RADARSAT Helps High-Tech Trek

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Among the first users of data from Canada's RADARSAT satellite [Nazarenko et al. 1996] was 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 (MSAT), route selection (RADARSAT), and equipment (skis, clothing, etc.) all of which contributed to their success. Although applied to arctic adventure in this case, many of the technologies employed are the same as those used by government and industry for safe and efficient operations in northern regions. The story of the trekkers provides a window into how these technologies can contribute to the success of remote operations of all sizes.

The start of the "Éxpédition Mobilité Satellite au Pôle Nord Magnétique" was from their base-camp in Montreal, Quebec, Canada, but they actually stepped onto the ice at Resolute, Northwest Territories, a small arctic settlement considered to be the transportation gateway to the High Arctic. On March 26, 1996 Yvan Désilets, Marc Fafard and Stéphane Lebeau set out on skis, pulling on sleds all their food, clothing and equipment. Although the straight-line distance between Resolute and their destination, the north magnetic pole, was 620km. it took the team 49 days and 800km to reach the pole (approx. 78°N, 104°W). One member of the team (Stéphane Lebeau) was forced to withdraw from completing the journey because of injury.

The team credits their success to their own perserverence, but also in large part to the information on ice conditions obtained from RADARSAT imagery. At about the same time, other expedition teams attempting the same trek, but without the RADARSAT supplied information, were forced to abandon their efforts because difficult multi-year and rubbled ice conditions made the route impassable and retreating caused unrecoverable delays. The Éxpédition Pôle Nord Magnétique team were able to select their route along relatively smooth, snow-covered first-year ice based on the interpretation of the radar imagery.

RADARSAT

The RADARSAT satellite is a C-band (5.3Ghz), 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 though the company Radarsat International Ltd. The satellite was launched in November 1995 and started to deliver data in a pre-operational mode to selected users agencies in February, 1996 while the SAR instrument was still in its commissioning phase. Among the users of the pre-operational data was the Canadian Ice Service (CIS) of Environment Canada. This federal government agency is responsible for monitoring the sea ice in Canadian waters, primarily for the purpose of marine safety (navigation in ice and deployment of the icebreaking fleet of the Canadian Coast Guard), and secondarily 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 conditions while the ice 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. In the past, the imagery required to provide full coverage of the region of interest was acquired through a 10-16 day airborne imaging mission during the dead of Arctic darkness and cold. For the first time this year the winter reconnaissance was performed by RADARSAT. The data were acquired from 10 orbits over a 3 day period, February 11-14, 1996. A mosaic of the western portion of the data set is illustrated in Fig. 1. One of the scenes acquired for this activity was the one used by the trekkers in there journey to the north magnetic pole.

The Expedition, Technologies for a Sleigh
In the North, there are two classic expedition goals which exploration has aspired to; the first is the Geographic North pole, and the second is the magnetic north pole. The magnetic pole has two conditions which this team favored for their endeavor, firstly the scenery was much more varied and interesting, and secondly the ice was known to be more stable. Expedition tolerances were extremely close in terms of weight and durability. The load constraint was 250 kg, of which communications and navigation equipment was 10% by weight. Supplies were for 51 days, and the equipment shared between initially the three skiers, the dogs pulling there own. There were 50 sponsors associated with the expedition, among them the major one was 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 primarily used to determine camp positions. When incorporated with the georeferenced 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 basecamp as an e-mail message. Capacity for only 250 characters of encrypted information could be transferred during each satellite transit. Message entry problems with this system lead eventually to the exclusive use of the M-SAT link-up which had not been guaranteed beyond the 65^{th} parallel. The expedition undertook to determine if this could be achieved on a routine basis when channel requests were sent from above 65^0N, when the satellite was less than 15^0 above the horizon. Using a KU-band mast antenna, and manually pointing it at the satellite during an overpass, regular linkups continued up to the magnetic north pole where the satellite visibility was only 3^0 above the horizon. The M-SAT linkup enabled principally telephonic communications facilities including the transmission of digital frame images from the expedition at a data rate of 2400 baud.

A further technology component was added when, on March 15, during the Montreal exposition of the expeditions sponsors at Collège Jean-eudes, 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 1:750000. 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, non-specialist users of radar imagery. Although the imagery was over 6 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.

The Expedition, Technologies for the Schools
Three Canadian high schools were strategically allied with the expedition: firstly, 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. Secondly, Collège Jean-eudes (Montreal, Quebec) acted as the communications hub for the expedition. In addition the school created, and maintained a website where the digital images, e-mail and voice messages were rendered into an expedition diary visible on the Internet. The results from this real-time interaction with the expedition can be accessed through the schools home page at http://www.jeaneudes.qc.ca. The students and teachers of Ecole Secondaire de Skippagan, St Johns, 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 arrival at Resolute, but prior to setting out on their journey, Stéphane Lebeau accompanied a low-level (2000 ft) aerial reconnaissance flight which traversed some of their proposed route. This provided

the first opportunity for the team to gain personal experience in the use of the imagery and to relate the image tones to ice conditions. On return, 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 translation of gray values into smooth, rough or vertical ice was only to be discovered once the team was finally enroute. Daily encounters of multi year ice and flows validated the gray levels in a context which was critical to the explorers' capabilities to manage their loads and negotiate safe passage.

By the eighteenth day the image gray levels for four ice types essential to sustaining progress had been validated and a real trust in the images begun. At Bathurst island, the team encountered vertical and un-traversable ice while proceeding along the route traditionally followed by expeditions in previous years. The consequences of any delay in progress by keeping to this route, and therefore possibly not meeting their final objectives resulted in adopting 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 they were on what the team called the "...dark part of the image,.. flat as a highway". This final validation of near zero gray-level density was the first year ice without any interfering rubble. The black lines could be followed and permitted circumnavigation of the older and rougher ice, rubble and flows. In one instance, a 4-5 m high ice ridge snaked away for over ten km. from the southern most tip of Ellef Ringnes (figures 2,3) 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 traverse the wall which, at the chosen location, was only a sleigh'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 22km/day during the final weeks.

Lessons Learned

At 200m resolution and resampled to 100m in the image, this mode of RADARSAT basically could provide 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. Here, local ice conditions were formed by the interaction of large ice-type groups driven by current and wind forces before their states became solidified by winter temperatures. A decrease in pixel size could not provide localized information at the very small scale which would compliment what was already visible while standing on the ice. Indeed, pixel variability at increased resolution would detract from the usable edge information which at the large scale, satisfactorily established the interaction mechanisms. An increase in the dynamic range of the radiometry might have been useful through increasing the number of interpretable ice types and their affect on the expedition's progress. Judging the importance of precision in the geocoded image was found to be limited by the selective availability of GPS CA code. Change in image features at the scale of a daily traverse was adequate to determine relative position.

Operational use of RADARSAT for Ice Monitoring

The Canadian Ice Service 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 known 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 operational use of RADARSAT data as soon as it was available, and were thus ready to take full advantage of the pre-operational 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 delivery of data, in-house pre-processing (geo-coding, enhancement), interpretation and, finally, dissemination of products. RADARSAT data are typically ordered 2-weeks to 1-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, they are equipped with one of only five RADARSAT Order Desks which permits direct entry of requests to the Mission Control System located at Canadian Space Agency Headquarters in St. Hubert, Québec. The CIS primarily makes use of the ScanSAR modes of RADARSAT which provide nominal swaths of 500km (at 100m resolution - ScanSAR Wide) or 300km (at 50m 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, Québec 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 4-hour delivery time for imagery, although experience to date indicates typical delivery times for data received at Gatineau to be closer to 2-hours. Signal data received at Prince Albert must be transmitted to Gatineau via Anik communications satellite, which can add as much as 1-hour to the delivery time because of the scheduling of transmission channels.

Processed data are delivered to the CIS through a dedicated T1 (1.44Mb/s) link from the processing facility. Once received, the data are ingested for pre-processing and analysis by the Ice Services Integrated System (ISIS). Standard pre-processing 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 experienced 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 5-10 classes (thickness and forms) of ice may be interpreted from SAR imagery supported by ancillary data. Standard products include 1:2M scale ice analysis and forecast charts, 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 sub-images 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 4-6 hours of satellite overpass.

Conclusions

The tale of the expedition has many anecdotes which blend technical and human endeavor in terms of real adventure and which are equally engaging in both. The use of RADARSAT imagery in the context of the expedition has represented one of those rare moments in which something new has contributed essentially to the future on an established enterprize. The successful validation of the RADARSAT mode for exploration using the same resolution as larger scale operations comes as a bonus, since the new users, the 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.

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RADARSAT imagery © 1995 Canadian Space Agency. Expedition photographs © 1996 Éxpédition 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 Éxpédition Mobilité Satellite au Pôle Nord Magnétique. Monty Lasserre and Mike Manore are at the Canada Centre for Remote Sensing, NRCan, Ottawa, Canada, and Bruce Ramsey is at Ice Services Centre, Environment Canada, Ottawa, Canada.

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