RADARSAT Helps High-Tech Trek to the Magnetic North Pole

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Among the first users of data from Canada's RADARSAT satellite [Nazarenko *et al.*, 1996] were a small group of adventurers who successfully trekked by ski to the Magnetic North Pole using RADARSAT imagery to guide them. The expedition exploited a variety of technologies for positioning (GPS, ARGOS), communications (M-SAT), route selection (RADARSAT), and equipment, all of which contributed to its success. Although applied to arctic adventure on this expedition, many of these same technologies are employed by government and industry for safe and efficient operations in northern regions. The story of the adventurers illustrates how these technologies can contribute to the success of remote operations of all sizes.

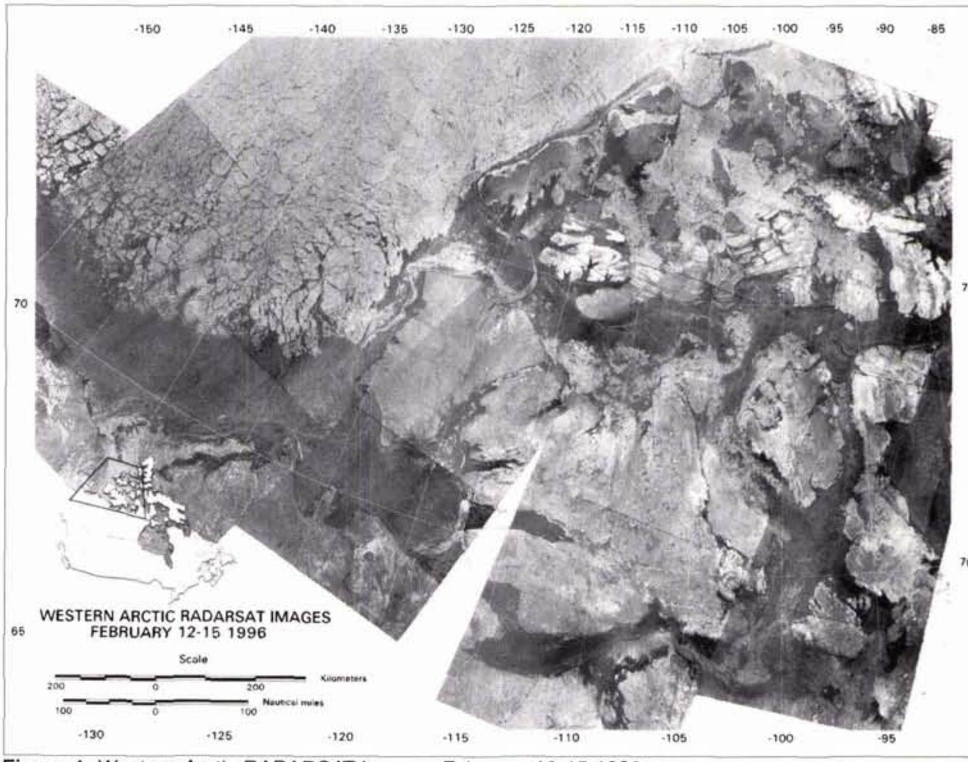

Figure 1. Western Arctic RADARSAT images, February 12-15 1996.

The base camp of *Expédition Mobilité Satellite au Pôle Nord Magnétique* was Montreal, Quebec, Canada, and the journey began at Resolute, Northwest Territories, a small arctic settlement considered the transportation gateway to the High Arctic. On March 26, 1996, Yvan Désilets, Marc Fafard, and Stéphane Lebeau set out on skis, pulling all their food, clothing, and equipment on sleds. Although the straight-line distance between Resolute and their destination was 620 km, it took the team 49 days and 800 km to reach the Magnetic North Pole (approximately 78°N, 104°W). One member of the team, Stéphane Lebeau, was forced to withdraw from the journey because of injury.

The team attributes their success to their perseverance, and also in large part to the information on ice conditions obtained from RADARSAT imagery. Around the same time, other expedition teams attempting the same trek without the RADARSAT information were forced to abandon their efforts because difficult multi-year and rubbled ice conditions made the route impassable. The *Expédition Mobilité Satellite au Pôle Nord Magnétique* team was able to select their route along relatively smooth, snow-covered, first-year ice based on the interpretation of the radar imagery by scientists at the Canada Centre for Remote Sensing.

RADARSAT

The RADARSAT satellite features a C-band (5.3 Ghz), horizontally polarized, Synthetic Aperture Radar (SAR) with flexible beam steering and resolution characteristics [Raney *et al.*, 1991]. RADARSAT is a project lead by the Canadian Space Agency in partnership with the United States (NASA, NOAA), several Canadian provinces, and private industry through the company Radarsat International Ltd. The satellite was launched in November 1995 and started delivering data in a preoperational mode to selected agencies in February 1996 while the SAR instrument was still in its commissioning phase. Among the users of the preoperational data were the Canadian Ice Service (CIS) of Environment Canada, responsible for monitoring the sea ice in Canadian waters. CSI monitors seaice primarily for the purpose of marine safety (navigation in ice and deployment of the ice breaking fleet of the Canadian Coast Guard), and also for climatic and global change studies.

Arctic Mosaic

Among the special activities of the CIS is an annual, winter-time reconnaissance of ice conditions over the entire Canadian Arctic Archipelago. This "snapshot" of ice that is largely consolidated (frozen in place, immobile) provides a valuable preview of the conditions to be faced by ships entering the region at the beginning of the summer shipping season. Previously, the imagery required to provide full coverage of the region of interest was acquired through a 10- to 16-day airborne imaging mission during the dead of Arctic darkness and cold. This year was the first time the winter reconnaissance was performed by RADARSAT in ScanSAR Wide mode (500 km swath, nominal 100 m resolution). The data were acquired from 10 orbits over a three-day period—February 11-14, 1996. A mosaic of the western portion of the data set is illustrated in Figure 1. One of the scenes acquired for this activity was used by the team in their journey to the Magnetic North Pole.

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The Expedition

In the North, exploration has aspired to two goals, the Geographic North Pole and the Magnetic North Pole. This team favored the Magnetic North Pole, firstly because the scenery was more varied and interesting and, secondly, the ice was known to be more stable.

Technologies for a Sled

The team carried supplies for 51 days and the load constraint was 250 kg, 10 percent of which was communications and navigation equipment. There were 50 sponsors associated with the expedition, the major one being Mobilité Satellite who had an interest in a high latitude demonstration of mobile telephone satellite systems using M-SAT. Another sponsor was Silva, whose GPS unit served as the only navigation aid and was used to determine camp positions. When incorporated into the geocoded RADARSAT images, waypoints were determined for passages through the ice. The unit's electronic compass was not used due to the magnetic fields at these latitudes.

Technologies exercised by the expedition included ARGOS units which relayed the position of the expedition at approximately 50-minute intervals. Using a method developed by Systems Engineering Society of Osterville, Massachusetts (SES), an expedition status report entered from the expedition's HP palm top computer accompanied the ARGOS position data stream which was then transmitted to base camp as an email message. Only 250 characters of encrypted information could be transferred during each satellite transit. Message entry problems eventually lead to the exclusive use of the M-SAT link-up which had not been guaranteed beyond the 65th parallel. The expedition undertook to determine if this could be achieved on a routine basis when channel requests were sent from above 65°N, when the satellite was less than 15° above the horizon. Using an L-band (1.5 to 1.6 GHz) mast antenna, and manually pointing it at the geostationary satellite, regular linkups continued up to the Magnetic North Pole where the satellite visibility was only 3° above the horizon. The M-SAT link-up primarily enabled telephonic communications including the transmission of digital frame images from the expedition at a data rate of 2400 baud.

Another technological tool was added on March 15, during the Montreal exposition of the expedition's sponsors at Collège Jean-Eudes, when three hard-copy sub-images of a RADARSAT scene were presented to the team, each covering a portion of the proposed route at a scale of approximately 1:750 000. This was a copy of the imagery received by the Canadian Ice Service for their winter arctic reconnaissance and was requested by the Canada Centre for Remote Sensing, where it was geocoded and enhanced to meet the needs of the expedition team. In addition, a simple interpretation key which related the image gray tones to ice age and relative surface roughness was prepared to assist the new users of radar imagery. Although the imagery was over six weeks old when delivered to the team, the immobile ice conditions meant that features imaged in February would still be in the same location when encountered by the team.

Technologies for the Schools

Three Canadian high schools were strategically allied with the expedition. First, Confederation High School (Nepean, Ontario) was the centre for SES's operations regarding the ARGOS positions, and the deciphering of the encrypted messages concerning the expedition status. Second, Collège Jean-Eudes (Montreal, Quebec) acted as the communications hub for the expedition. The students created and maintained a website where the digital images, email and voice messages were rendered into an expedition diary visible on the

Highlight

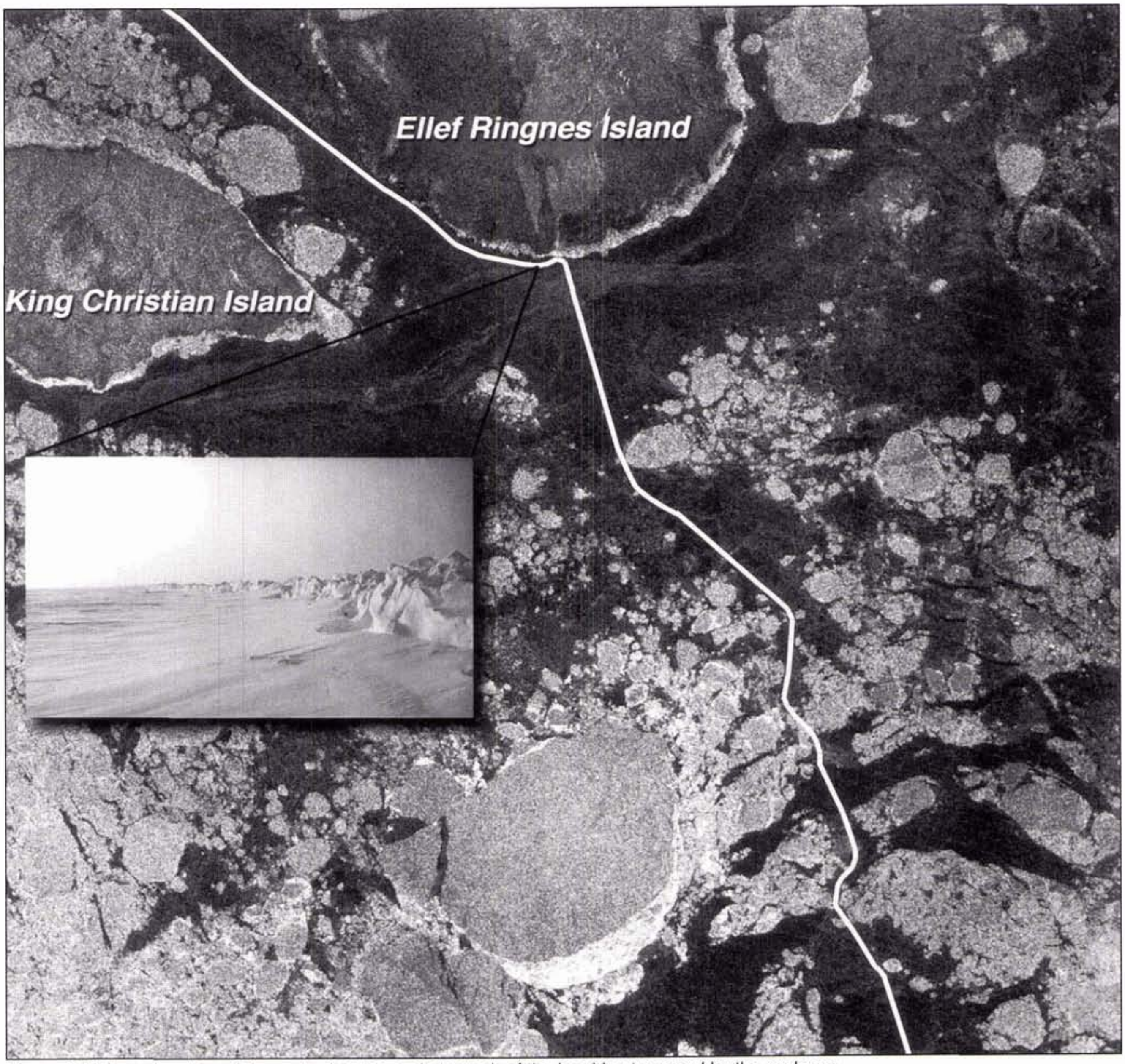

Figure 2. Enlarged portion of the route. Inset is a photograph of the ice ridge traversed by the explorers.

Internet. The results from this real-time interaction with the expedition can be accessed through the school's home page at <http://www.jeaneudes.qc.ca>. Third, the students and teachers of École Secondaire de Shippegan (Shippegan, New Brunswick) were responsible for press releases and media contact. Both Radio Canada and a local weather channel, Meteomedia, broadcast live interviews and showed the digital images received from the explorers.

Learning to Use the RADARSAT Images

After arriving at Resolute, but prior to setting out on their journey, Stéphane Lebeau accompanied a low-level (less than 1000 m) aerial reconnaissance flight over some of the proposed route. This was the team's first opportunity to use the imagery and relate the image tones to ice conditions. He was able to confirm ". . . the image looks a lot like the real thing. The island shapes formed by what I think is rugged ice . . . correlate with gray patches on the picture." The overpass made it possible to correlate only macro ice features at a scale of kilometers with ones in the image map. Large ice ridges and "pancake-like" features were confirmed, but still the reliable translation of image gray values into smooth, rough, or vertical ice would only be verified once the team was finally enroute.

By the 18th day, the explorers had validated the image gray levels for

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four ice types essential for progress and began to really trust the images. At Bathurst Island, the team encountered vertical, impassable ice as they proceeded along the route traditionally followed by expeditions in previous years. Any delay may have prevented them from meeting their final objectives, so they adopted a route defined by GPS waypoints based on the RADARSAT images. They headed away from the Pole toward Parker Island, and after a short time were on what the team called the ". . . dark part of the image . . . flat as a highway." Thus, the darkest image tones were confirmed as rubble free first-year ice which was critical to the explorers for managing their loads and negotiating safe passage. The black lines could be followed and permitted circumnavigation of the older and rougher ice, rubble and floes. In Figure 2, bright areas are multi-year or rubbled ice and the smooth, first-year ice appears in dark tones. Variations in brightness in the first-year ice are due to surface roughness, some of which may be buried under snow cover. In one instance, a four- to five-meter high ice ridge snaked away for over ten km from the southernmost tip of Ellef Ringnes Island (Figure 2) and impeded progress in a north westerly direction towards the Pole. Knowledge of the length and, to some degree, the width of the ridge enabled the team to cross the wall at the chosen location, which was only a sled's length wide. GPS positions confirm the real advantage in using the images. At the start of the expedition, the extra time consumed negotiating bad ice resulted in a daily rate of less than 10 km/day compared to 22 km/day during the final weeks.

Lessons Learned

At 100 m pixel spacing the ScanSAR Wide mode of RADARSAT basically provides information on large scale ice features. However, it was at the feature boundaries, and at the margins of islands and sea-ice, that the explorers found the most likely routes leading through to the highways of first-year ice. A decrease in pixel size could not provide localized information at the very small scale that would complement what was already visible while standing on the ice. Indeed, pixel variability at increased resolution would detract from the interpretability of the edges of large-scale ice features. The dynamic range of gray tones in the photographic prints was adequate but not as great as the original digital data which might have permitted an increase in the number of interpretable ice types. Judging the importance of precision in the geocoded image was found to be limited by the selective availability of GPS. Change in image features at the scale of a daily traverse was adequate to determine relative position.

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Operational use of RADARSAT for Ice Monitoring

The CIS is the largest user of RADARSAT data and has been an active participant in the program for many years. Indeed, the design of the RADARSAT SAR instrument and the Canadian ground segment was largely driven by the requirements for operational ice reconnaissance in the Gulf of St. Lawrence, the East Coast and Labrador Sea, and the Canadian Arctic. The CIS had been preparing to make use of RADARSAT data as soon as it was available, and was thus ready to take advantage of the preoperational data made available by the Canadian Space Agency in early 1996 [Ramsay and Weir, 1996]. The CIS has a long history of operational ice reconnaissance using optical and radar sensors including NOAA-AVHRR, DMSP SSM/I, airborne SLAR and SAR, and ERS-1.

The normal use of RADARSAT for ice reconnaissance by the CIS involves customized ordering, rapid data delivery, in-house preprocessing (geocoding, enhancement), interpretation and, finally, disseminating the products. RADARSAT data are typically ordered two weeks to one month in advance based on past knowledge of ice conditions in the regions of active commercial shipping. Because of the large volume of RADARSAT data used by the CIS, it is equipped with one of only five RADARSAT Order Desks which permits direct request entry to the Mission Control System located at Canadian Space Agency headquarters in St. Hubert, Quebec. The CIS primarily makes use of the ScanSAR modes of RADARSAT which provide nominal swaths of 500 km (at 100 m resolution—ScanSAR Wide) or 300 km (at 50 m resolution—ScanSAR Narrow). These modes are preferred because of the excellent geographic coverage and revisit capabilities at sufficient resolution for the interpretation of significant ice features.

Requested data are downlinked in SAR signal form to one of two Canadian receiving stations (Gatineau, Quebec or Prince Albert, Saskatchewan) operated by the Canada Centre for Remote Sensing. All signal data are processed into standard image products at the Canadian Data Processing Facility (CDPF) owned and operated by Radarsat International Ltd. Performance requirements stipulate a maximum four-hour delivery time for imagery, although experience indicates typical delivery times for data received at Gatineau to be closer to two hours. Signal data received at Prince Albert must be transmitted to Gatineau via Anik communications satellite, which can add as much as one hour to the delivery time because of the scheduling of transmission channels.

Processed data are delivered to the CIS through a dedicated T1 (1.44 Mb/s) link from the processing facility. Once received, the data are ingested for preprocessing and analysis by the Ice Services Integrated System (ISIS). Standard preprocessing of the imagery includes a 2x2 spatial average to reduce speckle and data volume, followed by geocoding to a standard map projection using control points from a modeled orbit. The RADARSAT imagery is then visually interpreted by ice analysts in combination with other available data sets (e.g., NOAA-AVHRR, DMSP SSM/I, meteorological stations, airborne SLAR, airborne ice reconnaissance, ship reports, etc.). Depending on location and season, typically five to ten classes (thickness and forms) of ice may be interpreted from SAR imagery supported by ancillary data. Standard products include ice analysis and forecast charts over scales of 1:100000 to 1:2M, as well as forecast messages in text form. More recently, RADARSAT and other images (or sub-images) have become standard products available through a dial-up bulletin board service. All of these products are made available by mandate to the CIS's primary client, the Canadian Coast Guard, but also to other users on a subscription basis. Resampled overviews or subimages of RADARSAT scenes (called *imagettes*) are also available under a commercial redistribution arrangement with Radarsat International Ltd. In normal operations, RADARSAT imagettes can be picked up by a ship at sea (via Inmarsat) or at any other location with a telephone link within four to six hours of satellite overpass.

Conclusion

The tale of the expedition provides many anecdotes which blend technical and human endeavor with real adventure—both equally engaging. The use of RADARSAT imagery in the context of the expedition has been one of those rare moments when something new has contributed essentially to the future on an established enterprise. The successful validation of RADARSAT for exploration using the same resolution as larger scale operations comes as a bonus, since the new users —explorers and outfitters of arctic expeditions—have access to existing bulletin board services. They can now plan their routes with knowledge of the current year's winter ice conditions.

Acknowledgments

RADARSAT imagery © 1995 Canadian Space Agency. Expedition photographs © 1996 *Expédition Mobilité Satellite au Pôle Nord Magnétique.*

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Yvan Désilets, Marc Fafard, and Stéphane Lebeau, c/o Collège Jean-Eudes, Montreal Canada, were the team of the 1996 *Expédition Mobilité Satellite au Pôle Nord Magnétique.* Monty Lasserre and Mike Manore are at the Canada Centre for Remote Sensing, Natural Resources Canada, Ottawa, Canada, and Bruce Ramsay is at Canadian Ice Service, Environment Canada, Ottawa, Canada.

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