The University of Kansas

Information and Telecommunication Technology Center

Technical Report

Mobile Sensor Web for Polar Ice Sheet Measurements (ITR/SI+AP) PRISM 2004 Field Activities Report

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ABSTRACT

We conducted experiments to evaluate the performance of sensors and systems being developed as a part of the Polar Radar for Ice Sheet Measurements (PRISM) project during July 2004. This report provides a summary of the field activities carried out, including lessons learned and plans for next year.

1.0 INTRODUCTION

The primary goals of the Polar Radars for Ice Sheet Measurements (PRISM) project are to design and develop radar sensors for use on a variety of platforms for measuring key ice sheet parameters, and to demonstrate the scientific utility of these sensors. We have made significant progress on the development of these radar sensors and other aspects of the project. We completed the design and development of a compact dual-mode radar for measuring ice thickness and mapping near-surface internal layers with fine resolution. We also completed the development of a prototype synthetic aperture radar (SAR) that operates in either bistatic or monostatic mode. We developed a rover with telemetry capability and GPS equipment to support bistatic SAR measurements and an intelligent system for coordinating and optimizing the radar's SAR operation mode. We developed a multi-modem Iridium link for supporting the project's outreach activities and transferring data from a polar field camp to anywhere in the world.

We conducted field experiments at the Summit Camp in Greenland during July 2004 to (1) test the sensors, the rover, and the communication and intelligence systems, (2) collect in-situ data for interpreting fine-resolution radar data, and (3) perform outreach activities. We accomplished most of the planned objectives of the field experiments. Major highlights and accomplishments include:

- Successful tests of the dual-mode radar, including the sounding of 3-km thick ice and mapping of deep internal layers with about 2-m vertical resolution and near-surface layers with about 10-cm resolution.
- Collection of a set of SAR images of the ice-bed interface. This is the first and only successful demonstration of SAR imaging of the ice-bed interface through 3-km thick ice to date.
- Successful integration of the rover with the radar, communication, and intelligent systems.
- Verification of the Bayesian decision-making engine, agent-to-agent messaging and communication of the intelligent system.
- Collection of in-situ data for interpreting the results of near-surface radar mapping.
- Implementation of a NetMeeting between staff in the field and teachers attending a workshop at the University of Kansas.
- Collection of data with an array radar for developing and testing a clutter rejection algorithm for ice sounding and mapping layers.

In the following sections, we provide a short summary of our field activities related to research and education under the following categories: sensors, robotics, intelligent systems, communications, science, outreach, and development of an algorithm for radar clutter cancellation. For each category, the objectives of the field tests, results, lessons learned and plans for next year are presented.

2.0 . DUAL MODE RADAR

2.1 Primary objectives

The primary objectives of the dual-mode radar field tests were the following:

1) Conduct field tests of the integrated dual-mode radar system.
2) Evaluate the performance of the antennas.
3) Collect depth-sounder data and fine-resolution data on near-surface internal layers over a 10 x 10-km area with 1-km spacing.

2.2 Results

We successfully tested the integrated dual-mode radar and found that it operated without interference between the near-surface internal layer mapping and depth-sounder sub-systems. Both sub-systems met or exceeded our design specifications. Over a three-day period we collected extensive data sets over the 10 x 10-km area. However, we had to restrict the depth sounder operation to the 100-170 MHz frequency range because of electromagnetic interference (EMI) at the camp. Operating in this band provided a strong basal echo (10 dB SNR) on the test area. Figure 2.1 shows results obtained with the depth sounder. We observed echoes from internal layers to a depth of about 1.8 km and clear bottom echoes. Some EMI came from hand-held VHF walkie-talkies used in the Summit Camp and ignition noise from snow mobiles. Other ambient EMI sources could not be identified, particularly those below 100 MHz. The radar sensitivity was degraded by about 15 dB by noise from the high-gain — 50 dB — power amplifier, which was left connected to the transmit antenna during the reception period. This problem could not be solved in the field during this season, but it can be easily solved by turning the amplifier off during the reception period in the future. This modification has now been implemented. The additional 15 dB sensitivity will allow us to map deep internal layers to a depth of 2.5 km or more, which is typically observed in narrowband sounder data sets.

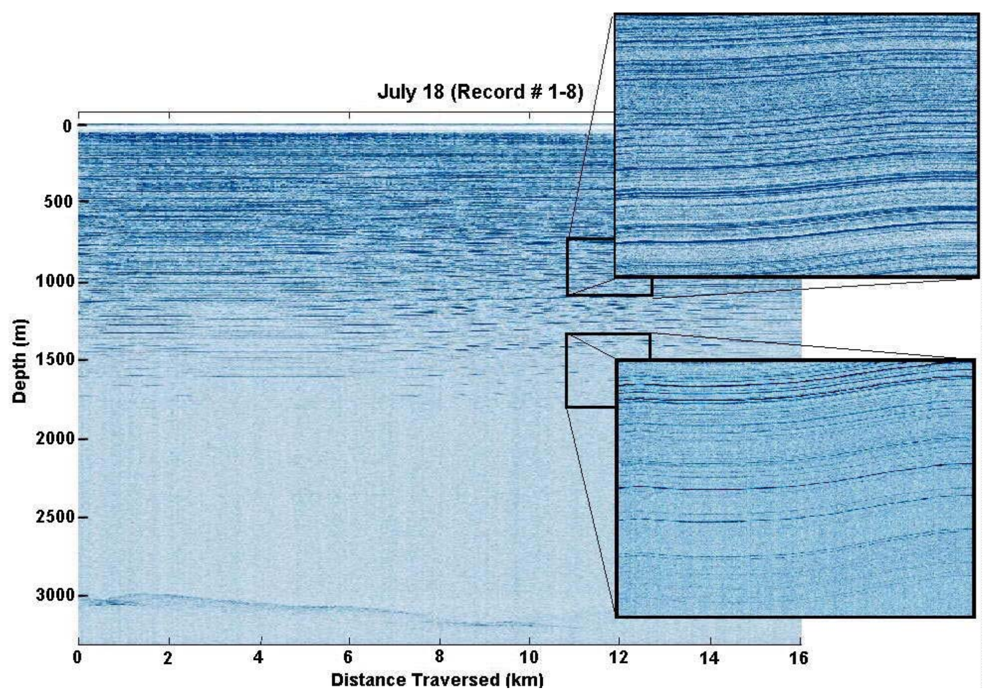
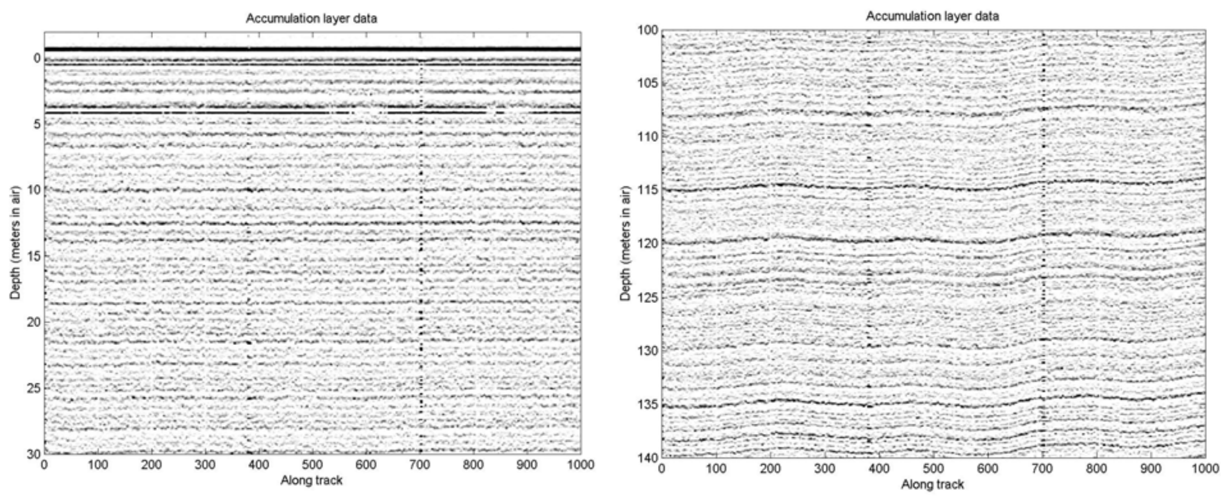


Figure 2.1: Wideband depth-sounder radar data showing the 3-km ice thickness as well as detailed internal layering.

The radar for mapping near-surface internal layers provided clear echoes to depths of about 270 m over most of the surveyed area. Figure 2.2 shows results obtained with the dual-mode radar operated in the near-surface layer mapping mode.

These tests also provided an opportunity to evaluate the performance of the antennas. Both antennas performed well. We measured each antenna's return loss with a network analyzer, and results showed it was better than 10 dB over the operating band. The radar data indicate that the antennas provided the desired radiation efficiency and spatial coverage.



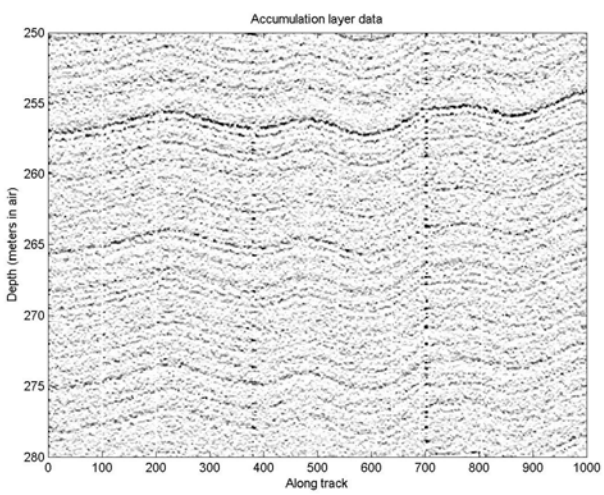


Figure 2.2: Accumulation radar data.
Top left: Map of the first 30 m of the ice sheet.
Top right: Map of the layers from 100 to 140 m in ice.
Bottom left: Map of the layers from 250 to 280 m in ice.

2.3 Lessons learned

We encountered only a few minor problems with the wideband depth sounder.

1) Because of RF interference at the camp, we could not operate the radar at frequencies below 100 MHz. In general, it is not necessary to operate the radar at frequencies below 100 MHz, which slightly degrades the vertical resolution from about 1 m to 1.25 m.
2) During these field tests the power amplifier was always on and connected to the transmit antenna. Because the amplifier gain is about 50 dB, the input noise was amplified and coupled to the transmit antenna. The amplified noise is coupled to the receiver because of the finite isolation between transmit and receive antennas. This degraded the radar sensitivity by about 15

dB. In future experiments, the power amplifier will be turned off during reception to eliminate this problem. This modification has already been implemented.

3) Harmonics of the transmit signal or noise produced in the transmitter's power amplifier interfered with the 400-MHz data link for the differential GPS measurement system. In addition, emissions from the radar system apparently activated the satellite-borne emergency locator system (ELS) used to find downed aircraft and others in distress. The source of the emissions was localized to a region a few kilometers north of the Summit Camp during the evening when the 10 x 10-km survey was being performed. When contacted by ELS staff, the camp administrator informed them of the likely source and the signal was classified as a false alarm. In the future, a bandpass filter to suppress the noise will be incorporated between the transmitter power amplifier and antenna.
4) Mechanical difficulties with the tandem sled system that transported the depth-sounder's two 4-element antenna arrays caused delays in the field and required occasional repair. Problems included the tow cable slipping out of its hook on the tow vehicle, mechanical failure of components in the tow cable linkage, and an antenna separating from the sled platform due to sled flexure and mechanical stresses caused by a significant build-up of snow on the sled and antennas. The snow build-up was due to a lack of "mud flaps" on the tracked vehicle.

2.4 Plans for next year

We will perform the following to improve radar performance and collect data during the next field season.

1) Incorporate a low-loss, bandpass filter between the transmitter and antenna.
2) Switch off the power amplifier during reception using already-implemented amplifier turn-off capability.
3) Conduct integrated measurements over a selected site to collect data to meet science requirements.

3.0 SYNTHETIC APERTURE RADAR

3.1 Primary objectives

1) Demonstrate SAR system operation in both monostatic and bistatic modes.
2) Validate bistatic-mode system synchronization.
3) Demonstrate image formation and analysis algorithms.
4) Collect radar scattering data at transmitter/receiver separation distances ranging from 0 (monostatic mode) to 4 km (bistatic mode).
5) Collect and process both direct (air path) and scattered radar signals for bistatic system synchronization. Over a 1 km x 1 km area, collect SAR radar scattering data in both modes and at all three frequencies at separation distances of 0, 2, and 4 km.

3.2 Results

3.2.1 *Monostatic SAR:* The monostatic SAR was operated at all three frequencies and with a variety of antenna configurations. The antenna configurations included transmit and receive from separate log-periodic antennas (LPAs), transmit using LPA and receive using 4-element array antenna mounted on a sled, and both transmit and receive using separate 4-element array antennas on sleds. Thus we verified system design through field operation. We observed adequate signal-to-noise ratios at 150 and 350 MHz (at 80 MHz, the SNR was below specification). Overall, the system performance met expectations and matched laboratory results. We also collected system noise data to determine the radar's sensitivity.

We collected multiple phase history datasets along 3-km lines at all three frequencies (80, 150, and 350 MHz) at HH polarization using various antenna configurations as outlined earlier. We also collected phase history datasets from parallel paths with offsets ranging from 2 to 10 m to test the feasibility of using an interferometric SAR to obtain additional information on basal conditions, specifically basal topography.

We have completed preliminary processing of the 150-MHz monostatic SAR data, and results are shown in Figure 3.1. These images show variations of reflectivity caused by ice-bed physical characteristics as a function of along-track and cross-track distance.

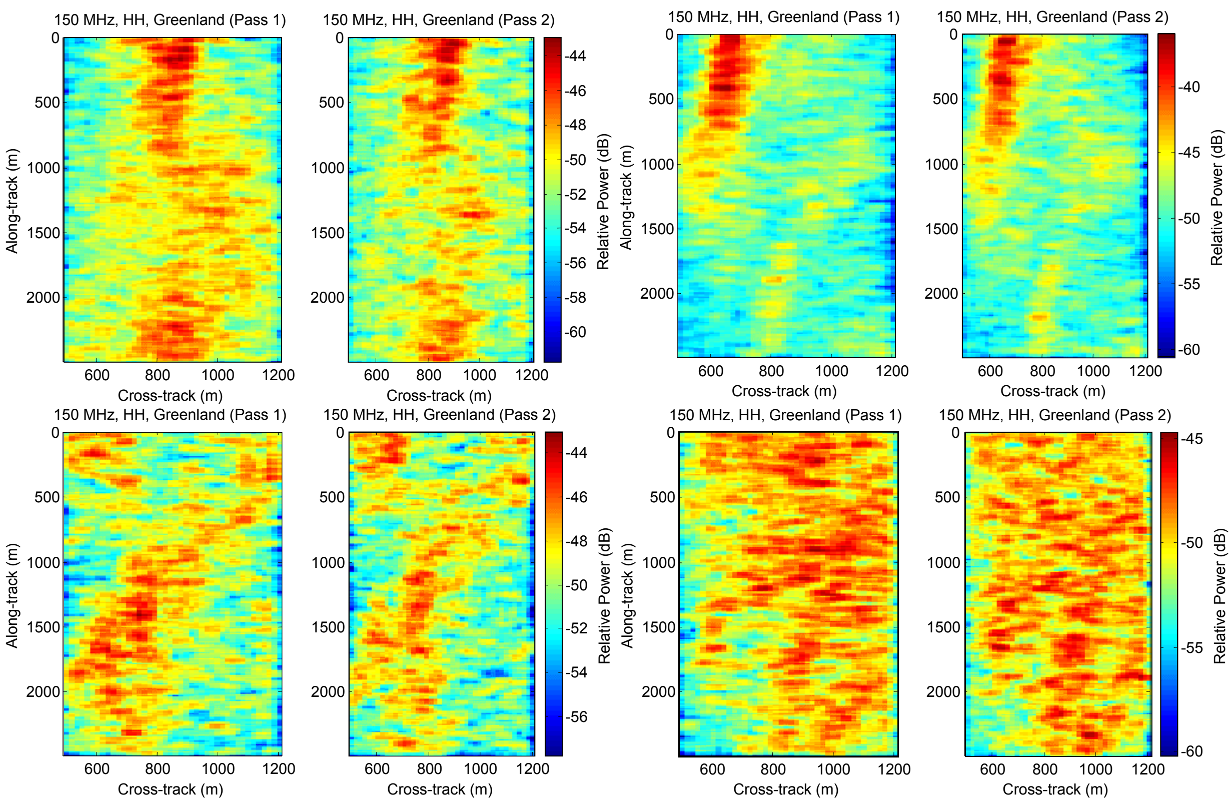


Figure 3.1: Four pairs of monostatic SAR backscatter maps from the base of the ice sheet near Summit Camp, Greenland. The SAR frequency is 150 MHz with HH polarization. Passes 1 and 2 refer to separate data collection passes over the same terrain.

3.2.2 *Bistatic SAR:* The bistatic SAR system was operated at all three frequencies and with a variety of antenna configurations. The antenna configurations included transmission from separate LPAs and a 4-element array antenna mounted on a sled, while the receive antenna was always a nadir-looking LPA.

Thus we verified system design through field operation. We were able to detect the bedrock at 150 and 350 MHz, but the noise power was significantly above expectation. No bedrock echo was detected using the 80-MHz band due to the failure of the transmit amp at 80 MHz. We also collected system noise data to determine radar sensitivity.

We collected a 150-MHz phase history dataset with HH polarization and a 4-km offset. Due to logistical problems, data could only be collected along a 115-m line using 100-m cross-track movement with 1-m separation between tracks of the bistatic receive antenna. We also collected datasets at all three frequencies (80, 150, and 350 MHz) in a common-midpoint configuration using nadir-looking LPAs with separation distances varying from 500 m to 4 km in HH polarization. The purpose of the common-midpoint tests was to obtain more reliable information on ice attenuation. By way of these efforts we verified the system design through field operation and verified the functionality of the bistatic synchronization software.

3.3 Lessons Learned

During the field work we encountered several problems or challenges:

1) A long lever arm was used to mount the log-periodic antennas on the tracked vehicle, which resulted in significant unmeasured vertical antenna movement that may cause challenges with image formation.
2) Due to the broad beamwidth of the LPAs, significant illumination at and near nadir resulted in left/right ambiguities in formed images. Also, the narrow antenna beamwidth of the horn antennas at 350 MHz caused the imaged swath to be limited when a beam-steered horn array was used.
3) Electromagnetic interference from snowmobiles and mobile radios degraded the radar sensitivity significantly. This prevented us from collecting data at 80 MHz.
4) Sideband signals at 350 MHz from the power amplifier output interfered with the 400-MHz GPS data link. However, we solved this problem by inserting a filter between the amplifier and the antenna.
5) Antenna coupling of noise from the power amplifier increased the receiver noise floor and reduced the radar sensitivity by about 15 dB.
6) Automatic phase locking of the two stable oscillators did not function properly.
7) The horn-array antennas did not provide sufficient direct-path signal to the nadir-looking log-periodic antenna on the bistatic receiver.
8) The required movement pattern for the bistatic receiver could not be achieved with the rover. Also, there was difficulty coordinating synchronous movement of both vehicles.
9) Communication between the tracked vehicle and the rover was intermittent and caused a few problems.
10) An observed significant increase in the bistatic receiver’s noise floor may have been caused by EMI from either the rover or its accompanying vehicle, from which the bistatic receiver was controlled through a wireless link. (No measure of EMI emanating from the rover, its various subsystems, or the accompanying vehicle was performed in the field.)

3.4 Plans for next year

3.4.1 Antennas

The horn-array antenna performance is satisfactory for the monostatic SAR, but it is inadequate for the bistatic SAR due to a weak direct path signal. We will refine the horn array design by making it mechanically robust. We will also provide separate source/receive direct paths for bistatic measurements.

3.4.2 Operating frequencies

We propose to operate only at frequencies above 100 MHz to avoid EMI problems and operate the radar over the frequencies from 100 to 350 MHz to obtain fine cross-track resolution and to get more target information.

3.4.3. Autonomous vehicle

We believe that the results obtained with the monostatic configuration may meet most of the glaciological requirements of an imaging radar. We need to assess the value of bistatic data relative to monostatic data to determine whether an increase in system complexity and data collection time is warranted. Regardless of whether the bistatic SAR is developed further, we will continue to develop and refine the rover, as its long-term mission is to support the overall radar operations. We also plan to use an 802.11 wireless link for all communications, including GPS data and voice telemetry. We will also develop multichannel Tx or Rx to reduce data collection time.

3.4.4 SAR software

We will develop real-time or near-real-time SAR image formation software to support on-site data evaluation, interpretation, and decision making, and fix the problem referred to in Section 3.3 with automatic phase-locking software.

3.4.5 Radars

Next year we plan to deploy an entirely new SAR system with an operating frequency band extending from 100 MHz to about 350 MHz. The design will incorporate the lessons learned from the 2004 field experience. The system implementation will address all problems encountered during the 2004 field experiments. Data from this system will provide basal-interface images with finer resolution than those obtained this year.

We plan to receive and record data from individual antenna array elements through multiple receiver channels. Through post-processing algorithms, this combination will permit the synthesis of various radiation patterns. One immediate benefit from this approach is the simultaneous collection of SAR phase-histories from both the left and the right sides of the vehicle, thus avoiding the need for repeated passes using different antenna geometries. Another benefit from this approach is that we will be able to collect depth-sounder data using the same hardware used for the SAR. Thus, with a single pass, SAR images covering a swath to the left and right are collected along with nadir-looking depth profiles.

Given the relative success of the monostatic SAR to image the bed, we will focus our resources on the monostatic mode to determine its operational limits and capabilities. For example, the 2004 data show that the collection of basal backscattering images with a swath width of 700 m is achievable. By offsetting parallel passes by about 500 m, a mosaic of images providing continuous basal coverage can be produced.

4.0 ROBOTICS

4.1 Primary objectives

The primary objectives for the summer 2004 field experiments were as follows:

1) Evaluate the structural and power modifications of the rover, including the new engine, the new throttle actuator, and changes to the frame and doors.
2) Evaluate the internal modifications of the rover, including the new sensors and the new rack mount cases for sensors.
3) Test the modifications to the GPS equipment.
4) Determine the performance of the rover on polar terrain.

5) Evaluate the integration of the rover with the radar, communication, and intelligence systems.
6) Test the autonomous waypoint navigation and bistatic SAR movements of the rover, including the S-curve pattern and the spiral pattern.

4.2 Results

1) The structural and power modifications were successful. The new rack mount cases for the sensors improved the space efficiency and modularity of the internal structure of the rover.
2) We tested the newly installed gyroscope, and merged information from the gyro with the GPS data for intelligent navigation.
3) The modified GPS equipment was successfully powered using a small generator and no longer relied on batteries, as batteries used during the previous field season sometimes failed to sustain their charge over extended periods of time.
4) Tests were performed to evaluate the integration of the rover with other onboard systems, including the radar, communication components, and the intelligent systems. The physical (structural) integrations of the systems were successful. The software integrations with the communication and intelligence systems also worked well.
5) The ability of the rover to provide autonomous waypoint navigation was tested, and moving in a perfectly straight line proved difficult for it. The rover would drift from its original path over time and required iterative adjustments. These adjustments resulted in changes to the position and orientation of the antenna, which interfered with the proper operation of the radar system. Testing the autonomous bistatic SAR movements of the rover involved movements in an S-curve pattern for the 5-m path offsets and spiral movements to provide 1-m path offsets. Due to difficulty with turning in place, traveling over prior tracks, and getting stuck in soft snow, the rover was seen to be incapable of providing the path navigations required by the bistatic radar system.

4.3 Lessons learned

1) Soft snow: The rover experienced difficulty with terrain composed of soft and sticky snow, and on occasion the rover would get stuck in the snow. This was unlike the results from North GRIP in the previous year. The matter was compounded when the rover had to turn in place or had to travel over prior tracks left by itself or other vehicles.
2) Moving in a straight line: Moving in a perfectly straight line is very difficult for most rovers, and the rover will eventually drift from its path and will have to make iterative readjustments. It is important to have previously established requirements specifying the type of readjustments (return to the original path versus redirection towards the goal) and the drifting thresholds allowed.
3) Path offsets: The amount of path offsets required for the bistatic SAR has a significant effect on the movements of the rover (e.g., 5-m offsets versus 1-m). Small path offsets beyond the turning capabilities of the rover require large spiral patterns, which further complicate movements since the rover would have to cross its own tracks in snow and would be required to turn in place, both of which were sources of difficulty during the 2004 field experiments.
4) Backup equipment: Equipment will fail, regardless of its robustness. It is important to have available backup equipment for all necessary devices since repair in the field may not be possible. This applies to GPS, UPS, power supplies, etc.

4.4 Plans for next year

We propose to carry out the following activities next year.

1) Consult with experts in polar field operations to evaluate the existing rover and explore the possibility of using other platforms to provide enhanced mobility on snow.
2) Improve the rover's mobility on snow by raising its ground clearance, increasing its footprint (track size), and decreasing its weight.
3) Enhance the control of the rover to better control and steer, e.g., moving forward a little while slowly turning in place. We will investigate the use of computer-aided machine learning techniques for the rover to autonomously adjust its driving algorithm to terrain conditions.
4) Incorporate obstacle detection and avoidance so that the rover can perform in environments with obstacles, such as sastrugi which are large enough to require path adjustments.
5) Design and develop mechanisms to actuate the antenna mounts to intelligently control the position and orientation of the antennas to compensate for the movements of the rover. This can further reduce the changes to the antennas' position and orientation as the rover moves and would therefore improve the quality of antenna movements, as required by the radar system.
6) Incorporate multiple camera images with the laser range finder and other sensors in order to produce three-dimensional models of the environment. These models will be utilized by the autonomous navigation modules and can be used for outreach purposes.
7) Incorporate additional proprioceptive sensors, including sensors to monitor the fuel levels in the rover and the generators in order to provide the intelligence modules with additional information about the status of the rover.

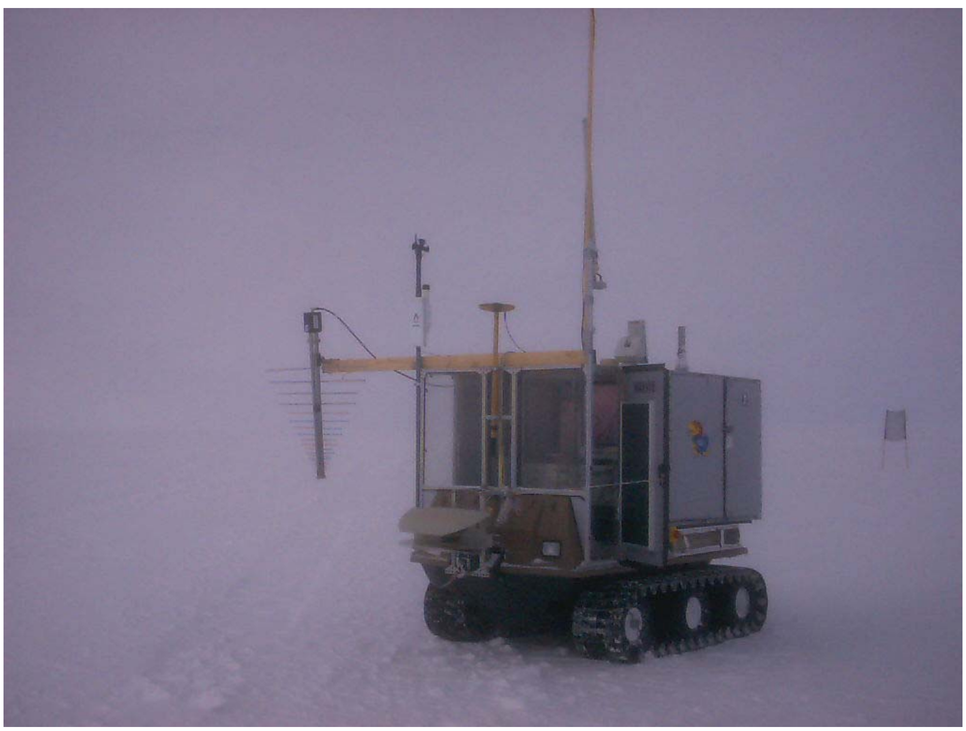


Figure 4.1: The rover deployed under autonomous control at the Summit Camp.

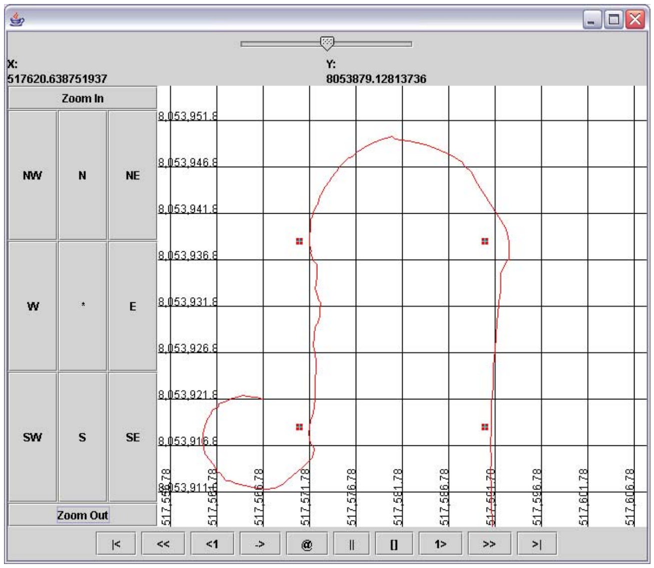


Figure 4.2: The figure shows the test of SAR movement in Greenland, covering four predetermined points on a 20 m x 20 m square. The grids are 5 m x 5 m each.
The actual path taken by the robot is shown in red.

5.0. INTELLIGENT SYSTEMS

5.1 Primary objectives

The primary objective for this summer's field experiment was to test the overall functionality of the intelligent system created so far. This includes verification of the following elements:

1) Agents
2) Matchmaker
3) Bayesian decision making engine
4) Agent messaging/communication
5) Log file rolling and maximum log file sizes
6) Thread timing and subscription startup in heavily loaded systems
7) Subscriptions

5.2 Results

1) Verification of agents: We had created a variety of agents, some interfacing with actual real-time rover sensor modalities such as the temperature sensor, heading sensor, position sensor, etc., and some interfacing with simulated data sources representing unavailable sensors or data sources such as radar sensors, satellite imagery, scientific data, etc. During the summer field experiments, we verified that all of the created agents are capable of functioning continuously and autonomously in the distributed real-time polar environment. We also verified that agents wrapping actual data sources such as rover sensor modalities were interacting with and receiving real-time values from the sensors. Some of these agents, such as the position agent, were able to retrieve only zero values from the respective sensors, as the actual robotics sensor code returned these values. This was because of the software changes the robotics team had to make in the field, which resulted in an apparent corruption of the software bridge to the sensors. This issue is being addressed in meetings between the Intelligent Systems group and the Robotics group.

2) Verification of Matchmaker: We used Kuokka's Matchmaker implementation in our multiagent collaborative architecture to handle the problem of connecting information providers (decision-making agents) with information consumers (source agents) in a multi-source, multi-sensor configuration environment. Prior to and during the summer field experiments, we verified that the Matchmaker implementation and service worked well. It ran continuously in the real-time polar environment, and paired up information consumers with information providers based on consumers' data requests and providers' data advertisements.
3) Verification of Bayesian decision making engine: We developed a decision-making engine based on Bayesian networks to dynamically accept real-time/simulated data from the real and simulated data sources, map them to predefined decision-states, populate the conditional probability tables of corresponding input nodes in the respective Bayesian network, and make Hugin API calls to propagate the newly collected evidence. The posterior probability marginals of the output nodes calculated upon evidence propagation were then queried by and written to the corresponding decision-making agent's log file. During the field experiments, we did not control the radar/rover operations with the intelligent system because we needed real data instead of simulated data for deciding the mode of operation. We observed from the summer field test logs that the decision-making engine was successful in making decisions based on the decision inputs, coded criteria/rules, and axioms of classical probability theory.
4) Verification of agent messaging/communication: Agents in our system communicate with each other by passing FIPA ACL messages. We verified successful agent-to-agent messaging and communication based on the system's experiment logs collected in the field this summer. We collected messages shared between the Matchmaker, decision-making agents, and source agents.
5) Verification of log file rolling and maximum log file sizes: We had set the maximum log file size for each agent in the collaboration to 10 MB. Prior to the experiment, we had tested the agent collaboration by starting it in verbose DEBUG log mode and letting it run for approximately 40 minutes; we saw that several agents had reached the 10-MB log file size limit. For those that went over the limit, the log file was capped at 10 MB, renamed, and rolled over. These defined features have guaranteed that no more than 2 times the max log file size worth of logs were collected for each agent.
6) Verification of thread timing and subscription startup in heavily loaded systems: We verified successful and continuous running of the system during the heavily loaded field experiments, and there were no thread timing or subscription startup issues in the system.
7) Verification of subscriptions: Two types of subscriptions were made available to agents in our multiagent architecture, namely time-driven and event-driven subscriptions. Different agents were subscribed to different data and subscription service types with the Matchmaker. We successfully verified that subscriptions had been made through interpretation of messages shared between agents. These are available with the test logs.

5.3 Lessons learned

The communication between the group in Kansas and the group in the field in Greenland made a tremendous difference in allowing quick fixes and improvement of the experimental set-up. E-mail communication and downloads of new executable files were essential to the success of the experiments. Another lesson learned, from the experience with the robotics sensors, is that software is not easy to change on the fly.

5.4. Plans for next year

We will use actual data sources to replace the now-existing simulated sources. Data source agents wrapping these actual and any additional data sources need to be written. Data/Image processing algorithms need to be derived and implemented. The Bayesian network may be expanded to accommodate any additional decision variables, parameters, and rules. The prior probability values specified now in the network nodes' conditional probability tables are to be verified, and modified in case of any future expansion or changes. The multiagent communication system that is now based on FIPA ACL is string-based. It can be modified into a more efficient system to allow more precise and brief data delivery formats. The intelligent system has to be expanded to act as a reflective agency to perform self-monitoring, resource scheduling and fault-tolerance.

6.0 COMMUNICATIONS

6.1 . Primary objectives

The primary goal was to develop, test and implement a reliable, fully autonomous and integrated 8-channel Iridium communication system. This involved developing an 8-Iridium to 8-Iridium data after voice (DAV) system, integrating all the components of the system in a single field unit, and developing a new Graphical User Interface (GUI)-based client software suite. Finally, the system was to be field tested at Summit Camp, and system performance was to be evaluated.

6.2 Results

1) We accomplished the following tasks:
    a. Modified the existing 4-channel client design to an 8-channel client system that can support all of the possible Iridium data modes.
    b. Implemented two 8-channel server systems, one server for the Iridium-Iridium configuration and the other for the Iridium-PSTN configuration.
    c. Developed an integrated and rugged field unit (Figure 6.1) that is powered through a single linear power supply and is controlled by an on-board computer.
    d. Developed a GUI-based client software suite that autonomously controls and monitors the operation of the unit and saves connection statistics.
    e. Replaced the patch antennas with inverted cone antennas, reducing the space required and increasing the ease of installation in the field.
    f. Implemented the system at Summit Camp and collected experimental data to evaluate the performance of the system.
    g. Implemented the system on a mobile platform in Greenland and demonstrated its reliable operation.

Figure 6.1: 8-Channel integrated Iridium communication system.

2) Our results were as follows:
   a. The variation of throughput with the number of modems was found to be linear, as shown in Figure 6.2. An average throughput of 18.6 Kbps was obtained with 8 modems, leading to an efficiency of 95%.

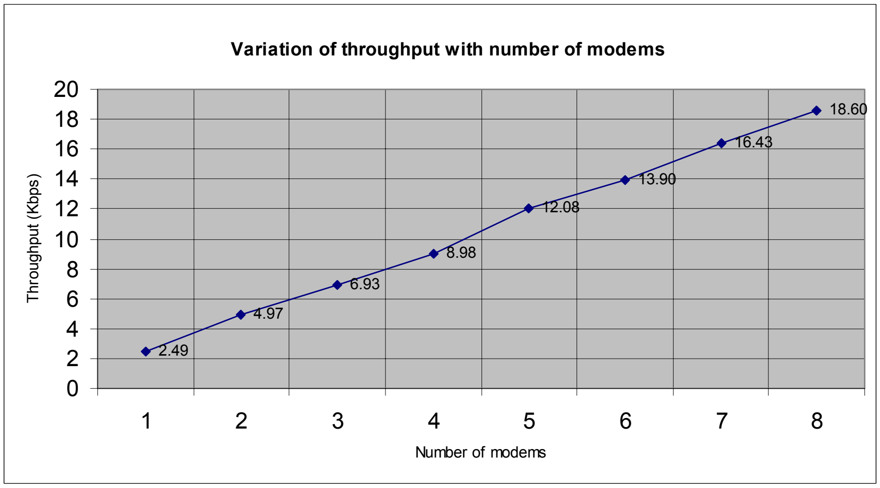


Figure 6.2: Variation of throughput.

   b. The system enabled successful transfer of large data files from the field to the University of Kansas. Figures for the effective throughput of these file transfers (using FTP) are given in Table 6.1. Due to call drops, the average 8-modem throughput over large periods of time is 15.38 Kbps.
   c. The typical round trip time (RTT) of the system in Iridium-to-Iridium mode was observed to be 1.4 seconds. The minimum RTT was 608 milliseconds.
   d. The average time interval between successive call drops was found to be 60 minutes and the full-capacity average uptime was found to be 85%.

Table 6.1: FTP throughput during data transfer from Summit Camp to KU.

Size of file in MB	Approx. Upload Time	Effective Throughput in Kbps
1.38	0:11:24	16.53
3.77	0:35:42	14.42
5.62	0:46:12	16.61
15.52	2:30:00	14.12
20.6	3:00:00	15.62
35.7	5:15:00	15.47
55.23	9:00:00	13.96

3) We encountered these problems:
   a. Due to a bug in the modem firmware, the 9505 modems lock up when operating in the DAV mode. This causes continuous call failure on the locked modem. Normal operation of the modem can be restored by cycling the power.

b. The internal RF circuitry of one of the modems failed during the field experiments and the modem had to be replaced.
c. Due to a bug in the MLPPP implementation in Linux, a call drop on the primary modem results in a connection reset.

6.3 Lessons learned

1) The system has higher efficiency and lower RTT with DAV mode as compared to the non-DAV modes.
2) GUI-based control software increases the ease of operation significantly and can be used by non-technical users as well.
3) The PC104 based multi-port serial cards are much more stable than the previously used USB to serial converters.
4) Cables and connectors form the weak link of the channel and need special attention in polar regions.
5) The mounting of the antennas, especially on mobile platforms, can be further improved.
6) Though the problems mentioned in Section 6.2 affect the performance of the system to a small extent, the 8-modem system in its current state is reliable enough to be operational for the 2005 field expedition.

6.4 Plans for next year

1) Research the problem associated with the primary modem drop and find methods to resolve it.
2) Upgrade the modem firmware (if available) to eliminate modem lockup. Otherwise, modify the control software to recognize such locked up modems and recycle power to them.
3) Analyze the network performance data collected during summer 2004 and characterize the behavior of Iridium over TCP/IP.
4) Conduct research on applying delay tolerant networking (DTN) technology to polar networking problems. Explore the feasibility of evaluating DTN protocols over Iridium in the polar regions.

7.0 SCIENCE

7.1 Primary objectives

The objectives were to support the interpretation and validation of PRISM near-surface layer mapping radar measurements, and to examine the relationship between passive microwave brightness temperature and snow accumulation rate.

7.2 Results

An in-situ accumulation rate was determined by excavating and making detailed measurements in two snow pits coincident with PRISM radar measurements. In one of the pits (Pit 2), visible stratigraphy, snow grain size and temperature were measured, and snow samples were collected for laboratory analyses of density and stable isotope concentrations. Measurements were made to a depth of 2 m. The density profile within this pit is shown below in Figure 7.1. In the second pit (Pit 3), the temperature profile was measured and snow samples were collected for laboratory analyses of density and stable isotope concentrations.

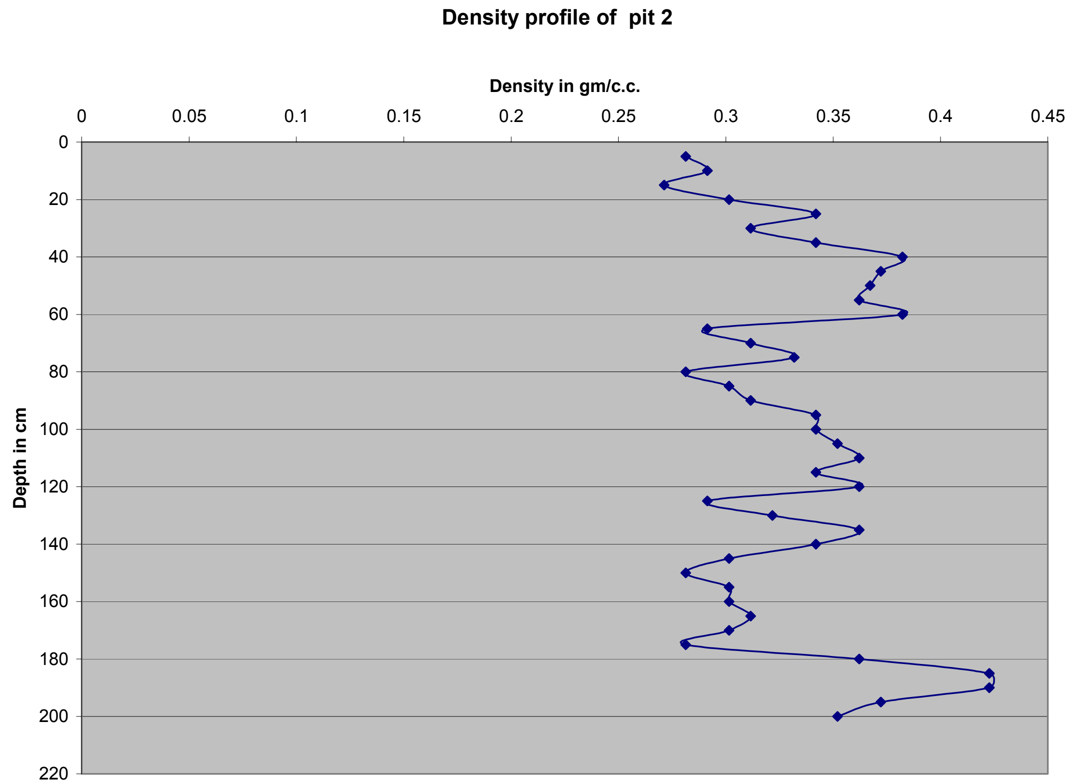


Figure 7.1: Density profile of Pit 2 (72.59598 N, 38.4760 W).

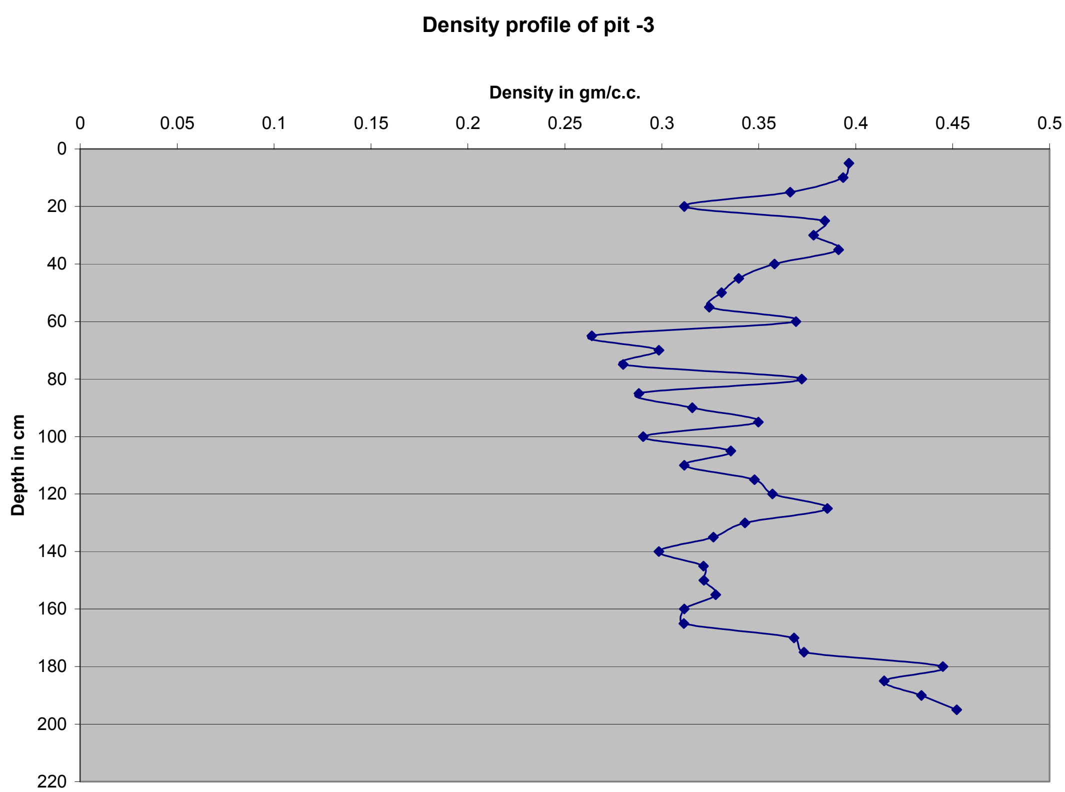


Figure 7.2: The density profile of Pit 3 (72.60268 N, 38.49622 W).

In addition, three shallow cores were extracted to determine the density of the upper firn and samples were collected for isotope analysis. One of the cores was coincident with the PRISM radar measurements and the other two cores were located 35.6 km from Summit Camp – one in the direction of the GRIP site (72.80885 N, 37.65947 W) providing a core to 6.60 m, and one in the opposite direction (72.34882 N, 39.25946 W) providing a core to a depth of 6.72 m.

Analysis of the stable isotope and density data show that the accumulation rate in Pit 3 was 21.85 cm of water equivalent from winter 2003 to winter 2002 and 22.02 cm of water equivalent from winter 2002 to winter 2001.

7.3 Lessons learned

Preliminary results of the snow pit temperature data show that temperature profiles in all the three pits were similar; however, the temperature profile of the third pit only goes to a depth of 1 m, because the weather deteriorated before we could complete the profile. We observed spatial variability in some of the visible stratigraphy horizons, and we will examine this variability in conjunction with the accumulation radar echoes. Snow and high winds prevented completion of sampling toward the end of the deployment at Summit Camp. We will look into some type of shelter to prevent this problem in the future.

7.4 Plans for next year

We will rely on the on-going efforts by science technicians at Summit Camp to collect snow pit data during the next field season. Radar measurements will be made in the vicinity of these pits, and will allow us to continue refining our inversion algorithms for the radar for mapping near-surface internal layers.

8.0 OUTREACH

8.1 Primary objectives

For the 2004 field season at Summit Camp, the primary focus was on developing content, data and modules for the PRISM web page aimed at the general public and at K-12 teachers and students. An overarching goal is to convey a sense of the excitement of carrying out field work in polar regions; hence the content needs to be timely and the interface for observing activities must be informative, easy to use and attractive. The objectives for this field season were to:

1) Redesign the virtual PRISM section of the web page to highlight the current season's activities, while also having the material from the 2003 North GRIP expedition readily available.
2) Redesign and write a daily field diary (including pictures and captions) describing the weather conditions, experiences of the field team, and accomplishments.
3) Collect weather data for use in K-12 lessons.
4) Conduct a NetMeeting from the field with teachers attending a workshop at KU.
5) Take pictures (digital) and video of experiments and support activities at Summit, compress, and send via the Iridium link to KU.
6) Take sufficient pictures of the Geobears at Summit to develop 8 to 10 stories of their adventures in Greenland geared toward a K-6 audience.
7) Collect data and panoramic video onboard the rover, transmit via the Iridium link, and use in the robot dashboard Java applet.

8.2 Results

The redesign of the virtual PRISM section of the web page allows visitors to view the virtual dashboard (Ride with us!), read the daily expedition journal entries, view and download weather data from the field, and view photos and video. Also available are all items posted the previous year during the expedition to North GRIP, and an online tool that allows users to create a calendar with pictures from polar regions. Figure 8.1 shows the redesigned Virtual PRISM web page.

The expedition journal was redesigned for the 2004 field season to include both text and pictures (including captions). An example of this new format is shown in Figure 8.2. Text, pictures and captions were e-mailed to KU daily, where they were edited, formatted, and placed on the web page. A total of 16 journal entries were made during the trip, with each journal entry averaging about 4 journal pages and including 4 pictures.

A Campbell Scientific weather station assembled just after arriving at Summit measured wind speed, wind direction, temperature, relative humidity, solar radiance, and an ultrasonic snow accumulation. These data were collected to support the K-12 lesson development efforts of PRISM. Measurements were made every 30 seconds, and one-hour averages were sent to KU on a daily basis to be archived on a database accessible to teachers and students. A total of 12 days' worth of data are available. The weather data archive is accessed by teachers and students through a separate interface on the PRISM website, where they can effortlessly download selected data to a spreadsheet. Based on our experience, this is one of the best and smoothest data download interfaces we've seen on any teacher-oriented science website.

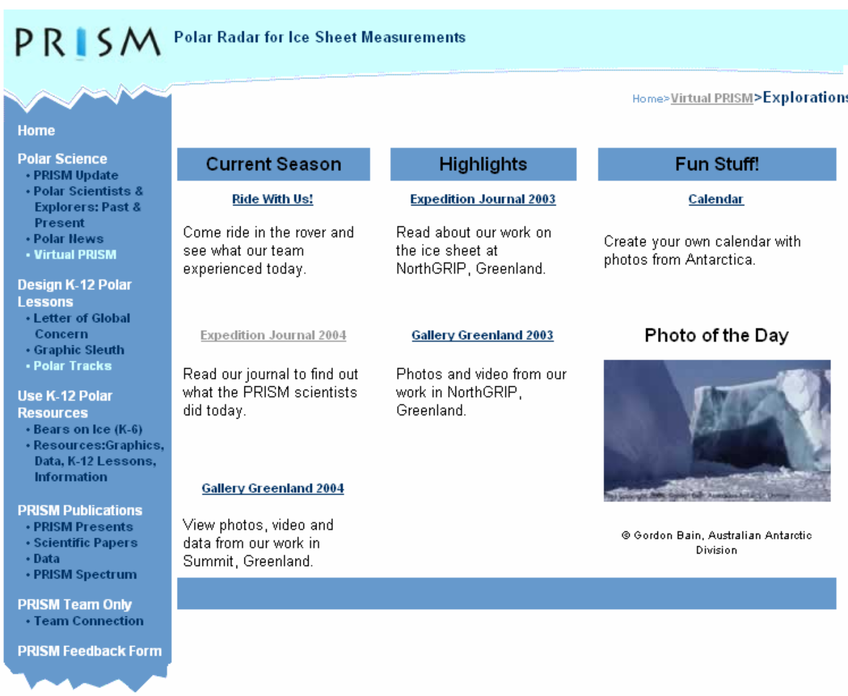


Figure 8.1: Redesigned Virtual PRISM web page that serves as a portal to the 2004 expedition and last year's trip to North GRIP.

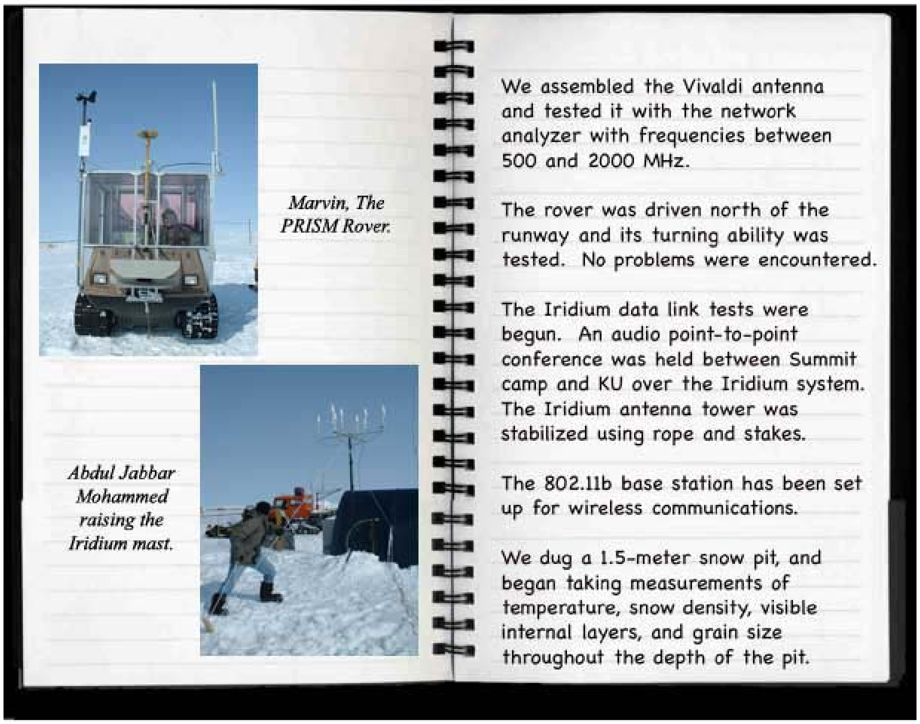


Figure 8.2: Example of an entry in the redesigned expedition journal during the 2004 field season.

A NetMeeting lasting about 90 minutes was held between members of the PRISM team at Summit Camp and teachers attending a PRISM sponsored workshop at KU. At the Greenland end, a laptop (with a wireless link, webcam and microphone) was connected to the Internet using PRISM's multichannel Iridium data link. Team members were able to describe the ongoing experiments to the teachers, and at the end of the NetMeeting, we took the wireless laptop outside and gave the teachers a brief walking tour of the camp. The teachers thought the NetMeeting was very successful, and they especially enjoyed seeing the camp. Throughout the meeting the audio was excellent with very little delay, and the picture quality was good, although because of the reduced refresh rate, it broke up somewhat during the movements.

A large number of digital pictures were taken by the PRISM field team and were transferred to KU using the PRISM Iridium link. These pictures were used in the expedition journal and are being placed in a gallery on the PRISM web page. Video clips of PRISM team members conducting their experiments, as well as clips of miscellaneous activities at Summit, were acquired, digitized, compressed, and sent via the Iridium link to KU, for inclusion in a gallery of video clips on the web page.

For the "Bears on Ice" K-6 outreach activity that is part of the PRISM webpage, story scenarios were developed before the PRISM team left for Greenland. The Geobears accompanied the PRISM team to Summit Camp, and team members took time to pose the bears in different settings and take pictures. More than 100 digital pictures were taken of the bears, and these will now be used to generate up to 10 stories of their adventures in Greenland and getting to Greenland.

For the robot dashboard Java applet, sensors on the rover collected data that was transmitted via the PRISM Iridium link to KU, where it was made available for viewing through the applet. An issue that was solved was the coordination between position, environmental and rover data displayed as dials on the dashboard, and the panoramic video on the dashboard that provides a view of the local terrain.

8.3 Lessons learned

Several of the outreach tasks undertaken this season were new and others were introduced during the summer of 2003 at NorthGRIP. New tasks, such as the collection of weather data, the NetMeeting and the robot dashboard, all went well, and we ironed out a lot of kinks in the procedures. More work is needed to get the dashboard interface linked automatically to the data stream coming from the ice sheet via the PRISM Iridium link. There was a limited amount of data that was sent from the field this season, but what we did have worked nicely. The weather station data was transferred regularly to KU, where it was time-stamped (greatly helping the outreach team at KU), and posted regularly.

The activities that were continued from the previous year included the expedition journal, the "Bears on Ice," and the picture and video gallery. Preparing and posting the expedition journal this field season went very smoothly. Including photos with the journal text made the journal more interesting, and the process that we incorporated allowed us to get the journals on the web in a relatively short period of time. We like the current format and will continue this in the future.

The formatting and navigation between the dashboard and archived data was found to be a little problematic. We are working on this to try to make the user experience a little smoother. For the next iteration, we intend to make it clear to the user what is being shown and the other options that are available.

The current arrangement with the weather station data link on the page with the rover dashboard makes the weather data hard to find. We will be moving this link to the main page of Virtual PRISM.

8.4 Plans for next year

For the 2005 PRISM field season in Greenland, the main outreach activities are described below.

1) Individual team members will be responsible for writing daily reports and taking pictures, and sending these reports and pictures to KU. A journalism student at KU will compile and edit these reports, select appropriate pictures, and place the journal entry on the web.
2) PRISM team members in the field will hold a NetMeeting with teachers and students.
3) Individual team members will be responsible for taking pictures and video of experiments and miscellaneous activities, and sending these via the Iridium link to the outreach team at KU.
4) Develop a system to collect data, images, or video for use in the the dashboard display Java applet.

During the next 6 months, the PRISM outreach team will:

1) Improve the navigation for the dashboard applet.
2) Develop an interface where a teacher can make and store an online lesson that incorporates the weather data and/or photographs from the gallery.
3) Write and post "Bears On Ice - Greenland 2004."
4) Make and post 4 to 5 interactive educational activities related to climate change and glaciers. These will focus on reading and understanding graphs, using some airborne data to determine elevation of the ice sheet, and ice core analysis. This will also include some of the PRISM data.

5) Continue with Polar News - updating every two weeks.
6) Continue to make the summer lecture series available as a web-accessible video lecture series. This work is being conducted by undergraduate students. The activity is very time intensive as the videos have to be broken into segments, a text script written, the videos captioned and put into a compatible format, and a web link made for each section. We estimate it takes between 16 and 25 hours to convert a one-hour lecture into a web-based lecture.
7) Continue to organize, caption and upload video and photos from the 2004 Greenland expedition.
8) Keep track of the traffic to the outreach components of the PRISM webpage.
9) Implement link checking software on the outreach components of the PRISM webpage.
10) Move the PRISM outreach web development site from the ALTEC server to an ITTC server so the hierarchy is more compatible, making the transition from developmental to operational a smoother process.

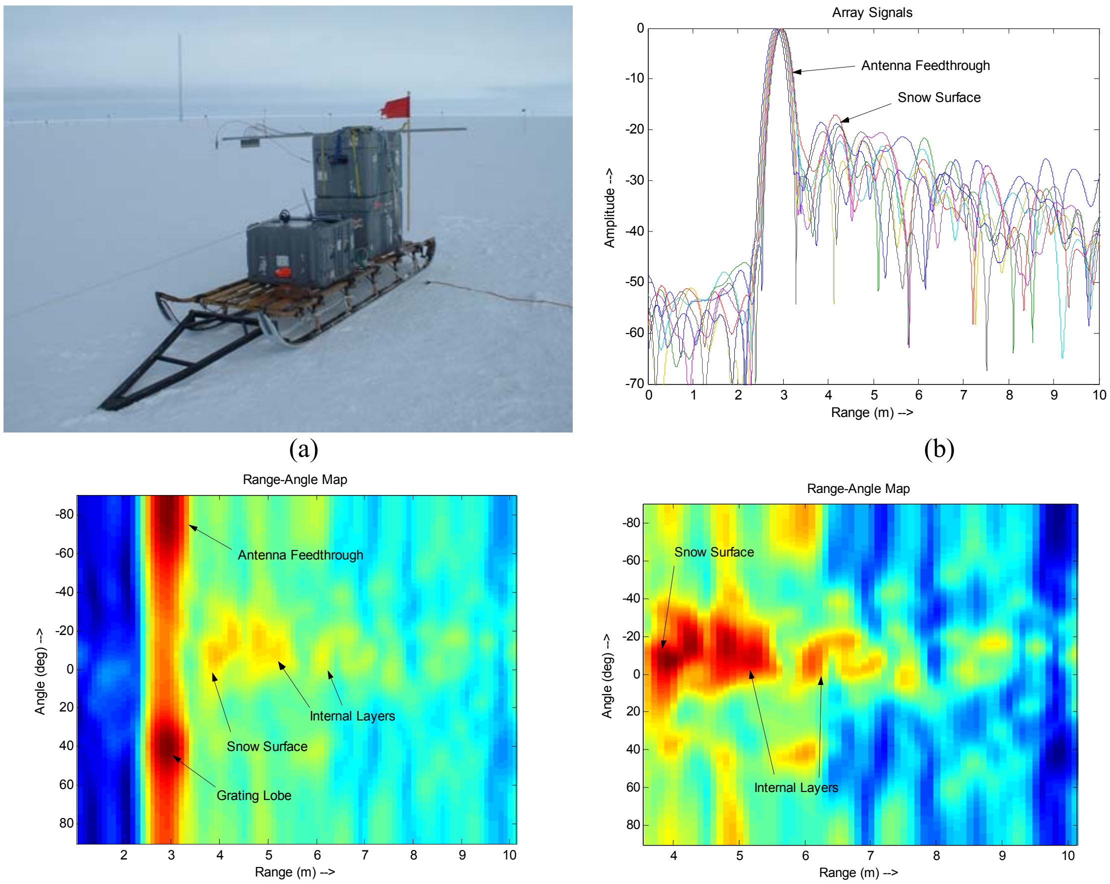
9.0 RADAR CLUTTER CANCELLATION

9.1 Primary objectives

The main objective of the clutter-cancellation experiments was to collect experimental data sets to test array processing algorithms that reduce the effect of surface clutter in ground-penetrating radars operating on ice sheets.

9.2 Results

The sled-mounted, network-analyzer-based measurement system had an antenna array mounted about 1.4 m above the snow surface so that as it was towed along, data could be collected on undisturbed snow. With an operating frequency band of 4 to 6 GHz, data were collected on a variety of surface conditions (pristine snow, rough surface, man-made artifacts buried in snow) to evaluate the system's clutter cancellation capabilities. Figure 9.1 shows the clutter-cancellation system setup as well as the measured data.



(a) (b)

(c) (d)

Figure 9.1: Measurement setup and results of the clutter-cancellation experiment system:
(a) the sled-mounted antenna and network analyzer system;
(b) a plot of the individual signals received through the various array elements;
(c) measured data in range-angle format; and
(d) measured data with antenna-feed-through signal gated out.

9.3 Lessons learned

There were no problems with this experiment, and the data needed to test the clutter rejection algorithm have been successfully collected.

9.4 Plans for next year

There are no plans to collect any additional data in support of clutter rejection algorithm development.

10.0 CONCLUSIONS

We had a very successful field program this year. We have tested all sensors, and identified problems that must be solved for collecting science data sets during the next field season. We have tested the rover, artificial intelligence and communication systems, and performed outreach activities. We are proceeding with modifications and improvements to various sub-systems and systems to be able to perform experiments in Greenland and Antarctica during the next calendar year.