drieman, J.B. Boisvert, T.J. Pultz

F. *Study Objectives & Methodology:*

The objective of the project was to determine the ability of ERS-1 to quantitatively estimate soil moisture and to evaluate the effect of surface roughness on the approach. A dry period in May and a wet period in October were used to insure a wide range of soil moisture conditions for the analysis. Ground measurements were made on surface soil moisture and roughness conditions. Regression analysis was used to evaluate the results.

G. *Results & Recommendations:*

The results showed a correlation coefficient of .8 between the radar backscatter and soil moisture values. This was improved to .95 by including RMS surface roughness in the regression. These results demonstrate that the radar backscatter can be used for quantitative surface soil moisture estimation and that surface roughness is a source of error to the approach and must be accounted for to get the best results.

H. *References:*

Boisvert, J.B., T.J. Pultz, R.J. Brown, B. Brisco, (1996) Potential of Synthetic Aperture Radar for Large Scale Soil Moisture Monitoring, *Cdn. J. of Rem. Sensing*, in-press.

Brown, R.J., B. Brisco, F. Ahern, S. Yatabe, J. Drieman, (1993) Preliminary ERS-1 Assessment for Canadian Agriculture and Forestry Applications, *Proceedings First ERS-1 Symposium*, Cannes, France, Nov. 4-6, pp. 611-616.

A. Project Title: **Use of ERS-1 Data in Canadian Renewable Resource Applications: Methodology Development**

B. Study Area: Melfort, Saskatchewan

C. ERS-1 Data: June 2, July 7, August 11, 1992

D. Principal Investigator(s):

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E. Co-Investigator(s):

Iisaka, Joji, T. Sakurai-Amano, and B.G. Brisco

F. Study Objectives & Methodology:

The objective of the project was to evaluate the use of a neural network for crop classification with multi-temporal ERS-1 data and to compare the results with those obtained using conventional approaches like maximum likelihood classification. The multi-temporal ERS-1 SAR data were classified using each approach with the resulting classification compared to a ground truth crop map.

G. Results & Recommendations:

Using a three layer, simple back propagation paradigm, peas, wheat, barley, canary grass, canola, and fallow were classified with an overall classification accuracy greater than 90 %, which was a significant improvement over the MLC. By adding textural information the classification accuracy increased to 95%.

H. References:

Iisaka, Joji, T. Sakurai-Amano, R.J. Brown, and B.G. Brisco, (1995) Neural Network Classification of Multi-temporal ERS-1 Imagery, *Proceedings of 17th Canadian Symposium on Remote Sensing*, Saskatoon, Saskatchewan, June 13-15, pp. 214.

A. *Project Title:* **RADARSAT Image Data Calibration System Methodology**

B. *Study Area:* Ottawa, Ontario, and various locations in Canada

C. *ERS-1 Data:* 1992 - June 6, July 11, Aug. 15, Sept. 19, Oct. 24, Nov. 28; 1993 - Jan. 2, Feb. 6, Mar. 13, April 17, May 22, June 27, July 31, Aug. 1, Sept. 4,5, Oct. 9,10, Nov. 13,14, Dec. 18, 19; Jan. 1992 - Dec. 1993.

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E. *Co-Investigator(s):*

R. Hawkins, L.Teany (CCRS), C. Cloutier (IITC), R. Saint-Jean, I.A. Neeson (Calian Communications Systems Ltd.),

F. *Study Objectives & Methodology:*

Calibration studies were performed using data from the ERS-1 SAR system in order to provide experience in calibration of spaceborne SAR systems and input to the development of the RADARSAT Image Data Calibration System. Signal data were processed to imagery using the CERS-1 processor at the Canadian Data Processing Facility (located at the Gatineau Satellite Station). As well, the dtSAR (developed by MacDonald Dettwiler and Associates Ltd.) and the PC-SAR (developed by the Atlantis Scientific Systems Group Inc.) processors were used.

Long-term study of point target imagery of passive (corner reflectors) and active (radar calibrators) targets and imagery of distributed targets was performed to evaluate the radiometric stability of the combined space and ground segments and determination of calibration constants. Through these studies, we were able to contribute to users of ERS-1 data including the provision of calibration constants for data processed on the CERS-1 and PC-SAR processors.

ERS-1 signal and imagery data were examined as part of a number of other calibration studies including the use of the pulse replica for the range reference function in SAR processing, determination of methodology and target areas for obtaining antenna elevation illumination patterns and antenna pointing from imagery data, methodologies of point target (impulse response) analysis, determination of absolute location error and geometric distortion in SAR imagery, conversion from floating point data within a SAR processor to the 8- or 16-bit output products to optimize the available dynamic range, and examination of possible calibration target location.

G. *Results & Recommendations:*

Calibration constants and their associated variation were determined for slant range (MLD) and ground range (SGF) products produced by the CERS-1. These studies indicated that use of data from CERS-1 under the assumption of radiometric stability is accompanied by significant uncertainty in the results as this processor was not designed to provide radiometrically calibrated products. This is especially critical where a number of images of the same area are being compared. Significant variation in the integrated power from point targets imaged at the same geometry was determined with a minimum-maximum variation of more than 4 dB and a standard deviation of .9 dB (Lukowski, 1994).

Significant improvement has been obtained in reprocessing a subset of these data with the other processors (dt-SAR and PC-SAR) where a standard deviation of 0.2 dB was obtained compared to 1.0 dB using the CERS-1. For those users who need calibrated data, it is recommended that the raw products obtained from the CERS-1 be processed to imagery using one of these alternate processors.

A calibration constant has been made available to users processing ERS-1 data on the PC-SAR.

Lessons learned and results obtained from the calibration studies have been exploited in the development of the RADARSAT calibration methodology and the RADARSAT Image Data Calibration System.

H. *References:*

Lukowski, T., R. Hawkins, K.Draper, R. Saint-Jean, P. Hamm, L. Teany, (1993) ERS-1 SAR Calibration Studies: Preparation for RADARSAT, *Proceedings of the 16th Canadian Symposium on Remote Sensing*, Sherbrooke, P.Q., June 7-10, 1993, pp. 353-358.

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Lukowski, T., R. Saint-Jean, R. Hawkins, K. Draper, P. Hamm, R. Moucha, T. Khandelwal, (1993) ERS-1 SAR Calibration Studies, *ESA Special Publication: ESA WPP-048 SAR Calibration Workshop Proceedings*, Noordwijk, the Netherlands, Sept. 20-24, 1993, pp. 247-254.

Lukowski, T., R. Hawkins, R. Moucha, T. Khandelwal, I. Neeson, (1994) Spaceborne SAR Calibration Studies: ERS-1, *Proceedings of IGARSS'94*, Pasadena, Ca., U.S.A., Aug.8-12, 1994, pp. 2218-2220.

A. *Project Title:* **Evaluation of Multi-Season ERS-1 Data for Boreal Forest Type Discrimination**

B. *Study Area:* Whitecourt Alberta

C. *ERS-1 Data:* 22 January, 16 July, 20 September, 29 October, 1993

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E. *Co-Investigator(s):*

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F. *Study Objectives & Methodology:*

The purpose of the project was to determine the utility of multi-season ERS-1 for general forest cover type mapping. Four ERS-1 scenes were combined into a three-channel colour combination using a principal component transformation followed by a Martin Taylor colour space transformation. We generated enlarged colour prints which were visually compared with enhanced Thematic Mapper images which had been previously interpreted in terms of forest cover type.

G. *Results & Recommendations:*

The ERS-1 colour composite showed regenerating burned areas distinctly. General cover types (conifer vs. deciduous vs. mixed woods) could only be moderately well discriminated. Clearcuts and other anthropogenic features were only occasionally visible. Clearcuts were more clearly visible on the 1993/08/20 image than the 1993/07/16 image. We surmise that this difference may result from different meteorological conditions on the two dates. The radiometric influence of topography interferes with the ability to discriminate vegetation types.

H. *References:*

Schaller, S., I. McKirdy, F. J. Ahern, M. Akhavi, (1995) The Use of Multi-Temporal Spaceborne SAR for Discrimination of Forest Features in the Whitecourt, Alberta Area, *Proceedings of the 17th Canadian Symposium on Remote Sensing*, Saskatoon, Saskatchewan, June 13 - 15, 1995, pp 700 - 705.

A. *Project Title:* **Comparison of ERS-1, Almaz and JERS-1 Sensors for Clearcut and Forest**

B. *Study Area:* Chalk River area, Ontario

C. *ERS-1 Data:* 9 Feb., 19 April, 2 Aug. (2), 6 Sept., 11 Oct., 15 Nov. 1992
24 Jan., 18 July, 22 Aug., 1993; 11 Feb. 1994

D. *Principal Investigator(s):*

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E. *Co-Investigator(s):*

None.

F. *Study Objectives & Methodology:*

The images selected for detailed analysis were co-registered to 25 m and filtered with an adaptive filter. Training areas, which included clearcuts, forest types, wetlands and open fields, were created and spectral signatures obtained from each image. Field visits had been made to all of the clearcut areas used in the study, supplemented by ground and oblique aerial photography. J-M Distance measurements were computed to obtain a measure of spectral separability between signatures.

The images not selected for detailed analysis were assessed on a purely visual basis; they were filtered, then viewed directly on the computer screen and also as a photographic product. 1. To evaluate the capability of the three sensors to discriminate clearcuts from surrounding forest land 2. To evaluate the capability of the sensors to distinguish individual forest types from one another 3. To investigate the effects of sensor characteristics, ground cover, terrain relief, environmental conditions and phenology on the resulting images.

G. *Results & Recommendations:*

All three sensors resulted in a decrease in contrast between clearcuts and forest as the vegetation density on the clearcuts increased. ERS-1 images were inferior to the Almaz and JERS-1 images for discriminating between clearcuts and forests.

There was a very wide variability between ERS-1 images in terms of the visibility of clearcuts and their separability from forest. The backscatter of cuts in C-band appeared to be strongly related to the environmental conditions at acquisition time, including precipitation, moisture on vegetation, ground moisture and snow cover. Optimal clearcut mapping in C-band appears to be either dry summer conditions or winter conditions with below-freezing temperatures and a dry snow cover. In comparison, the clearcuts in the JERS-1 images were consistently visible, and separable from the forest; there did not appear to be major differences between images from date to date.

The ERS-1 images were superior to the JERS-1 and Almaz images for distinguishing forest type, resulting in highest separability between individual forest types. In the ERS-1 images, red pine had the lowest backscatter, followed by jack pine, hardwoods and black spruce; this sequence was consistent in every image except for the two winter images. The overall ERS-1 separability, however, were low, and suggested that SAR data from ERS-1 could not be used alone for mapping forest type.

H. *References:*

Leckie, D. and S. Yatabe, (1994) Discriminating Forest Cuts with ERS-1 Radar Imagery, *Proceedings of SPIE*, Vol. 2314, pp. 415-428.

Yatabe, S. M. and D. G. Leckie, (1995) Clearcut and Forest-Type Discrimination in Satellite SAR Imagery, *Cdn. J. of Rem. Sensing*, Vol. 21, No. 4, pp. 455-466.

A. Project Title: **Evaluation of ERS-1 for Geological Mapping in Glaciated Terrains**

B. Study area: Sudbury Basin, Ontario.

C. ERS-1 data: 1 scene 06/1992

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E. Co-investigator(s):

Dr. B. Rivard (MIR), Dr. P. Lowman (NASA), Dr. H. Bulter (INCO)

F. Objectives & Methodology:

The objectives of the study were to assist structural mapping in the Sudbury Basin in order to better understand the tectonic evolution of the Basin and mineral emplacement. Additionally, there was the mapping glacial deposits to support drift prospecting techniques for base metals, and the integration of ERS-1 with vertical gradient magnetics and geochemical data in support of geological mapping in Canadian Shield terrains.

The goal of the study was to evaluate ERS-1 data for reconnaissance lithological structural and terrain mapping in the Sudbury Basin, a well mapped area of a complex geological terrain in the Canadian Shield. The data was filtered using a gamma filter and rectified using digital terrain elevation data to minimize geometric distortions which could induce error in structural interpretations and integration with geological and vertical gradient magnetic data. Structural interpretation was conducted by CCRS, NASA and INCO on different parts of the Basin..

G. Results & Recommendations:

Enhanced ERS-1 SAR is suitable for reconnaissance structural mapping in areas of the Canadian shield characterized by rolling topography. However, images acquired in winter and under conditions of rough lake waters are poor for geological interpretation.

The most promising use of ERS-1 for structural mapping is the integration of ERS-1 imagery with vertical gradient magnetic data.

N-S eskers are clearly visible on enhanced ERS images, and as such the images are suitable for the search construction aggregates in northern Canada.

H. References:

Kenny, F, P. Barnett, V. Singhroy, (1994) Application of Airborne Multispectral and Radar Images for Quaternary Geology Mapping,.*Cdn. J. Rem. Sensing*, Vol 20, No. 3, pp. 286-292.

Kenny, F., V. Singhroy, P. Barnett, (1994) Integration of SPOT,ERS-1 and DEM for Terrain and Surficial Mapping, *Proceedings ERIM Exploration Geology*, pp. 503-516.

Moon, W, J.S. Won, V. Singhroy, P. Lowman, (1994) ERS-1 and CCRS: C-SAR Data Integration for Look- Direction Bias Correction Using Wavelet Transform, *Cdn. J. Rem. Sensing*, Vol 20, No. 3, pp. 280-285.

Rivard, B., R. Kellett, R. St Jean, V. Singhroy, (1994) Characterization of Faulting and Dyke Intrusion in the Benny Deformation Zone, North Range of Sudbury, from Airborne Magnetics and SAR, *Cdn. J. Rem. Sensing*, Vol 20, No. 3, pp. 324-328.

Singhroy, V., B. Rivard, R. St Jean, B. Guindon, (1994) Guidelines for Enhanced SAR Images Techniques for Geological Applications, *Proceedings ERIM Exploration Geology*, pp. 626-634.

Singhroy,V., R. Slaney, D. Lowman, J. Harris, W. Moon, (1993) Radarsat and Radar Geology in Canada, *Cdn. J. Rem. Sensing*, Vol. 19, No. 4, pp. 338-351.

Singhroy,V., P. Lowman, C. Morasse, (1993) ERS-1 of Sudbury Basin: Initial Results, *Proceedings 16th Can.Sym.on Rem Sen*, Sherbrooke, Que., pp. 277-282.

A. Project Title: **Characterization of the Benny Deformation Zone, Sudbury, Ontario, Using ERS-1 SAR.**

B. Study area: Geneva Lake, Sudbury basin, Ontario.

C. ERS-1 data: 1 scene, 18 June, 1992

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E. Co-investigator(s):

Dr. R. Kellett (U of Calgary), Dr. V. Singhroy (CCRS).

F. Study Objectives & Methodology:

The objectives were twofold: a) evaluate the benefit of ERS-1 SAR for structural mapping in the shield of the Sudbury region, and b) establish a comparison with ERS-1, JERS-1, and narrow swath airborne data which provide a different viewing geometry. These objectives were addressed by selecting a study area which includes structural features typical of the shield, in this case the Geneva brittle and ductile deformation zone located 40 km north of the Sudbury structure. Filtering and geo-referencing were completed for the three data sets.

G. Results & Recommendations:

The main results are: 1) structures are more visible on the ERS-1 image then on the JERS-1. For the airborne data, structures are enhanced by the presence of shadows occurring at a grazing viewing geometry. Structures are enhanced on the ERS-1 data because of the strong contrast between foreslopes and backslopes resulting from the steep local incidence angles typical of this terrain. Because topography is rolling and terrain slopes rarely exceed 15 degrees, the 35 degree incidence angle of JERS-1 does not provide optimal contrast between foreslopes and backslopes. The lack of contrast decreases our ability to extract geological structures from the JERS-1 data when compared to the ERS-1 imagery.

ERS-1 is well suited for structural mapping in rolling topography typical of the Canadian shield.

H. References:

Kellett, R., B. Rivard, D. Long, T. Spray, (1994) Combining Remote Sensing and Geophysical Data to Characterize Faulting and Dike Intrusion Around the Sudbury Impact Structure, Canada, *Geological Society of America Fall Meeting*, Seattle, Washington,1994.

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Rivard, B., R. Kellett, R. St-Jean, V. Singhroy (1994) Mapping Structures and Lithologic Contacts in the Area of Geneva Lake, Sudbury Using Sar, Digital Topography, and Airborne Geophysics, *Geological Association of Canada Annual Meeting,* Waterloo, Ontario, 1994.

A. Project Title: **Structural Analysis of a Deep Crustal Shear Zone Using ERS-1 SAR.**

B. Study area: Mont-Laurier, Quebec.

C. ERS-1 data: 1 scene, 5 July, 1995.

D. Principal Investigator(s):

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F. Study Objectives & Methodology:

The goal of the study was to use ERS-1 data for a well mapped area of a complex geological terrain to develop predictive capabilities for reconnaissance mapping of faults, folds and intrusives in lesser well known areas. The objective was adressed by taking part in an ongoing mapping program of the geological survey of Canada focusing on the eastern Grenville geologic province of Quebec, Canada. The data were filtered using a gamma filter and rectified using digital terrain elevation data to minimize geometric distortions which could induce error in structural interpretations. Image interpretation of structures was completed for reconnaissance mapping and followed by two week of field verifications.

G. Results & Recommendations:

Results from image interpretation include the delineation of intrusive bodies (alkaline plutons and sheeted monzonites), of variations in the orientation of the regional foliation, and of zones of ductile deformation. In some instances the sense of displacement along some zones of deformation was established.

Recommendations: ERS-1 SAR appears well suited for reconnaissance structural mapping of high grade complex geological terrains in areas of the Canadian shield characterized by rolling topography.

H. References:

None.

A. *Project Title:* **The Role of Earth Observation Technologies in Flood Mapping: A Manitoba Case Study**

B. *Study Area:* Assiniboine River, Manitoba

C. *ERS-1 Data:* 23 March, 13 April, 2 May, 13 May, 6 June, 1995

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F. *Study Objectives & Methodology:*

Earth Observation technologies and Geographical Information Systems (GIS) are beginning to play a larger role in the development of these resource management information systems. In this work we illustrate, through a case study of the Assiniboine River in Southwestern Manitoba, how airborne and satellite synthetic aperture radar (SAR), Landsat Thematic Mapper (TM) and GIS can be used in both the assessment and mitigation components of flood management.

More specifically the study addresses a series of management concerns, expressed as follows: Can the boundaries of the flooded area be identified using aerial and/or orbital synthetic aperture radar data ? Can the type and area of landcover classes affected by the flood be computed ? Can information on the temporal aspects of the flood be derived from orbital ERS-1 SAR data ?

G. *Results & Recommendations:*

Results from this work indicate that the ERS-1 sensor is not particularly well suited for mapping flood regions or for monitoring the time series evolution of the conditions experienced in this flood. ERS-1 has however, been used successfully for flood mapping in other areas; the Mississippi flood of 1993 in particular. The CV-580 data indicate that a larger incidence angle (greater than about 45 degrees) maximizes our ability to delineate flooded areas by creating a specular return from the flooded area surface. This creates a very low scattering, texturally homogeneous return. We have shown that this delineation can be used in combination with Landsat Thematic Mapper (TM) data to assess the areal coverage of land cover types impacted by the Assiniboine flood of 1995. Total area of the flood can be easily computed and the classification of the affected cover types can be modified for specific purposes by changing the classification criteria used in the TM assessment. The processing of these data are possible on inexpensive microcomputers. Image analysis and GIS software is sufficiently inexpensive that the types of analysis illustrated here can how be conducted directly by the resource manager.

The results can be extended much further than the illustrative analysis presented here. Integration of demographic, socioeconomic, and cultural information with the Earth Observation datasets can provide a wealth of information in many aspects of the flood management paradigm.

H. References:

Barber, D.G., K. P. Hochheim, R. Dixon, D. R. Mosscrop, M. J. McMullan, (1996) The Role of Earth Observation Technologies in Flood Mapping; A Manitoba Case Study, Research Note, *Cdn. J. of Rem. Sensing* (in press).

A. *Project Title:*

Temporal Analysis of ERS-1 SAR Backscatter for Hydrology Applications

B. *Study Area:* Carp River watershed, Ontario

C. *ERS-1 Data:* July, 1992 - July, 1993 (12 scenes)

D. *Principal Investigator(s):*

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E. *Co-Investigator(s):*

Y. Crevier (Intera), T. I. Lukowski and T. Toutin (CCRS)

F. *Study Objectives & Methodology:*

A series of 12 ERS-1 SAR scenes were used to examine the effects of environmental conditions and human disturbance on radar backscatter from a variety of land-cover targets of particular interest to hydrological applications. Imagery covering the Ottawa region was acquired for the period of July 1992 through July 1993. This dataset was radiometrically calibrated using software developed at CCRS. The calibration process is essential in order to compare the radar backscatter of bare fields, pastures, wetlands, and forests in the 12 images. A precise geometric correction method was also applied to the multi-date images. In addition, a Landsat Thematic Mapper image was used to extract the training areas which are representative of the land-cover classes. Descriptive statistics (mean, standard deviation) are extracted from the ERS-1 SAR images for each land-cover class. These statistics are used to generate temporal signatures. Associated meteorological data and ground information are used in the interpretation of backscatter response.

G. *Results & Recommendations:*

The analysis of the temporal signatures of the land-covers of interest yielded the following conclusions:

The backscatter of bare fields shows the largest yearly dynamic range of all the studied surfaces (10 dB) because of its high sensitivity to changes in environmental conditions (dry/wet, thaw/freeze) and cultivation effects.

Backscatter from bare fields and pasture tends to drop drastically during the winter months (approximately 5 dB). This decrease can be related to several factors such as the presence of the snow cover and the frozen state of the soil.

Wetland surfaces show a stable backscatter profile from July to October (»-8 dB). For this period, the temporal signature of wetlands is very similar to mixed forest. For heterogeneous areas, wetland and forest may be difficult to distinguish during these months which can complicate automated water/land interface monitoring using ERS-1 SAR data. We also observed that the variance of backscatter values for wetland increased in November. It suggests that it maybe possible to discriminate wetland classes using late-autumn backscatter values.

Mixed-forest sites show a stable backscatter profile from July to October. The backscatter of approximately -8 dB. For the same period, we did not observe differences in tree types within the forest sites. Mixed-forest targets present the lowest yearly dynamic range (2-3 dB). Precipitation events of October and November are not detectable on the backscatter signatures. In addition, forest cover exhibits small within-scene variance which suggest that the ERS-1 SAR imaging configuration (frequency, incidence angle) may not be ideal for tree-type or species discrimination. During the growing period, at a steep incidence angle (23° for ERS-1), the differences in crown surface geometry between the two tree types may be negligible. However, in winter we observed a subtle but perceptible difference in the backscatter values where the variance within the forested sites increased. The differences in the geometry and dielectric properties of deciduous trees in winter, due to the absence of leaves, may be sufficient to discriminate them from coniferous.

H. References:

Crevier, Y., T.J.Pultz, T.I.Lukowski, T.Toutin, (1996) Temporal Analysis of ERS-1 SAR Backscatter for Hydrology Applications, *Cdn. J. of Rem. Sensing* (in press).

Mullins, D.W., T.J.Pultz, T.I.Lukowski, (1994), Evaluation of a Multitemporal ERS-1 Dataset for Hydrological Applications, *Proceedings IGARSS 94*, Pasedena California, August 21-18, 1994, pp.1484-1487.

A. *Project Title:* **Soil moisture in Pasture Fields Using ERS-1 SAR Data**

B. *Study area:* Grand River watershed, Ontario

C. *ERS-1 Data:* 21 July, 9, 25 August, 13, 29 September, 18 October, 3, 22 November, 1993

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F. *Study Objectives & Methodology:*

The focus of this study is on pasture fields, which broadly refer to grassed fields, parkland and playing fields. This is in contrast to many previous studies in which mostly bare and cropped fields were sampled. However, pasture fields are particularly suitable as repeatable targets in a watershed because their use rarely changes and their vegetation cover and roughness characteristics vary little within the year. The question that remains is whether or not the soil moisture signal is strong enough in satellite imagery of pastures to provide useful estimates for modeling purposes. Field data collection across the watershed was conducted between 10:00 a.m. and 2:00 p.m. for the following days of 1993: July 21, August 9, August 25, September 13, September 29, October 18, November 3 and November 22. Ten soil samples were collected (0-5 cm) in each field using samplers with known volume.The relationship between average backscatter and the field-average ground-truth soil moisture was examined for each scene separately and across scenes through scatter-plots.

G. *Results & Recommendations:*

Although pasture fields are a practical choice for index fields in deriving soil moisture maps, C-VV imagery contains only limited information about soil moisture for individual fields in a scene. However, the results based on linear regression equations across scenes were much better than the ones obtained for within scenes. It seems that different ground wetness scenarios, based on the average of many fields over a large area (1500 km^2) can be detected in C-VV SAR images.

It should be possible to extract information from a scene at a scale between field size and that of the study area in order to generate a soil moisture map for a watershed at modelling scales. For the study area, this would involve producing estimates for 100 km^2 computational units. Unfortunately, the within-field soil moisture variability is as high as the among-field variability, which means conventional interpolation methods such as regression techniques, will have difficulty producing meaningful trend surfaces upon which to base the maps. However, there is a spatial correlation structure to image backscatter that may relate to the soil moisture variability. Geo-statistical methods, which fully exploit this in the interpolation process, are therefore worth pursuing.

H. References:

Rotunno Filho, O.C., E.D. Soulis, A. Abdeh-Kolahchi, N. Kouwen, T.J. Pultz, Y. Crevier, (1995) Soil Moisture in Pasture Fields Using SAR Data, *Proceedings IGARSS'95*, July 10-14, 1995, Florence, Italy, pp. 731-733.

Rotunno Filho, O.C., E.D. Soulis, A. Abdeh-Kolahchi, N. Kouwen, T.J. Pultz, Y. Crevier, (1996) Soil Moisture in Pasture Fields Using SAR Data: Preliminary Results, *Cdn. J. of Rem. Sensing* (in press).

A. *Project Title:* **ERS-1/Optical Data Integration for Sea Ice Properties**

B. *Study Area:* East Coast of Newfoundland

C. *ERS-1 Data:* (to be supplied)

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E. *Co-Investigator(s):*

None.

F. *Study Objectives & Methodology:*

The objective of this project was to investigate the synergistic information content of ERS-1 and optical data (SPOT, Landsat Thematic Mapper, NOAA-AVHRR) for sea ice properties off the east coast of Canada. The focus of the project was the potential operational uses of a combined data set. In particular, the discrimination of ice from open water and estimates of ice type. An additional objective of the work was to explore the digital processing methods to integrate the different data sets.

G. *Results & Recommendations:*

Attempts to physically integrate ERS-1 SAR with Landsat, SPOT and NOAA-AVHRR data were frustrated by the lack of suitable data which matched the time and location of the SAR. Coincidence in time was of critical importance to the physical integration of the data sets in this highly mobile ice regime. It was found that a time separation of 12 hours was still too great for successful data merging. As a consequence, it was not possible to explore the integration methods as planned. Because of these difficulties, the conclusion from the operational perspective was that SAR and optical data integration will remain a function for the human analyst

H. *References:*

Manore, M.J., (1993) ERS-1 Sea Ice Applications Development Activities at the Canada Centre for Remote Sensing, *Proceedings, 2nd ERS-1 Symposium*, Hamburg, 11-14 October, 1993.

A. Project Title: **RDDP Sea Ice Applications Development**

B. Study Area: East Coast of Newfoundland, Gulf of St. Lawrence, Arctic Islands

C. ERS-1 Data: ~250 scenes received by CCRS and Ice Services (ISEC)
~ 600 scenes provided under RDDP-AO to ISEC
~ 2000 scenes purchased by AES from CCRS

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F. Study Objectives & Methodology:

The RDDP Sea Ice Applications development program at CCRS had the goal of preparing the user community for the operational use of satellite SAR imagery for operational ice reconnaissance and forecasting. ERS-1 was recognized as an excellent opportunity to demonstrate the characteristics of a C-band, satellite SAR in anticipation of RADARSAT. All projects were undertaken with research partners from other government departments, industry and universities. Among the focused objectives of the program were: 1) to develop proficiency in ERS-1 interpretation for operational ice reconnaissance and forecasting at ISEC through field validation experiments in the Gulf of St. Lawrence, Labrador Sea, and the Arctic. (ISEC, U. Waterloo, DFO/BIO); 2) to evaluate the information content of ERS-1 for strategic and tactical ship navigation in ice (Canarctic Shipping, CCG); 3) to demonstrate advanced image compression algorithms for SAR images of sea ice (CCRS/MSD); 4) to demonstrate the transmission of SAR imagery to ships at sea via cellular and marine satellite communications channels (ISEC, Canadian Coast Guard, Canarctic Shipping); 5) to simulate the information content of RADARSAT ScanSAR imagery from a mosaic of ERS-1 SAR (ISEC); 6) to demonstrate near-real time SAR usage for sea ice forecasting in China (GlobeSAR); 7) to demonstrate automated algorithms for ice motion and ice-water discrimination (ISEC, Industry).

G. Results & Recommendations:

ERS-1 data was used extensively within CCRS and by other research groups in the successful demonstration of the use of satellite SAR for ice reconnaissance. Ice Services Environment Canada routinely received fast-delivery ERS-1 data from Gatineau (>2500 scenes) which were integrated into their standard ice analysis operations and transmitted to Coast Guard Ice Offices and ships at sea using communications and data compression schemes first demonstrated by CCRS.. A simulation of RADARSAT imagery developed from ERS-1 was widely used to demonstrate the expected information content of ScanSAR wide; and experience with ERS-1 for ice reconnaissance was successfully applied to demonstrate the value of near-real-time SAR data for ice forecasting in China

Overall, the ERS-1 experience was very beneficial for the operational sea ice community as a technical lead up to RADARSAT. However, the narrow swath width, infrequent revisit period, and restricted programming control limited the utility of ERS-1 to truly meet operational reconnaissance needs.

H. References:

Brown, R.J., M. Manore, D. Bedard and C. Hepburn, (1994) Information Content of Compressed Remotely Sensed Data, *Proceedings, IGARSS'94*, Pasadena, August, 1994.

Carrierres, T., (1993) The Use of ERS-1 Within an Operational Ice Monitoring Program, Presented at *From Optics to Radar - SPOT and ERS Applications Symposium*, Paris, France, 1993, May 10-13.

Gauthier, M.-F., (1993) Operational Use of Remote Sensing Data for Ice Monitoring Along Canada's East Coast - Winter 1992/93, *Proceedings IGARSS'94*, Tokyo, Japan, 1993, August 18-24.

Iisaka, J. T Sakurai-Amano, M. Manore, (1996) An Approach to Automated Sea Ice Classification for ERS-1 SAR Images, *Proceedings, 17th Cdn. Symposium on Remote Sensing*, Saskatoon, June 1996.

Lasserre, M., M. Manore, N. Eldridge, D. Roach, (1995) Compression of SAR Sea Ice Imagery using Wavelet and Fractal Methods: A Case Study, *Proceedings, 17th Cdn. Symposium on Remote Sensing*, Saskatoon, June 1995.

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A. Project Title: **Radar Geocoding with DEM**

B. Study Area: Rocky Mountains, British Columbia

C. ERS-1 scenes: July 3, 1993

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E. Co- Investigator(s):

K. Thomson (U du Laval), VIASAT Inc., PCI Inc.

F. Study Objectives & Methodology:

SAR standard products generally available to the users are SAR images and not raw signals. Registration of SAR images and their integration with other images and vector data thus require precise and robust geometric processing, as well as user friendly systems.

A geometric correction model developed at CCRS has been integrated to take into account the geometric distortions of the full viewing geometry (sensor-platform-Earth) and the map projection. It enables ortho-images to be generated with DEM. Furthermore, speckle filtering can be applied during the rectification process to avoid multiple resampling.

G. Results & Recommendations:

This geometric correction model has been ported into operational environments of system and service companies, such as PCI and VIASAT. Accuracy in the order of one to two resolution cells can be achieved with few (10-12) GCPs.

The major advantages of this system are: 1) only one image correction system is needed for different types of sensors; 2) it is easily adaptable for other data in the future such as RADARSAT; 3) the user controls the full process and can monitor the error propagation; 4) the user can choose the data and the process depending on the required accuracy and on the application.

H. References:

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Toutin, T., Y. Carbonneau, M. Côté, P. Vincent, (1995) Le Géocodage d'Images Radar Complexes, *Proceedings 17 th Canadian Remote Sensing Symposium*, Saskatoon, June 13-15, pp. 250-255.

Cheng, P., T. Toutin, C. Pohl, (1995) A Comparison of Geometric Models for Multisource Data Fusion, *Proceedings of Geo Informatics '95*, Hong Kong, May 1995, 10 pages.

A. *Project Title:* **Opposite Side ERS-1 SAR Stereo Mapping**

B. *Study Area:* Sudbury Basin, Ontario.

C. *ERS-1 Data:* August 22, 28, 1992

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F. *Study Objectives & Methodology:*

Opposite side radar stereo images have been considered unsuitable for stereo viewing due to illumination differences which limit the ability to identify the same features in the image pair. In some contexts such as a rolling topography, the shadow, layover and foreshortening effects will not be overwhelming with an opposite-side stereo pair. Issues of stereo viewing and plotting were examined as well as problems and compromises for obtaining good geometry and radiometry. Ways of overcoming these problems were also investigated.

Using a rigorous photogrammetric solution on a low-cost digital stereo-workstation (DVP), planimetric and altimetric features were extracted from an ERS-1 SAR stereo pair for both ascending and descending orbits.

G. *Results & Recommendations:*

As a trade-off between obtaining good stereo geometry and good radiometric fusion it was decided to use ERS-1 SAR ascending and descending stereo images over a rolling topography, which reduces the radiometric disparities. From the raw images, features were interactively stereo-extracted and compared to digital topographic data. In planimetry, the accuracy for a lake shoreline is 17 metres. The orientation, the location and the size of the lakes do not have an effect on this accuracy. In altimetry, an accuracy of 24 metres with a 10-m bias was achieved for the DEM. These findings are the result of: 1) a favourable geometry with opposite side stereo pair; 2) a good stereo fusion with a rolling topography; and 3) a complementary aspect in radiometry with East-and-West looking images and day-and-night images.

H. *References:*

Toutin, T., (1996) Opposite Side ERS-1 SAR Stereo Mapping Over Rolling Topography, *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 34, No. 2, March, 10 p.

Toutin, T., (1995) Generating DEM from Stereo Images with a Photogrammetric Approach: Examples with VIR and SAR Data, *EARSeL Journal Advances in Remote Sensing*, Vol. 4, No. 2, 8 p.

A. *Project Title:* **Structural Geomorphology**

B. *Study Area:* Charlevoix, Québec

C. *ERS-1 Data:* February, May, August 1992

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E. *Co-Investigator(s):*

R. Desjardins (U. du Québec à Montréal),

F. *Study Objectives & Methodology:*

Within the project undertaken by the Canada Centre for Remote Sensing for evaluating the usefulness of radar data, we have analyzed ERS-1 data in the determination of the structural geomorphology of a crater in Quebec called "Astroblème Charlevoix". This study analyzed the data acquisition date, the geometric correction process for this type of area where topographic elevation can vary within 1000 m, and the integration of different data sources to optimize the understanding of the geomorphological environment. Different types of radiometric processing were used to enhance geomorphological feature interpretability and extraction.

G. *Results & Recommendations:*

This study reveals the importance in finding the data to best differentiate features (radiometric homogeneity of surface, better contrast between soil and water, GCP localization). A precise geometric correction process to rectify and integrate SAR and VIR images with DEM is also mandatory in this type of geomorphological relief. It gives a better interpretability, positioning, extraction and orientation of lineaments. In this application, ERS-1 SAR was an important source of information because two-thirds of the lineaments present on the 1:20000 geological map have been extracted. However, the use of complementary data, like Landsat-TM is useful for this kind of geomorphological application.

H. *References:*

De Sève, D., R. Desjardins, T. Toutin, (1994) Contribution des Donneés Radar d'ERS-1 dans l'Apprehension de l'Organisation des Linéaments : Le Cas de l'Astroblème de Charlevoix, *Journal canadien de télédétection*, Vol. 20, No. 3, Septembre, pp 233-244.

De Sève, T. Toutin, R. Desjardins, (1996) Evaluation De Deux Méthodes de Correction Géometrique d'Images Landsat-TM et ERS-1 RAS dans Une Étude de Linéaments Géologiques.

A. Project Title: **ERS-1 Wave Spectra Validation**

B. Study area: Grand Banks, Newfoundland

C. ERS-1 Data: 11, 12, 14, 15, 17, 18, 20, 21, 23, 24, 26, and 27 Nov. 1991

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F. Objectives & Methodology:

The objectives of this project were fourfold. The first objective was to provide ESA with a calibrated set of high sea-state wave measurements to determine accuracy of ERS-1 AMI image mode measurements of ocean waves. The second was to determine the utility of SAR image spectra for initializing wave models. The third was to investigate the coupling of wind and waves. The fourth was to intercompare various means of modelling and measuring ocean wave spectra.

In support of these activities, a field program was carried out on the Grand Banks near coordinates N46 W51, involving the following assets: BIO Research Vessel CSS "Hudson" (wind, waves, marine radar), 11-24 Nov.; Soviet Research Vessel "Georgii Ushakov", 18-21 Nov.; ERS-1 SAR (12 passes); Almaz SAR (1 pass); CCRS CV-580 SAR (7 flights); NASA P-3 ROWS or SCR (4 flights); NRSL HF radar station at Cape Race, Nfld.; AES wave modelling (forecast and hindcast).

G. Results & Recommendations:

This field program has produced a number of well-validated case studies relevant to microwave remote sensing measurement of wind and wave phenomena. In particular, the following SAR-specific results were obtained:

The performance limits for ERS-1 SAR measurement of ocean waves was delineated by comparing the large range-to-velocity ratio ERS-1 SAR with the small range-to-velocity ratio CCRS SAR using accurate in situ wind and wave measurements.

A new quasi-linear SAR forward mapping function was developed and integrated into an efficient SAR inversion scheme.

New methods of calculating SAR image spectra were developed.

New methods of extracting wind and wave parameters from SAR images were developed.

The synergy between SAR image spectra and wave forecasting models was demonstrated.

Analysis of this extensive data set is still ongoing, and has also yielded new understanding of ocean wave evolution and measurement which is outside the SAR context.

H. References:

Buckley, J.R., M. Allingham, F.W. Dobson, P.W. Vachon (1992), Comparison Of Measured Directional Wave Spectra in the ERS-1 Cal/Val Experiment, *3rd International Workshop on Wave Hindcasting and Forecasting*, Preprint Volume, Montreal, Canada, 19-22 May 1992, Environment Canada, Atmospheric Environment Service, Downsview, Ont. pp. 374-381.

Dobson, F.W., M. Khandekar, L. Lalbeharry, P. Vachon (1992) The ERS-1 Cal-Val Experiment, *CMOS Newsletter* 20(2).

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Vachon, P.W. and F.W. Dobson (1996) Validation of Wind Vector Retrieval from ERS-1 SAR Images Over the Ocean, *The Global Atmosphere and Ocean System*, Accepted for publication.

PART D:

APPENDIX

ERS-1 SAR image of Belle Isle, NFLD., 16/02/92, produced at CCRS / © ESA 1992

Canadian ERS-1 A/O Data Set Specifications

Proj. #	P.I.	Location	Date
1	Major	Southeast. Alta.	10/08/91 13/08/91 20/08/92
2		Southeast Alta.	17/07/92 4/11/92 13/01/93 28/04/93 2/07/93 7/08/93 11/08/93 17/11/93 19/11/93 11/05/94
3	Huffman	Southern Alta. & Man.	2/06/93 2/06/93 10/06/93 15/07/93 19/08/93 23/09/93 20/10/93 20/10/93 28/10/93
4	Dixon	Altona, Man.	24/07/92
5	Korporal	Summerside, P.E.I.	2/07/93 3/07/93 7/07/93 8/07/93 11/08/93 12/08/93 28/08/93
6	Hinse	St-Leonard D'Aston, Que.	25/07/92 28/07/92 16/08/92
15		Gaspe, Que.	13/09/92 25/07/92 28/07/92 16/08/92 8/10/92 21/10/92

Canadian ERS-1 A/O Data Set Specifications, Continued

Proj. #	*P.I.*	*Location*	*Date*
8	Saper	Kanata, Ont.	22/05/93
43		Northern California, USA	12/07/94
			26/07/94
			10/01/95
			11/03/95
9	Cihlar	Thomson, Man.	
		Candle Lake, Sask.	
		Flin Flon, Man.	
10	Goodenough	Sooke, B.C.	21/07/94
		Parson, B.C.	24/07/94
		Clayoquot, B.C.	3/08/94
		Victoria, B.C.	7/08/94
			13/08/94
11	Jaques	W. Vancouver Island, B.C.	11/07/92
			15/08/92
12	Franklin	Eastern N.B.	1/08/93
13		Western NFLD	29/07/92
			18/09/92
			29/07/92
32		Dawson Creek Yukon	3/06/92
53		Slims River, Aishihik Lake, Yukon	29/06/92
			16/08/92
			18/08/92
14	lisaka	Petawawa, Ont	28/03/93
			13/06/93
			2/07/93
16	Broster	Fraser Plateau, B.C.	8/08/93
			1/09/93 12/09/93
17	Campbell	Lillooet, B.C.	1992 (2)
18		Quesnl, B.C.	1992 (1)
19			18/05/92
20	Dong	Revelstoke, B.C.	6/05/92
21	Brown	Whiteshell, Man.	27/01/92
			16/06/92

Canadian ERS-1 A/O Data Set Specifications, Continued

Proj. #	P.I.	Location	Date
22	Mersereau	Northern. N.B.	9/07/92
			13/08/92
			21/02/93
			28/03/93
			6/06/93
23	Harris	Labrador City, NFLD	6/09/91
			6/09/91
		Shefferville, Que.	20/03/92
			20/03/92
24	Moon	Nahanni, NWT	10/93 - 01/94 (6)
28		Sudbury, Ont.	08/03/93
		Snow Lake, Man.	31/05/93
25	Akhavi	Truro, N.S.	10/05/92
			10/05/92
26		Central N.S.	29/05/92
			29/05/92
			18/06/92
			18/06/92
			8/08/92
			8/08/92
27	Rutty	Southern Ont.	8/05/92
			8/05/92
			8/05/92
29	Desjardins	Charlevoix, Que.	2/02/92
			9/05/92
			22/08/92
30	Moreau	Desmaraisville, Que.	5/08/92
			15/08/92
			6/09/92
7	Chen &	Central & Northern Sask.	16/06/93
31	Shaner		21/07/93
			25/08/93
			5/09/93
			29/09/93
			15/10/93
			3/11/93

Canadian ERS-1 A/O Data Set Specifications, Continued

Proj. #	*P.I.*	*Location*	*Date*
33	McDermid	St. Elias Mountains,Yukon	29/06/92 16/08/92 18/08/92
34	Brugman	Peyto, B.C. Sentinel B.C. Place, B.C.	05/92 (3) 04/93 (1) 16/09/93 10/10/93
35 37	Jaques	Western Vancouver Island, B.C.	11/07/92 15/08/92
36	Maxfield	Banff, Alta.	25/04/92 14/05/92 30/05/92 18/06/92 4/07/92 12/09/92
38	Tang	Central N.B.	29/11/92 30/01/93 14/03/93 30/03/93
39	Bajzak	Churchill Falls, NFLD	1/09/92 6/10/92 19/01/93
40	Soulis	Fort Simpson, NWT	5/05/92 8/05/92
41	Duncan	Algonquin Park, Ont.	5/05/92 5/05/92 8/05/92 8/05/92
42	Fortin	Riviere La Grande (LG4), Que.	16/08/93 25/10/93 12/02/94 26/03/94 4/05/94 10/06/94 25/09/94
44	Manore	East Coast	~600

Canadian ERS-1 A/O Data Set Specifications, Continued

Proj. #	P.I.	Location	Date
45	Gorman	Admiralty Inlet, NWT	21/01/92 15/05/92 18/05/92 18/05/92
46	Guindon	Southern B.C. Vancouver Island	06-08/92(53) 02-03/93 (16)
47	Mercer	Vancouver, B.C.	11/04/92 (3) 24/04/92 (2)
		Calgary, Alta.	8/04/92 (2) 14/04/92 (2)
		Ottawa, Ont.	10/04/92 (2) 16/04/92 (2)
48	Seymour	Vernon, B.C.	5/09/91 15/01/92 8/09/92 11/09/92
49	Derenyi	Gagetown, N.B.	13/08/92 22/10/92 4/02/93 20/05/93 11/11/93
50	Nielsen	Shinning Tree, Ont.	25/03/92 13/04/92 13/08/92 11/03/93
51	Moore	Ottawa, Ont.	14/08/91
52	Vachon	Shefferville. Que.	1992 (3) 1993 (2) 02-04/94 (17)
54	Gray	Landers, California, USA	24/04/92 30/06/92 3/07/92 4/08/92
55	McKenna	Brooks Pen. B.C St John's NFLD	26/01/92 15/09/92 30/10/92

Canadian ERS-1 A/O Data Set Specifications, Continued

Proj. #	*P.I.*	*Location*	*Date*
56	Drapeau	Isle-de-la-Madeleine, Que.	30/06/92 16/07/92 17/07/92 4/08/92 8/09/92 13/10/92
57	Collins	Gulf of Maine	8/09/93 10/09/94 (3) 13/09/94 (2)
58	Bjerkelund	Beaufort shore, NWT	5/07/92 9/08/92 13/09/92
		Mackenzie Delta, NWT	(~6)
59	Werle	Central N.S.	10/05/92 10/05/92 29/05/92 29/05/92 18/06/92 18/06/92 /08/92 8/08/92
60	Thomas	Sable Island, N.S.	12/08/92
61	Wilson	Orange Co., Califorina USA	17/06/92 19/07/92
62	Thomson	Estevan, Sask.	28/01/92

ESA ERS-1 A/O Data Set Specifications for Canadian Projects

Proj. #	*P.I.*	*Location*	*Date*
E1	Brown	Southern Alta.	10/08/91
E2		Southeast Alta.	4/11/92
E3		Medicine Hat, Alta	11/08/91 13/08/91
E4		Altona, Man	24/07/92
E7		Melfort, Sask	2/06/92 7/07/92 11/08/92
E5		Lake St. Clair Delta, Ont	05/92-04/93
E6		Oxford County, Ont	27/05/92 14/10/92
E8	Lukowski	Various locations	01/92-12/93
E9	Ahern	Whitecourt Alta.	22/01/93 16/07/93 20/09/93 29/10/93
E10	Yatabe	Chalk River, Ont	9/02/92 19/04/92 2/08/92 6/09/92 11/10/92 15/11/92 24/01/93 18/07/93 22/08/93 11/02/94
E11	Singhroy	Sudbury Basin, Ont.	06/92
E12	Rivard	Geneva Lake, Ont.	18/06/92
E13		Mont-Laurier, Que.	5/07/95
E14	Soulis	Assiniboine River, Man.	23/03/95 13/04/95 2/05/95 13/05/95 6/06/95
E15	Pultz	Carp River, Ont	07/92-07/93

ESA ERS-1 A/O Data Set Specifications, Continued

Proj. #	*P.I.*	*Location*	*Date*
E16	Soulis	Grand River, Ont.	21/07/93 9/08/93 25/08/93 13/09/93 29/09/93 18/10/93 3/11/93 22/11/93
E17	Manore	East Coast of NFLD	~250
E18		Gulf of St. Lawrence	~600
		Arctic Islands	~2000
E19	Toutin	Rocky Mountains, BC	3/07/93
E20		Sudbury Basin, Ont.	22/08/92 28/08/92
E21		Charlevoix, Qué	02/92 05/92 08/92
E22	Vachon	Grand Banks, NFLD	11/11/92 12/11/92 14/11/92 15/11/92 17/11/92 18/11/92 20/11/92 21/11/92 23/11/92 24/11/92 26/11/92 27/11/92

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IMAGE CREDITS

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FURTHER INFORMATION

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