The University of Kansas

Information and
Telecommunication
Technology Center

Technical Report

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

2005 Annual Progress Report

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1.0 Introduction

The primary goals of this project are to design and develop intelligent radar sensors deployed on robotic platforms to measure key polar ice sheet parameters, and to demonstrate the scientific applicability and value of these measurements. Also required are communications and GPS systems that allow the radar sensor web to coordinate measurements and their positions. Hence, our major research and education activities are reported under the following sections: sensors, robotics, intelligent systems, communications, and science. Education and outreach activities are described in the appropriate sections.

2.0 Research and Education Activities

2.1 Sensors:

The primary sensors being developed by this project are a synthetic aperture radar (SAR) that operates in bistatic or monostatic mode over the frequency range from 100 to 300 MHz, and an ultra wideband radar that operates over the frequency range from 500 to 2000 MHz. The SAR will generate two-dimensional reflectivity maps of the bed for determining basal conditions, including the presence and distribution of basal water. It can also measure ice thickness and map layers at depth with fine resolution. We have made significant progress in the development of these radar sensors. The ultra wideband radar maps near-surface internal layers with about 10 cm resolution.

2.1.1 Dual-mode radar

We completed the design and development of the dual-mode radar and a prototype SAR as originally proposed. Using these systems, we conducted extensive field tests at Summit, Greenland during August 04 [Gogineni et al, 2004]. We operated prototype monostatic SAR at three center frequencies of 80, 150 and 350 MHz and a combination of antenna configurations. The detailed description of field operations in described in earlier report [Gogineni et al, 2004].

2.1.2 SAR

These tests showed we can image the ice-bed interface through 3-km thick ice with a monostatic SAR operating at incidence angles between 5 and 20 degrees. We observed adequate signal-to-noise ratios at 150 and 350 MHz. Also we collected multiple phase history datasets along 3-km lines at 80, 150 and 350 MHz with HH polarization using various antenna configurations [Gogineni et al., 2004]. We 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. Figure 2.1-1 shows sample results obtained with the SAR at 150 and 350 MHz. These images show variations of reflectivity caused by ice-bed physical characteristics as a function of along-track and cross-track position.

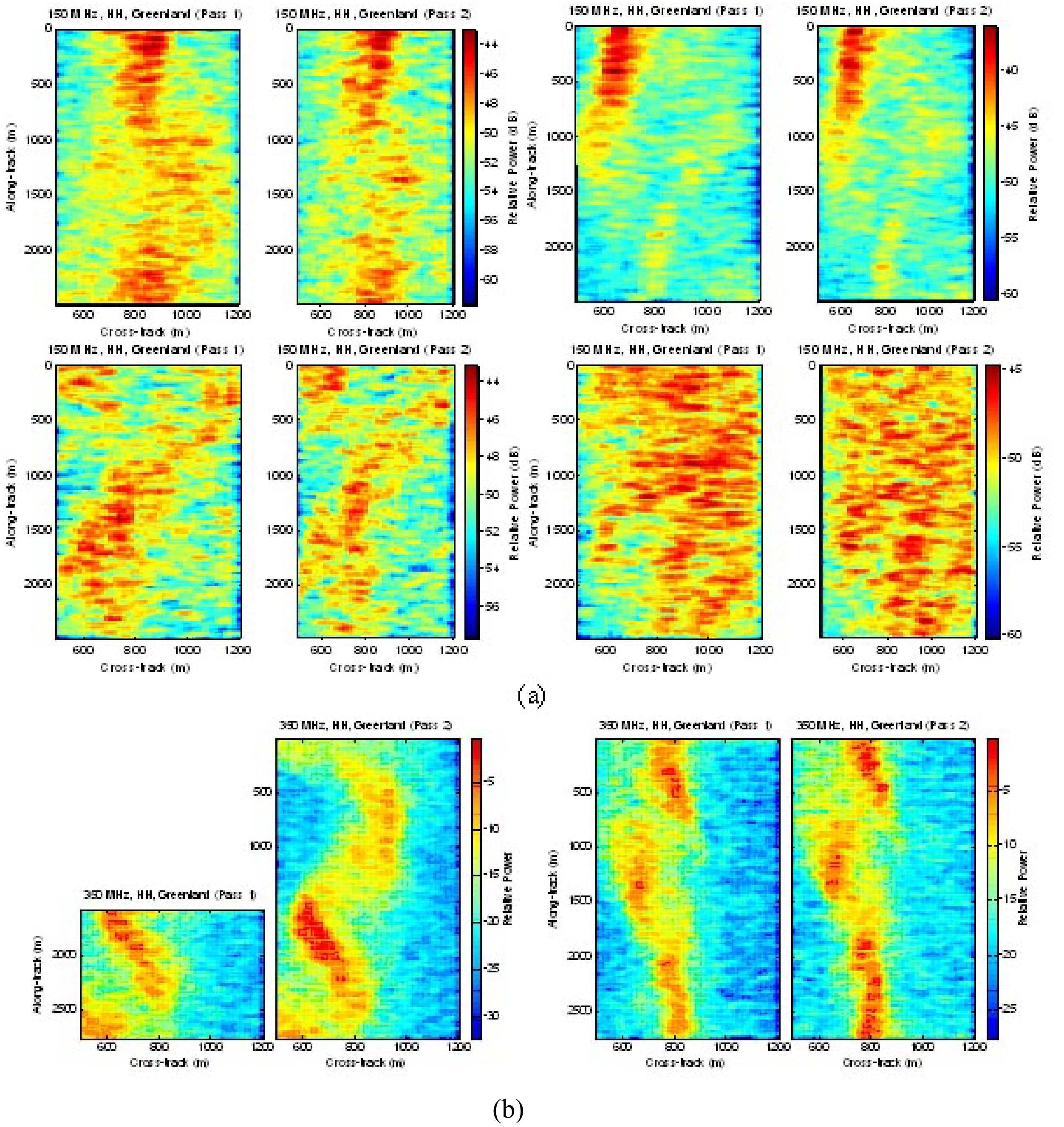
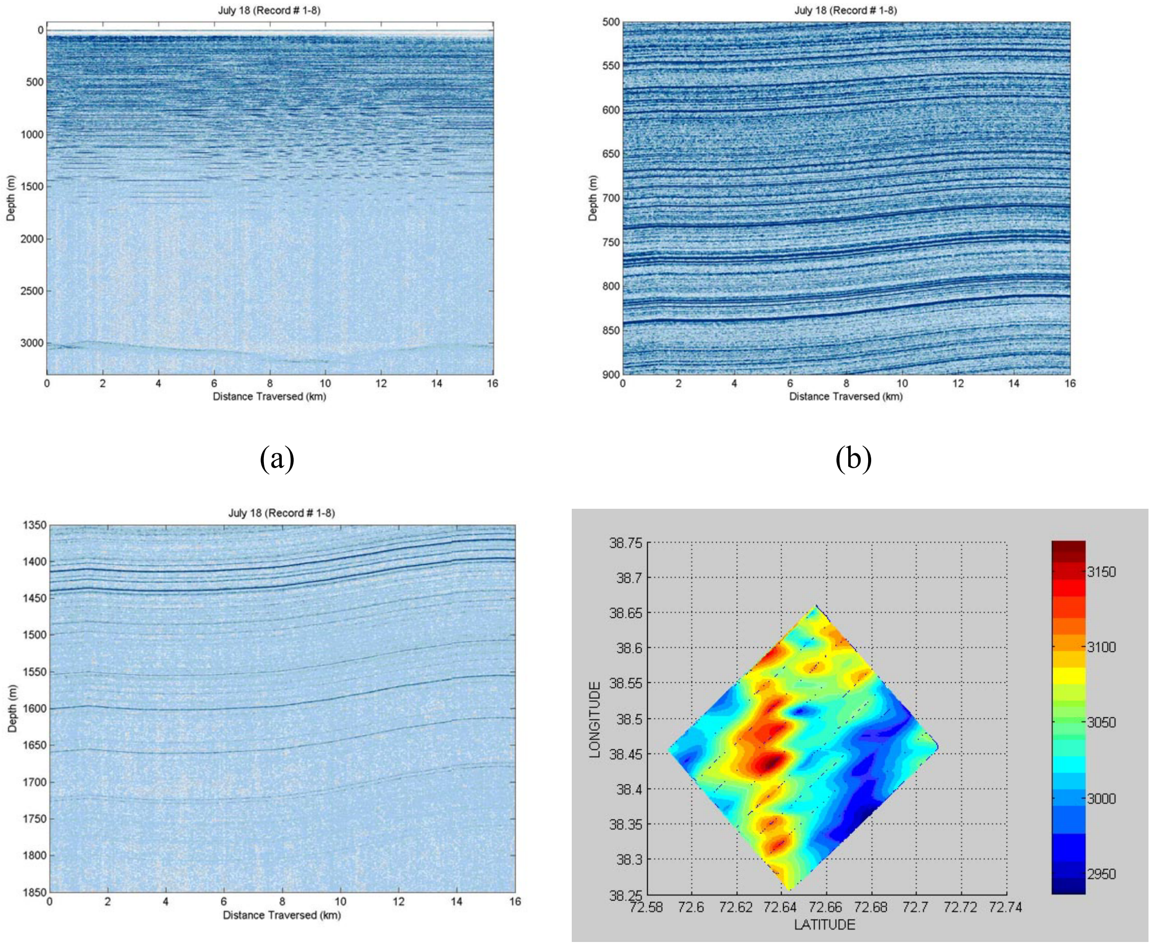


Figure 2.1-1: (a) shows four pairs of 150-MHz, HH-polarized, monostatic SAR backscatter maps from the base of the ice sheet near Summit, Greenland. (b) shows two pairs of 350-MHz, HH-polarized, monostatic SAR backscatter maps of similar basal regions near Summit. In both image sets, passes 1 and 2 refer to separate data collection passes over the same terrain.

We also successfully tested the dual-mode radar. Figure 2.1-2 shows sample results obtained with the radar operated as a sounder. Based on these successful tests, we have decided to develop a multimode radar that operates over the frequency range from 100 to 300 MHz that can simultaneously image the ice-bed interface over a swath of 700 m or more on either side of the radar-carrying vehicle, measure ice thickness and map layers at depth along the vehicle path. We combined the multimode radar with the ultra wideband radar developed earlier so we can image the ice-bed interface, measure ice thickness, and map both deep and near-surface internal layers with fine resolution.



(a) (b)

(c) (d)

Figure 2.1-2 a shows the ice thickness mapped near Summit camp with the dual mode radar. Figure 2 b shows the internal layers from 500 m to 900 m, and 2 c shows the internal layers from 1350 m to 1850 m. We were able to map the layers with a resolution of about 1 m. Figure 2 d shows the contour map of the ice thickness.

2.1.3 Wideband Synthetic Aperture Radar (SAR)

We have completed the design and development of a compact synthetic-aperture radar for collecting data at Summit, Greenland, and at the West Antarctic Ice Sheet (WAIS) divide core site in Antarctica. To support the single wide-bandwidth operation, we developed a high-speed, wide-bandwidth digital waveform generator (Figure 2.1-3) and data acquisition system for digitizing the received signals (Figure 2.1-4).

We also developed two 4:1 multiplexers (Figure 2.1-5) to collect data from each antenna element to form multiple beams digitally in post processing. We also developed a new dual-channel, wide-bandwidth receiver (Figure 2.1-6) for operating the radar over the frequency range from 100 to 300 MHz.

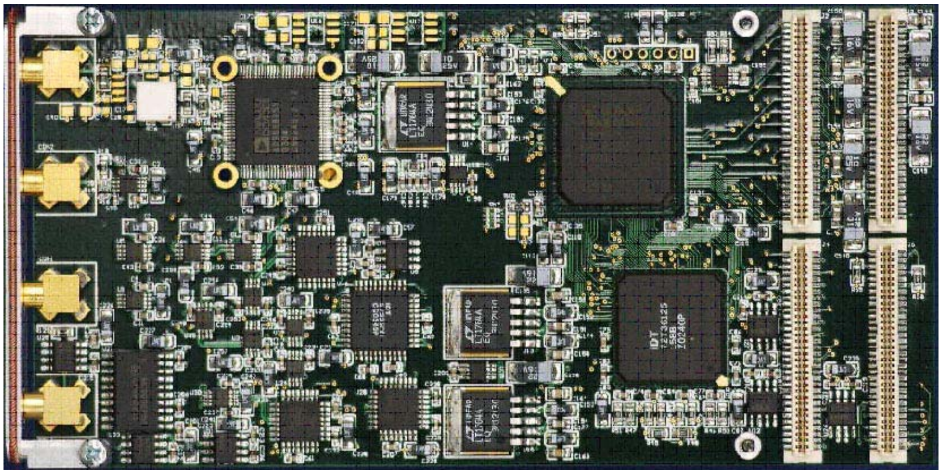


Figure 2.1-3: Printed wiring assembly of the waveform synthesizer that digitally produces the transmit waveform.

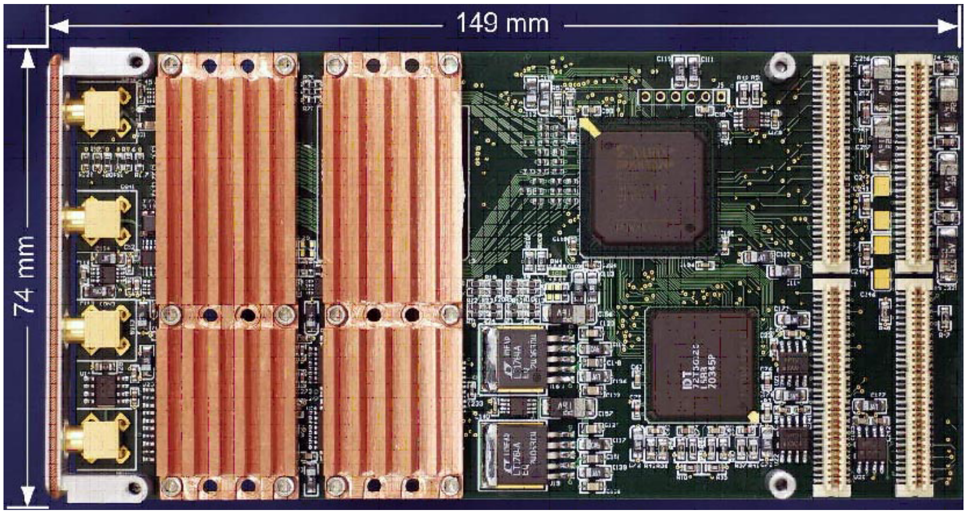


Figure 2.1-4: Dual-channel data acquisition printed wiring assembly that digitizes and processes the received signals.

The RF portion of the transmitter, without the power amplifier, is shown in Figure 2.1-7.

New antenna elements are also developed to accommodate operation in the 100-to-300-MHz band. A prototype of the new TEM horn antenna (shown in Figure 2.1-8) has been fabricated and integrated into an array. Eight such antennas will be arrayed in the cross-track direction to form a receive array, each one connected to a receive channel (via a multiplexer), thus enabling digital beam formation in post processing. The antennas will have integrated low-noise amplifiers to maintain the required receiver noise figure in this new configuration. Four more antennas will be used for transmitting the radar signals; thus, a total of twelve such antennas will be used in the radar.

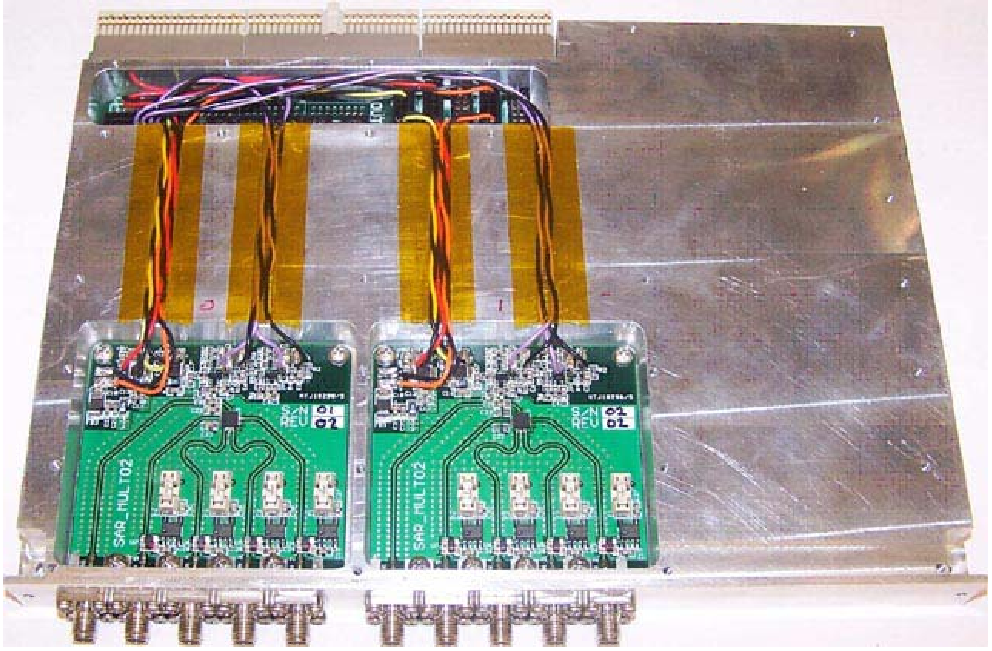


Figure 2.1-5: 4:1 Multiplexer.

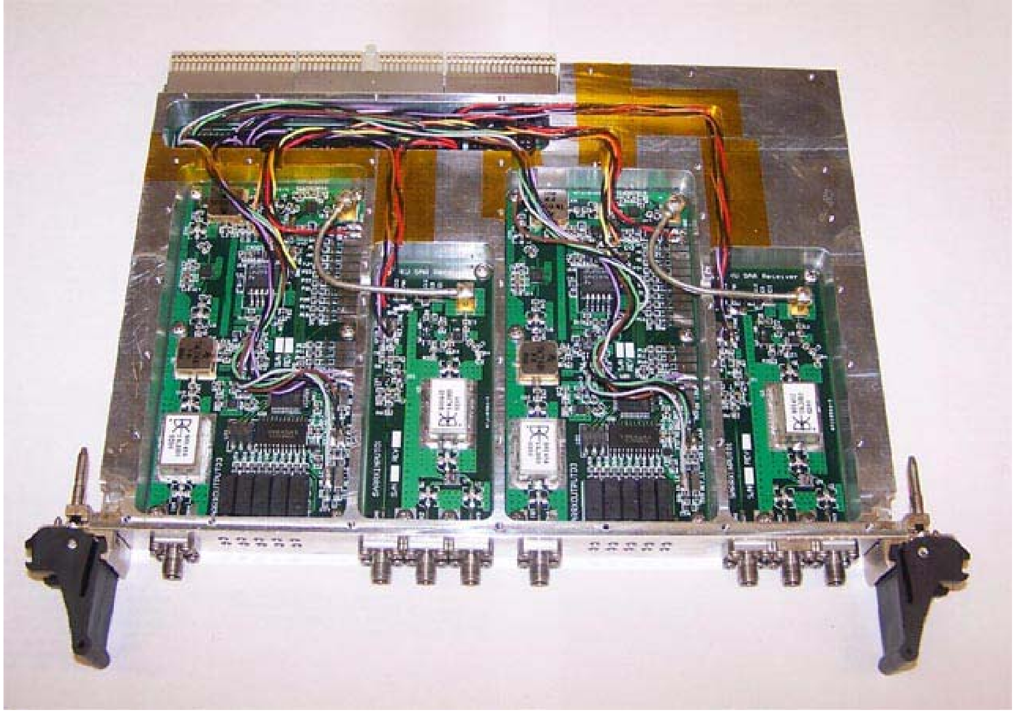


Figure 2.1-6: Wide-bandwidth receiver assembly in its compact PCI module.

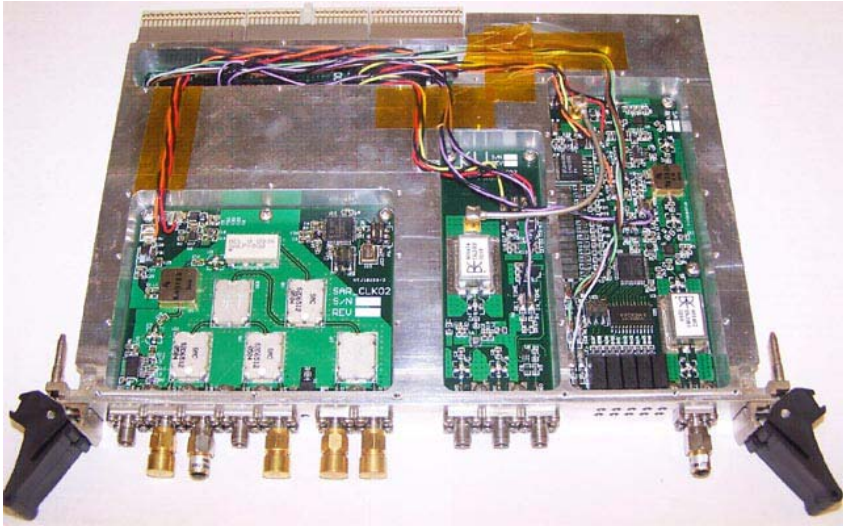


Figure2.1- 7: RF portion of the wide-bandwidth transmitter assembly in its compact PCI module.

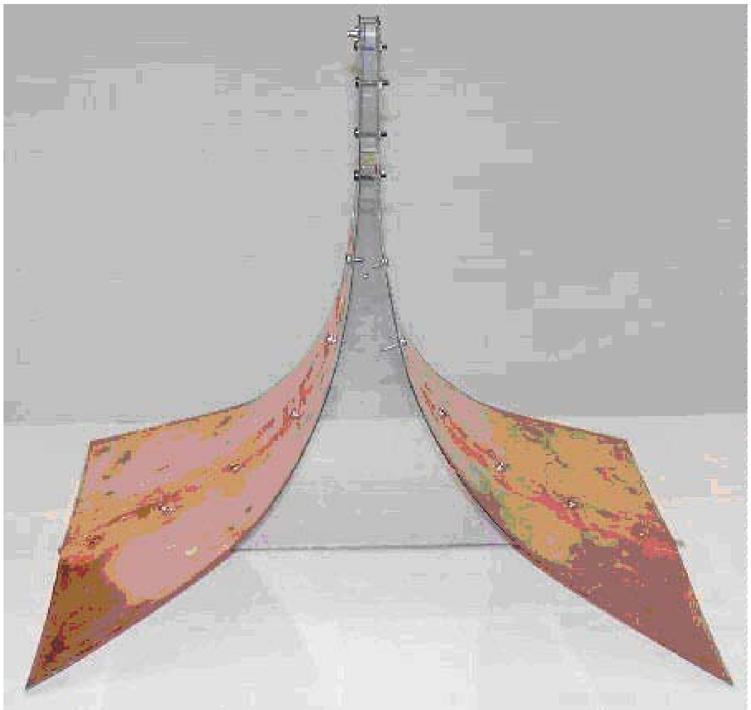


Figure 2.1-8: Prototype TEM horn antenna. Nominal dimensions are 23" x 23" x 24".

Real-time SAR processing software has yet to be developed. Modifications have been completed that enable differential GPS signals to be transmitted over the 802.11 link.

2.1.4 Ultra wideband radar

The ultra wideband operates in FM-CW mode over the frequency range from 500 to 2000 MHz to obtain fine range resolution of about 10 cm for mapping shallow internal layers. We used the system to collect data at Summit during the 2004 field season. The results shown in Figure 2.1-9 confirm that we can map internal layers to a depth of more than 100 meters with our low-power, compact system.

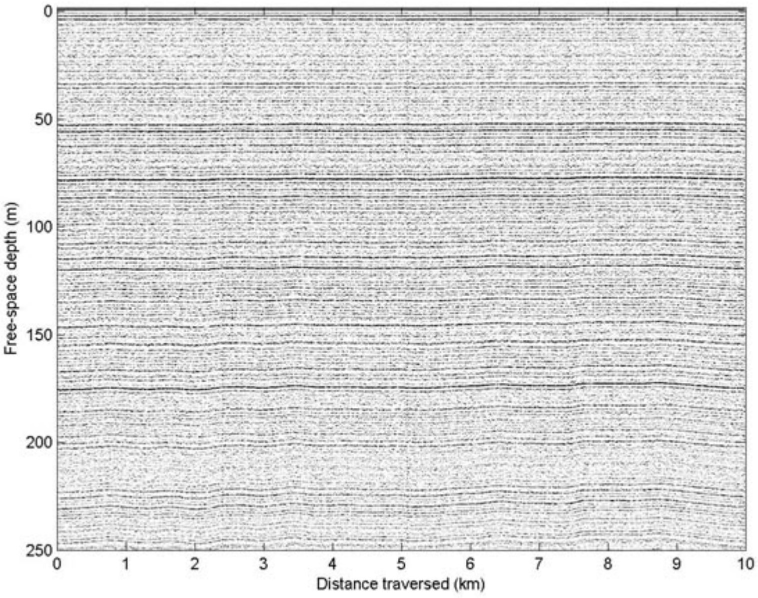
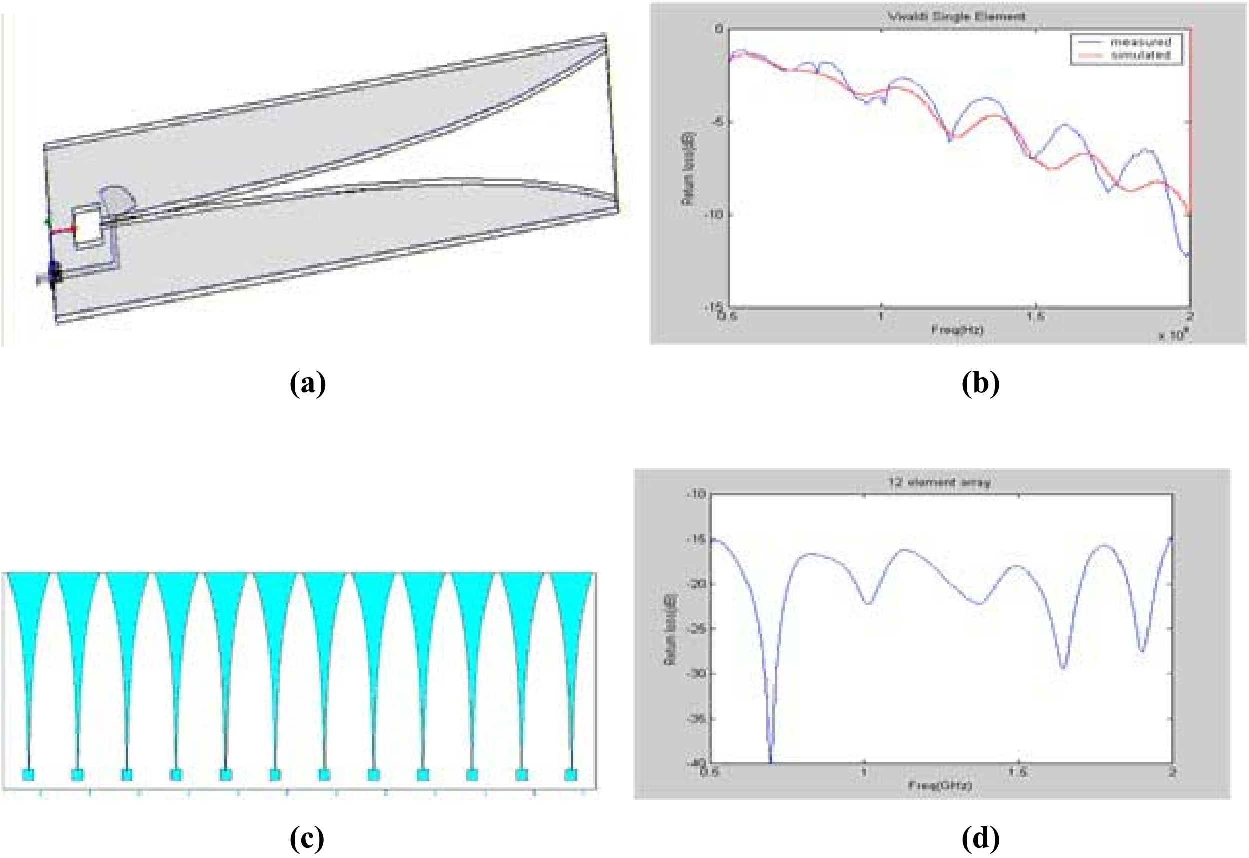


Figure 2.1-9. The echogram shows isochrones that were mapped with our ultra-wideband radar.

Our only major modification involved replacing the TEM horns antennas with Vivaldi array antennas. We chose tapered slots, often called Vivaldi antennas, as the array elements. Vivaldi antennas are characterized by large bandwidths and are relatively simple structures, since they are constructed using printed circuit board technology. In addition, Vivaldi elements tend to become more broadband when configured in arrays. Using COTS software packages, we performed a thorough design study to determine the optimal Vivaldi element dimensions to be used in the array. The objective of the design study was to test antenna parameters over a wide frequency range, so as to determine the smallest possible elements that would yield acceptable return-loss performance over the entire band when used in one dimensional broadside arrays ranging in size from 7 to 12 elements. Figures 2.1-10a and 2.1-10b show a single element of the array and its simulated and measured return loss over the design frequency range. The element feed structure consists of a coaxial-fed stripline feed that couples symmetrically to the radiating slots on both sides of the dielectric slab. The element is 35 cm long, 8 cm wide, 0.64 cm thick, and weighs 0.37 kg. We also fabricated two antenna arrays (Figure 2.1-10c) – one transmit and the other receive – and evaluated their performance. The return-loss measurements show good agreement with the numerical simulations shown in Figure 2.1-10d. The measured return loss is less then 15 dB over the entire 0.5 – 2.0 GHz frequency range. The simulated far-field radiated E-plane and H-plane patterns of the 1 x 12 array sticks are shown in Figure 2.1-11 for the case where all elements are fed with equal amplitude signals at 1 GHz. The beamwidths in the E- and

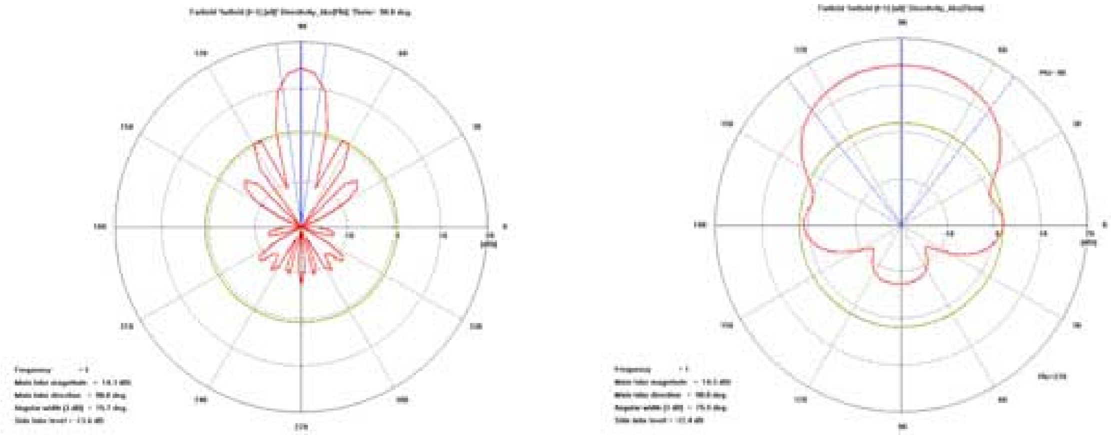
H-planes are 15.7° and 75.5°, respectively, and the sidelobe levels in the E-plane are –13.6 dB. These sidelobe levels will be lowered further to –26 dB by using a tapered feed.



(a) (b)

(c) (d)

Figures 2.1-10a and 2.1-10b show the single element of the Vivaldi antenna array and its measured and simulated return loss respectively. Figures 2.1-10 c and d show a Vivaldi antenna array and its measured return loss.



Figures 2.1-11a and 2.1-11b show the simulated E-plane and H-plane antenna patterns for the array.

We also developed digital systems to control the timing and operation of the radar, to generate the transmitter signal for the wideband depth sounder, and to digitize, process and display radar data in real time. Figure 2.1-12 shows the various sub-systems and how they are housed in milled boxes that can be plugged into a compact PCI case. These radars are designed such that they can be easily modified for operation from a twin-engine or long-range aircraft in the future.

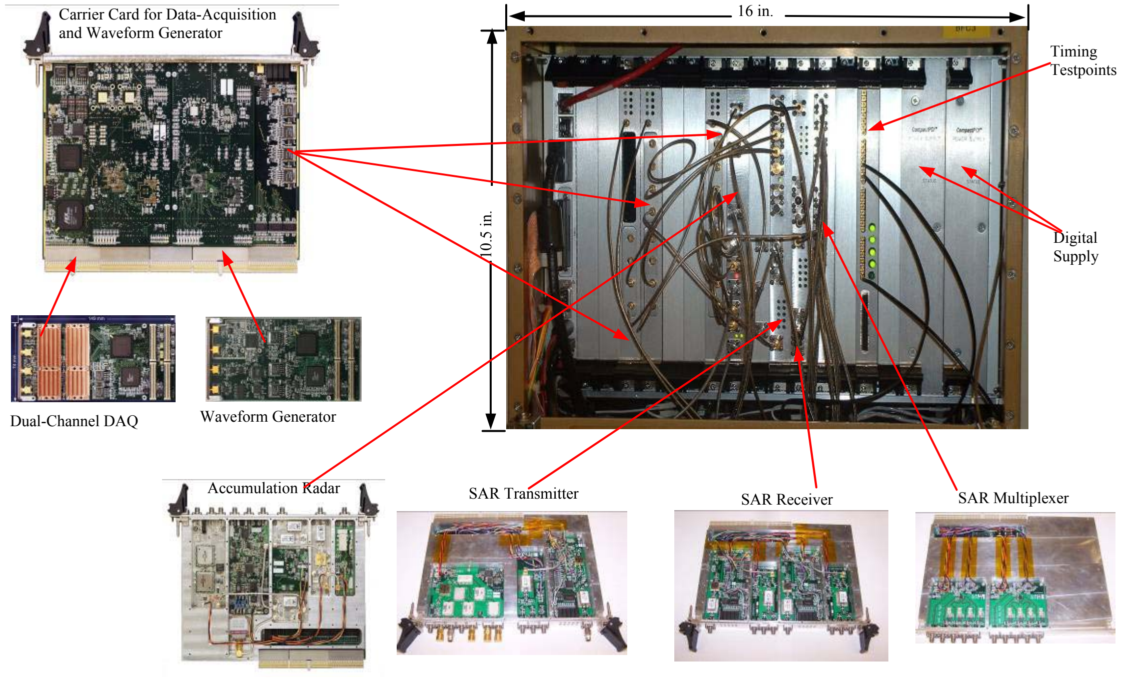


Figure 2.1-12. Radar sensors package with parts of the individual radars.

2.1.5 Plans for Next Year

We have developed a radar that operates over the frequency range from 100 to 300 MHz that can image the ice-bed interface, measure ice thickness and map layers at depth simultaneously. Using this system, we will image a 30 km x 9 km area between the GRIP and GISP-2 drill sites during July 05 and map layers at depth with a fine resolution of about 1 m. We will also use our ultra wideband radar to map near-surface internal layers with 10 cm resolution during these experiments. We will perform similar measurements at the WAIS drill site during December 05-January 06.

2.2 Robotics:

The primary objective of the PRISM robotics group is to design and develop a mobile platform for the radar data collection effort that provides autonomy, mobility, navigation, communications, precision positioning, power, and environmental protection. Under the PRISM project a rover system has been developed and evaluated in previous field experiments. Results from those tests led to system modifications which were tested during the summer 2004 field season where the rover was deployed at the Summit in Greenland and field tested. The goals of the field tests were to evaluate the autonomy and navigation of the mobile rover and test the integration of the rover with other onboard systems and components. Results from these field tests are fed back to provided further modifications to the system to improve its performance and its ability to support the radar mission.

2.2.1 Navigation

The rover's initial navigation approach relied on waypoints, i.e., the rover would autonomously navigate to a series of distant GPS coordinates by determining the rover's current position, computing the current and the desired heading, and moving to the new location. Problems with this approach surfaced during the 2004 field test. As the rover would drift from its original path and iterative adjustments were made, the resulting position and orientation of the radar's antenna would not meet the system's requirements, hindering the operation of the radar system. To overcome this problem, a new navigation approach will be developed and evaluated wherein the system will strive to follow a proscribed series of travel lines rather than using widely spaced waypoints.

To aid rover navigation, a gyroscope was added to supplement the GPS system with heading information. This combination was successfully tested and the data between the gyroscope and the GPS system were merged for intelligent navigation. In addition, the GPS equipment was modified to accept power from an onboard generator so that it no longer relied on batteries, which had proved troublesome in the past.

To avoid electromagnetic compatibility issues with a 400-MHz data link, the communications system of the differential GSP was enhanced to use the 802.11 wireless network for transmission of GPS corrections instead of packet radios. This approach addressed the communication issues and conflicts with radar systems which occurred in Greenland. The conversion eliminated the need for VHF radio in the field, as the system operates using the PRISM long-range 802.11 wireless bridge between base station and roving receivers. A Neteon DE311 Serial-to-Ethernet converter was used.

2.2.2 Rover power and control

To address the various problems with rover mobility and control observed in previous tests, various improvements have been made. To overcome problems with commanding rover movements, the throttle actuator was replaced with a more powerful unit to provide more pulling force on the throttle cable. Similarly, to provide the rover with more towing power, the original 20-horesepower engine was replaced with a 27-HP engine. During the 2004 field test, the new throttle actuator and engine performed well; however, problems with mobility and precision movement remained.

2.2.3 Equipment accessibility and environmental control

The physical structure of the rover was improved through adjustments and redesigning of the frame and the doors. The new design allows easier operations of the doors, provides better access to the onboard equipment, and creates a sealed and winterized enclosure. In addition, sensors and other onboard equipment were placed in rack-mount boxes to protect them, improve space efficiency, and increase the modularity of the rover. The new rack mount cases for the sensors improved the space efficiency and modularity of the internal structure of the rover.

Figure 2.2-1: The rover deployed under autonomous control at Summit (summer '04)

2.2.4 Rover mobility

The rover experienced difficulty with terrain composed of soft and sticky snow, and on occasion it would get stuck in the snow. This was unlike the results from the North Greenland Ice Core Project (NGRIP) camp 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. 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-meter path offsets and spiral movements to provide 1-meter path offsets. Due to difficulty with turning in place, traveling over prior tracks, and getting stuck in soft snow, the rover was not capable of providing the platform movement with the precision required for the bistatic radar system.

The mobility difficulties the rover experienced on certain types of snow were due to insufficient ground clearance. To overcome this problem, possible solutions were explored with the conclusion that an entirely new vehicle was required. After an extensive survey of commercially available vehicles, we selected and purchased a Terra-track RangeRunner. Its 9" ground clearance (vs. MARVIN's 4"), 34-HP diesel engine (vs. MARVIN's gasoline-powered 27-HP), hydrostatic transmission (vs. MARVIN's skid steering), and hydraulic actuators with integrated speed sensors overcome the previous rover's shortcomings. We have equipped with it with actuators, sensors, and controls, similar to the equipment used on the first rover, to transform it into the next generation of PRISM autonomous mobile rover (MARVIN II). This vehicle will support the Dec 05-Jan 06 Antarctic field work.

Figure 2.2-2: The new rover with the new control box.

The actuators for the new rover have been mounted on welded custom mounting plates inside the rover to steer it through the control of hydraulic flow to its left and right side. The actuators are connected to a controller which is interfaced to the control box. The control box and actuation have been successfully tested through joystick control experiments with the rover.

To build full autonomy into the new rover, we will develop a feedback control loop in which the speed sensor data are utilized to control the steering of the rover so that it can follow a straight line. Waypoint navigation, as implemented for the first rover, will be enhanced to be used for the new rover. To increase the proprioceptive capabilities of the rover, we will integrate fuel sensors into the rover to enable the intelligent system to make decisions based on its available fuel, determining its next plan of action. Additionally, software is being developed for higher-level control of the rover, so that a laptop computer can be interfaced to the control box. The laptop computer can then provide high-level control commands. A graphical display system is under development to enable the display of the rover's status on the control box's LCD screen. The new rover will be deployed in Antarctica during the 2005-06 field season.

2.3 Intelligent Systems:

The primary objective of the PRISM Intelligent Systems group is to develop a near real-time intelligent system for dynamically selecting the "optimum" configuration for the PRISM radar sensors and rover. This includes determination of the appropriate operating mode (monostatic vs. bistatic) and frequency (60, 150 and 350 MHz) for the PRISM Synthetic Aperture Radar (SAR) and the appropriate speed and scan path for the autonomous rover (MARVIN). The intelligent system that is being developed will use multiple collaborative agents for collection, analysis, and dissemination of near real-time data from multiple sources in a distributed computing environment. It will also act as a reflective agency to allow self-monitoring, resource sharing, and integrated reactive and planned activities.

Last year we completed the basic infrastructure for the intelligent system, by building a flexible collaborative agent architecture that is capable of collecting, analyzing and disseminating near real-time data from multiple sources including satellite, rover, radar and other ancillary sources, in a distributed computing environment. We also built a probabilistic inference engine that is capable of fusing data sets from multiple sources and making decisions concerning the radar and rover in near real-time. This year we focused on implementing a continuous software maintenance routine and development of the software infrastructure.

Our basic research focused on two main issues that face autonomous rovers performing ice sheet measurements:

1. Coordination and collaboration
2. Information exchange

In the area of coordination and collaboration of agents, we have been looking into observation-based coordination as a way to minimize explicit communication between autonomous rovers (and the agents representing them). This research includes state-based coordination, reactive coordination, joint intentions theory and joint responsibility theory. We are also looking at plan recognition and proactive agent behavior, especially as it relates to the recognition of team coordination failure.

In the area of information exchange, we are continuing to study information search and peer-to-peer agent architectures. One of the biggest problems in a decentralized peer-to-peer multi-agent architecture is how agents can find other agents which can provide useful information. Some of the other issues in this architecture include detecting the reliability of the information being presented and offering incentives so that other agents are motivated to provide information. The concepts in this research will be applied to PRISM's intelligent system to enable agents, who are wrapped around sensors, to proactively provide data to information-processing agents, thus reducing inter-agent communication and at the same time improving the system's team coherency and real-time capabilities.

2.3.1 Plans for Next Year

Next year we will continue researching the issues of cooperation and peer-to-peer communication for PRISM agents, and we will implement such mechanisms. First we will perform a cost-benefit analysis and see if the addition of capabilities for observation-based coordination would improve performance and reliability by any considerable amount, taking into account the current size of the agent population in PRISM, available communication resources, and also the real-time demands of the system. We will initially conduct tests using a subset of agents or a single subsystem, and if the results are promising we will go ahead with full-scale implementation.

The PRISM intelligent system uses Matchmaker to match information by connecting decision-making agents with data-providing agents. The current system is a centralized architecture. Matchmaker can be a potential bottleneck as information producers and consumers can be matched only via the Matchmaker. Our future plan is to implement a decentralized architecture and investigate the following research issues: How can decision-making agents initially locate data-providing agents without flooding the network with messages? How do we develop reliability models for resolution if multiple agents are providing conflicting information about the same data source? How do we develop an incentive mechanism for agents to provide information to their peers?

2.4 Communications:

The goals of the past year were to conduct field experiments at Summit, Greenland, analyze the results, improve the system based on the field results, and prepare the system for the 2005 field experiments.

An 8-channel Iridium-to-Iridium data after voice system with custom management software was developed for autonomous field operation. The current system can be configured in three different data modes, store various configuration profiles, and store connection statistics for performance analysis, and it provides an easy-to-use graphical user interface. The integrated field unit, shown in Figure 2.4-1, is a rugged stand-alone system that houses up to 8 Iridium modems, a central power supply and an on-board control system. This system was deployed at Summit from July 14 to July 25, 2004.

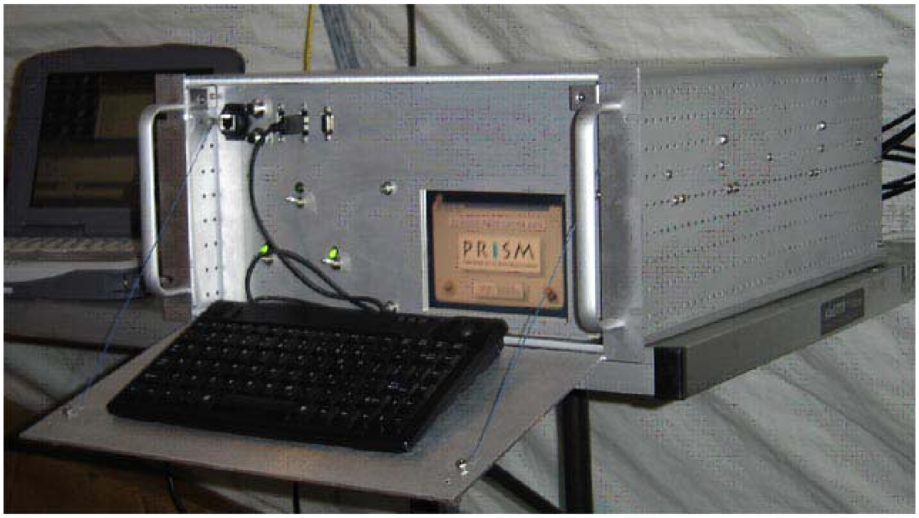


Figure 2.4-1: Integrated communications field unit.

a. The variation of throughput with number of modems was found to be linear, as shown in Figure 2.4-2. An average throughput of 18.6 Kbps was obtained with 8 modems, leading to an efficiency of 95%.

b. The 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.

c. The system enabled successful transfer of large data files from the field to the University of Kansas. The effective throughput of these file transfers (using FTP) is given in Table 3.4-1. Due to call drops, the average 8-modem throughput over large periods of time was 15.38 Kbps.

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%.

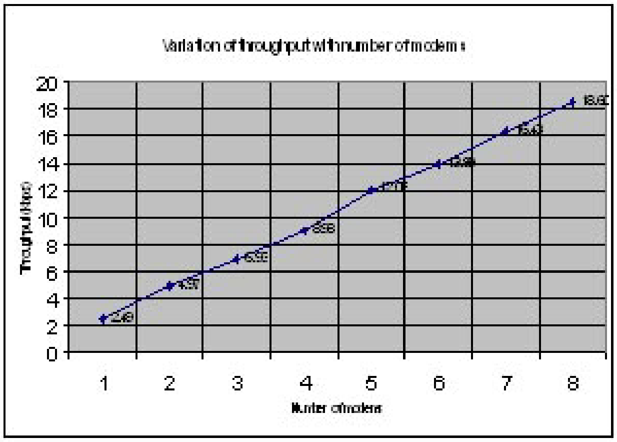


Figure 2.4-2: Variation of throughput

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

Table 2.4-1: FTP throughput

2.4.1 Plans for Next Year

a. Based on the lessons learned from the 2004 field experiments, new management software has been developed to overcome the problems of the previous system.

b. A new implementation of the point-to-point has been adapted to overcome the primary call-drop problem. With this software, a call drop on the primary modem does not cause a connection reset; instead, the connection is maintained with the remaining links. This improves the time interval between connection resets, providing uninterrupted data sessions for long periods of time.

c. Intelligent selection of the primary modem has been incorporated. This module maintains the performance statistics (such as the number of call drops, time interval between call drops, etc.) of each modem in real time. The modem with the best performance is selected as the primary modem.

d. The new system automatically detects the non-responsive modems (that may be due to failed modem or cable problems), and blocks the dialing of those modems. This avoids potential network problems at the Iridium gateway.

e. The upgraded modem firmware solves the problem of modem hang-ups that required power recycling.

The 8-channel system with the new control software has been extensively tested in the lab at the University of Kansas, and it will be deployed for project outreach in Greenland during the 2005 field experiments. A stand-alone server unit will be developed to be used with the existing client unit for point-to-point communication between two remote locations.

We have also considered how future work in this area should be focused. Communication from polar regions involves similar problems to those addressed by Delay Tolerant Networking (DTN), e.g., connectivity over low speed links and intermittent connectivity over high speed links. Methods developed for networks with intermittent connectivity would be suitable for communication over satellite links with frequent call drops as experienced with Iridium. Future work involves applying DTN technology to polar networking problems; exploring the feasibility of evaluating DTN protocols over Iridium in polar regions; and studying end-to-end transport protocols specific to low bandwidth, high-delay networks without congestion.

2.5 Science:

The primary objectives of the science component of PRISM are to support the interpretation and validation of PRISM ultra wideband radar measurements, and to examine the relationship between passive microwave brightness temperature and snow accumulation rate. Data collection in 2004 was at Summit, Greenland.

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 2 m. The density profile within this pit is shown below in Figure 2.5-1. 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. The density profile of this pit is shown in Figure 2.5-2.

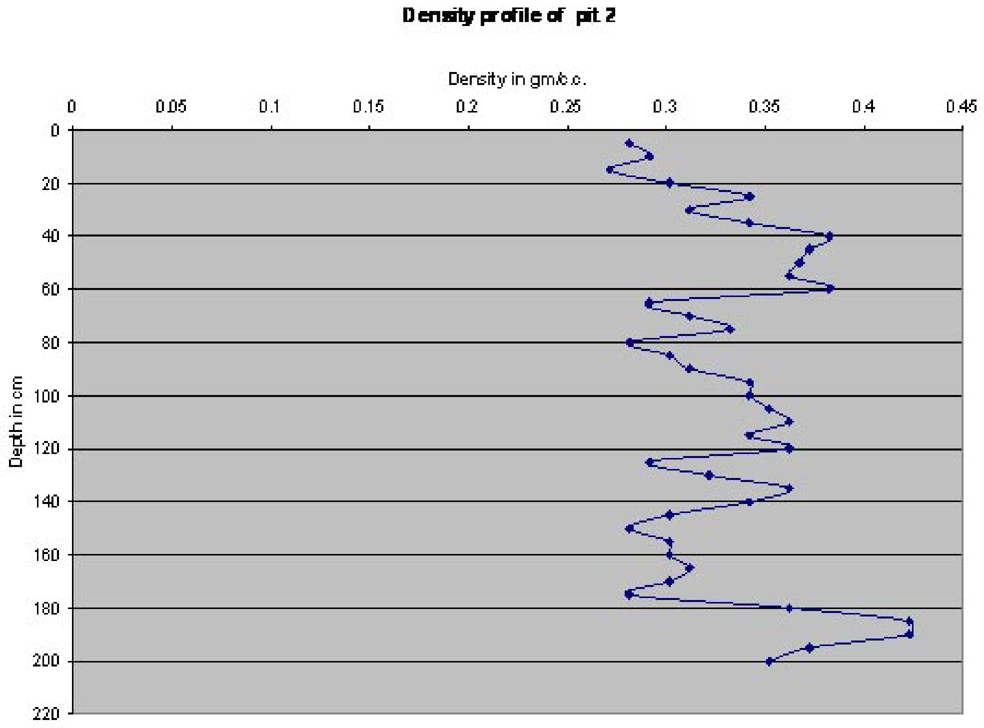


Figure 2.5-1. Density profile of pit 2 (72.59598 N; 38.4760 W).

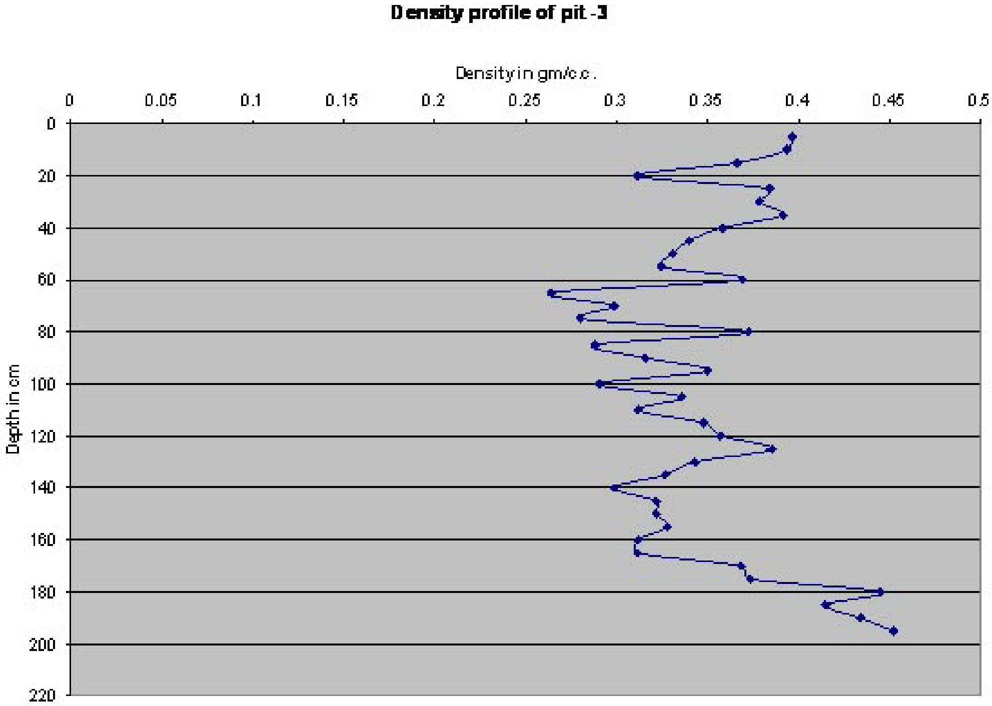


Figure2.5-2. The density profile of pit 3 (72.60268 N, 38.49622 W).

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 PRISM radar measurements and the other two cores were located 35.6 km from Summit camp – one in the direction of the GRIP site, and one in the opposite direction.

2.6 References:

Gogineni, S. P., C. Allen, D. Braaten, T. Akins, P. Kanagaratnam, A. Agah, E. Akers, I. Bhattacharya, D. Dunson, V. Frost, H. Harmon, K. Jezek, K. Mason, A. J. Mohammad, R. Parthasarathy, S. Sivashanmugam, R. Stansbury, V. Ramasami, and C. Tsatsoulis, "Mobile Sensor Web for Polar Ice Sheet Measurements (ITR/SI+AP) PRISM: 2004 Field Activities Report," Technical Report ITTC-FY2005-TR-27640-05, November 2004.

3.0 Findings

3.1 Sensors:

3.1.1 Dual-mode radar

We successfully sounded a small area at Summit with our depth sounder and mapped near-surface internal layers with fine resolution, a depth of more than 100 meters [Parthasarathy et al., 2004]. The dual-mode radar needs to be operated only in ultra wideband mode in future experiments because we integrated depth sounding and deep layer mapping capability into the

SAR system. The ultra wideband can be used for routine fine resolution mappings of near-surface layers both from surface-based and airborne platforms with suitable antennas.

3.1.2 Synthetic Aperture Radar (SAR)

The field experiments at Summit, Greenland, with our prototype SAR resulted in the first and only successful radar imaging of the ice bed 3 kilometers below. The field experiments showed that we can operate the radar in monostatic mode to image the ice-bed interface at incidence angles between 5 and 20 degrees with adequate signal-to-noise ratio. This finding resulted in a modification of our radar development activity.

Traditionally, radars for ice sheet studies are operated in altimeter mode at normal incidence, which results in poor resolution in the cross-track direction. On the other hand, a Synthetic Aperture Radar (SAR), which is operated off-vertical, can provide a two-dimensional reflectivity map with fine resolution (10-30 m) over a swath of a few hundred meters. Radar reflectivity depends on ice sheet topography and dielectric contrast at the ice-bed interface. A wideband SAR can also be operated in interferometric mode to determine topography. Thus we can use SAR data to separate topography and reflectivity effects to determine basal conditions unambiguously. The SAR can contribute to obtaining the data needed to understand rapid changes of polar ice sheets taking place now.

3.2 Robotics:

Testing of the first generation rover during the summer 2004 field season showed that mechanical and structural modifications are adequate for operating the radar to collect data. These tests also demonstrated integration of the rover with other onboard systems, including the radar, the communication, and the intelligent systems was successful. The software developed to integrate the communication and intelligence systems worked well.

We found two major problems with the rover: (1) the rover experienced difficulty operating over areas with soft and sticky snow, and on occasion it would get stuck in the snow; and (2) over time, the rover drifted from its programmed path for collecting image radar data and required iterative adjustments. Bistatic SAR measurements required that the rover move in an S-curve pattern for the 5-meter path offsets and spiral movements to provide 1-meter path offsets. Due to difficulty with turning in place, traveling over prior tracks, and getting stuck in soft snow, the rover could not navigate as required for these bistatic measurements.

3.3 Intelligent Systems:

The complete PRISM intelligent system architecture and probabilistic inference engine were tested during the Greenland field trip in summer 2004. The experiments showed the feasibility of our approach and the success of our implementation, both in general and in a near real-time setting. The system responded well to typical scenarios, including time-driven and event-driven updates. The strength of probabilistic reasoning using Bayesian networks was effectively demonstrated for the project. With source inputs being uncertain and changing unpredictably, the decision-making agents came up with the best possible decisions. Input evidence was correctly entered and propagated. The conditional probability tables were effectively updated/adapted and yielded correct and revised beliefs on propagation.

3.4 Communications:

Our results show that multi-modem Iridium link can be used to establish reliable voice and data communication links between remote field camps and continental US. The use of eight modems resulted in an average data throughput rate of 18.6 Kbps with an efficiency of 95%. We observed that the average time interval between successive call drops was 60 minutes and the full-capacity was available 85% of the time.

3.5 Science:

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

We found that there is a large amount spatial variability in the visible stratigraphy and density profile observed at Summit. We also found that high resolution density measurements (depth interval of ~5cm) are very important for EM modeling and inversion of the radar data.

3.6 References:

Parthasarathy, R., P. Kanagaratnam, T. Akins, S. Gogineni and K. Jezek, "A compact high-resolution radar for determining snow accumulation rates," International Geoscience and Remote Sensing Symposium (IGARSS'04), Anchorage, Alaska, September 21-24, 2004.

4.0 Training and Development

A total of 15 graduate and 5 undergraduate students are currently involved in various aspects of the project. Graduate students from electrical engineering, computer science, geography and geophysics are working on the design and development of sensors, rovers, communication and intelligent systems, evaluation of these systems and their use to collect data on polar ice sheets, and analysis and interpretation of data. Several students attended and presented their work at major international conferences, including the American Geophysical Union (AGU); the IEEE International Geoscience and Remote Sensing Symposium (IGARSS); and the International Symposium on Advanced Radio Technologies. We also involved three high school seniors in research. The project also contributed to the training of undergraduate students from underrepresented groups (please see section on Contribution on Human Resource Development).

5.0 Outreach Activities

PRISM outreach has continued to focus on K-12 teachers and students, and the involvement of faculty and students at Haskell Indian Nations University through their GIS laboratory. We have also had the opportunity to involve underrepresented students from KU, Elizabeth City State University (undergraduate) and local high school students in PRISM research activities.

An overarching goal of our K-12 outreach efforts is to convey a sense of excitement of polar research and carrying out field work in these regions. Our primary focus has been on developing content, data and modules for the PRISM web page (http://www.ku-prism.org) aimed at the general public, and K-12 teachers and students. The PRISM web page continues to grow in popularity, with 119,738 hits (and 512,540 hits overall) in April 2005, and we have received several prestigious commendations (listed below in Section 5.1). We strive to make the content relevant and timely, and to make the web interface informative, easy to use and attractive. We have also made numerous presentations at individual schools and regional meetings to publicize our work and to receive feedback. Our major activities during the past year include:

1) Redesigned and updated the web site.
2) Collected weather data for use in K-12 lessons and provided these data to teachers and students in a seamless, online database.
3) Conducted a NetMeeting from the field with teachers attending a workshop at KU.
4) Developed a Bears on Ice chapter of the Geobears research trip to Summit in Greenland that is geared toward a K-6 audience.
5) Continued development of a "virtual dashboard" Java applet and a field unit with a camera and sensors that transmits data and images via the Iridium link to a server at KU.
6) Continued development of "DataDocker" for use by teachers and students.
7) Continued developing and cataloging TrackStar tracks related to polar regions and robotics.
8) Gave presentations at schools and conferences.
9) Updated Polar News every two weeks.
10) Made the PRISM 2004 summer lecture series available as a web-accessible video lecture series. Lectures are video taped, and the videos are broken into segments. A text script is written, the videos captioned and put into a compatible format, and a web link made for each section.

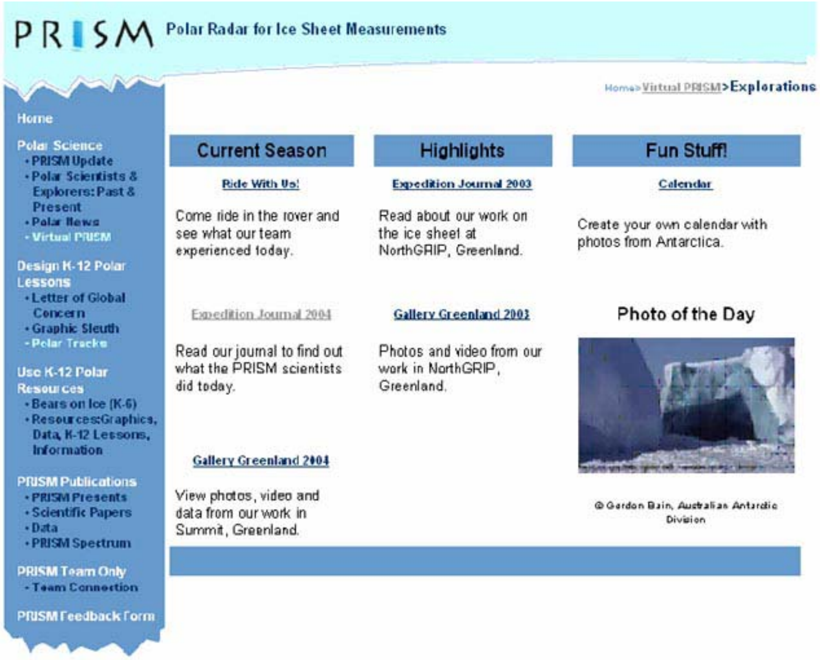
Haskell Indian Nations University has continued to mentor American Indian undergraduate students and involve some of these students in PRISM research. Haskell has also held several GIS workshops for members of Indian tribes in the surrounding region. During the past year PRISM faculty have worked with two McNair Scholar students from KU (Cora Kalukuta and Kirby Mullenberg), two students from Elizabeth City State University and two local high school students.

5.1 Field Outreach Activities:

The redesign and updating of the virtual PRISM section of the web page has resulted in a web page with three main sections plus a navigation bar on the left hand side that is largely the same as the navigation bar of our previous design. This new design allows visitors to easily view the virtual dashboard (Ride with us!), read the daily expedition journal entries from Summit, view and download weather data from the field, view photos and video, as well as many other features. The web site also makes available previously posted items from NorthGRIP, and an online tool that allows users to create a calendar with pictures from polar regions. Figure 5.1-1 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 5.1-2. Text, pictures and captions were emailed to KU daily, where they were edited, formatted, and placed on the web page. A total of 16 daily journal entries were made during field season at Summit, with each journal entry averaging about 4 journal pages and including 4 pictures. In addition, 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 send via the PRISM Iridium link to KU, for inclusion in a gallery of video clips on the PRISM webpage.

A Campbell Scientific weather station was assembled just after arriving at Summit, measuring wind speed, wind direction, temperature, relative humidity, solar radiance, and an ultrasonic snow accumulation measurement. 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. Data from a total of 12 days 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.



Come ride in the rover and see what our team experienced today.

Read about our work on the ice sheet at NorthGRIP, Greenland.

Create your own calendar with photos from Antarctica.

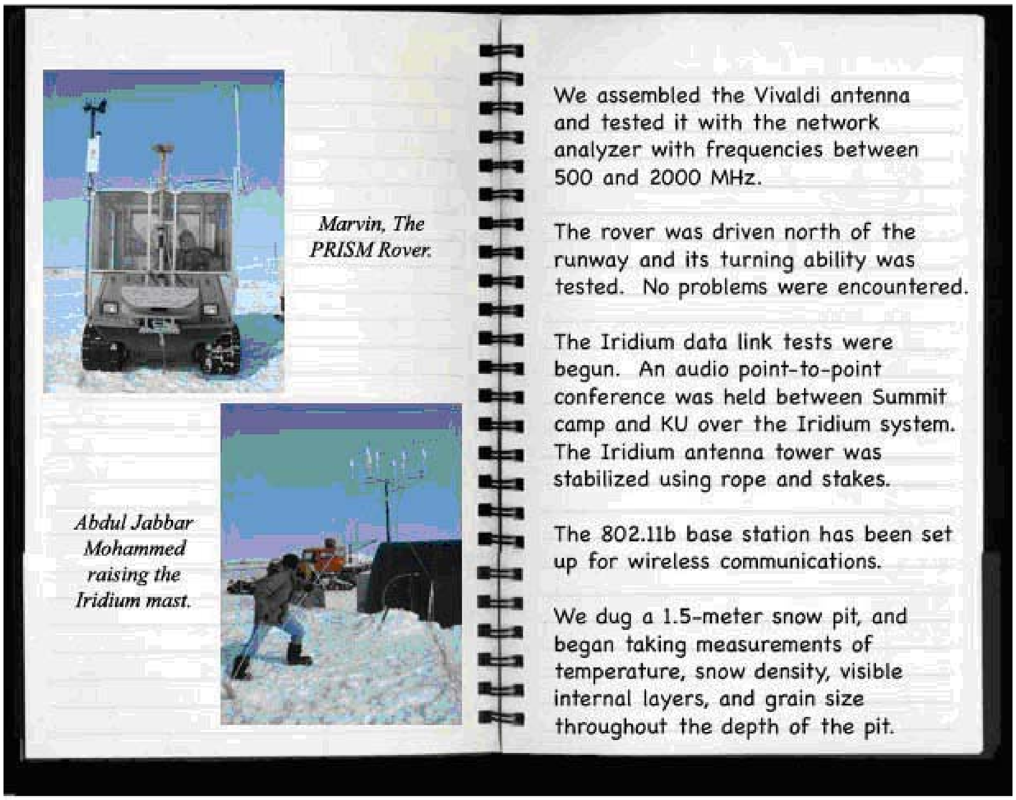
Read our journal to find out what the PRISM scientists did today.

Photos and video from our work in NorthGRIP, Greenland.

View photos, video and data from our work in Summit, Greenland.

© Gordon Bain, Australian Antarctic Division

Figure 5.1-1. Redesigned Virtual PRISM web page that serves as a portal to the 2004 expedition and last year's trip to NorthGRIP.



Marvin, The PRISM Rover.

Abdul Jabbar Mohammed raising the Iridium mast.

We assembled the Vivaldi antenna and tested it with the network analyzer with frequencies between 500 and 2000 MHz.

The rover was driven north of the runway and its turning ability was tested. No problems were encountered.

The Iridium data link tests were begun. An audio point-to-point conference was held between Summit camp and KU over the Iridium system. The Iridium antenna tower was stabilized using rope and stakes.

The 802.11b base station has been set up for wireless communications.

We dug a 1.5-meter snow pit, and began taking measurements of temperature, snow density, visible internal layers, and grain size throughout the depth of the pit.

Figure 5.1-2. 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 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, 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 was good, although because of the reduced refresh rate, it broke up somewhat during the movements.

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, and team members took time to pose the bears in different settings and take their picture. 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. We expect to have this Bears on Ice expedition fully deployed on the PRISM web site by October 2005.

The "virtual dashboard" Java applet available on the PRISM web page is intended to give someone viewing the web page the feeling of traveling along the ice sheet. Indicators provide position information and weather data, and a camera provides the images that appear as if the viewer were looking through the windshield of a vehicle. Data and images are transmitted in near real-time via the PRISM Iridium link to KU, and uploaded on the PRISM server where it is made available for viewing through the applet. We intend to fully test this system during the Greenland 2005 field season, and have it operational in Antarctica during January 2006.

5.2 K-12 Outreach Activities:

We have continued our development of the DataDocker application for teachers. This is an interface that allows a teacher to make and store an online lesson that incorporates the weather data and/or photographs from the gallery. Currently the requirement and design documentation is being written, and we expect DataDocker to be deployed for testing during summer 2005.

Our close collaboration with the Advanced Learning Technology Program (ALTec) at KU has continued during the past year. We are continuing to develop interactive, resource-based lessons (called tracks) on-line for K-12 teachers and their students using ALTec's TrackStar. During the past year, we have developed new tracks and tested existing tracks to assure that all links are working. The total number of the TrackStar tracks that were developed on specific polar topics include: Antarctic 268; Arctic 437; Global Warming/Ozone 270; Animals of the Antarctic 411; Animals of the Arctic 168; Inuit Peoples 61; Robotics 155; Auroras 82; Iditarod 130; Polar Explorers 30; Ice, Snow & Glaciers 422.

5.3 Outreach Accomplishments:

Our outreach program has been recognized both nationally and internationally. In particular:

- The website was cited in Digital Dozen, a list of exemplary web sites for educators selected by the Eisenhower National Clearinghouse (ENC)
- The website was selected for inclusion in the Digital Library for Earth System Education at http://www.dlese.org. The Digital Library for Earth System Education (DLESE) is a collaborative effort to provide support and leadership in addressing the national reform agenda for science education, scientific literacy, and scientific discovery.
- The website was selected for inclusion in the GEsource Geography and Environment Gateway: http://www.gesource.ac.uk. Led by the Gesource team at the University of Manchester, Gesource is a free online catalogue of high quality Internet resources in geography and environmental science. Resources are selected, catalogued and indexed by researchers and other specialists in their respective fields.

In November 2004, Haskell Indian Nations University (Haskell) conducted a 3-day introductory GIS workshop for Indian tribe members. Tribal members from the Chippewa Cree Nation (Rocky Boy, Montana), Omaha Nation (Nebraska), and Sac & Fox Nation (Kansas/Nebraska), participated in the workshop. Participants were introduced to fundamental GIS concepts and applications through lectures and hands-on exercises using GIS software. GIS map layers donated by the Prairie Band Potowatomi Nation (Mayetta, Kansas) were incorporated into the workshop exercises. A faculty member and a staff member from the Kansas Applied Remote Sensing (KARS) Program presented guest lectures about applications of remotely sensed satellite imagery. The workshop was the second of its kind sponsored by PRISM. Due to the success of both workshops and further interest among several tribal communities, additional workshops will be offered in the future.

Figures 5.1-3 GIS workshop for Indian tribe members in the Haskell GIS laboratory

Ten students successfully completed the Introduction to GIS course offered in the spring semester at Haskell. Dr. David Braaten from the PRISM project presented a guest lecture to the course about global climate change and applications of GIS in the PRISM Project.

5.4 Outreach Activities Summary:

Several of the outreach tasks undertaken this year were new and other tasks were updating or improving components developed during the first three years of PRISM. New tasks such as the weather data, the NetMeeting and the "virtual dashboard" all went well and we ironed out a lot of kinks in the procedures. We discovered that more work was needed to get the "virtual dashboard" interface linked automatically from the ice sheet via the PRISM Iridium link. The weather station data has been very useful in developing K-12 lessons.

Several activities that were continued from the previous year (expedition journal, and "Bears on Ice",) were much improved this year, and went very smoothly. The transfer and uploading of picture and video clips from the field to the PRISM web page gallery was slow, and will be given more attention in upcoming field seasons. Some of the links on the PRISM web page were hard to find, and we have corrected this. We are satisfied with the current web page and expedition journal format and will continue to use this with only minor modifications in the future.

5.5 Plans for Next Year

During the 2005 PRISM field season in Greenland, and the 2005/06 field season in Antarctica, the main outreach activities planned include:

- Expedition journal. 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.
- PRISM team members in the field will hold a NetMeeting with teachers and students.
- Individual team members will be responsible for taking pictures and video of experiments and miscellaneous activities, and to send these via the Iridium link to the outreach team at KU.
- Implement a system to collect data and images (or video) for use in the dashboard display Java applet.
- Implement and test the DataDocker interface where a teacher can make and store an online lesson that incorporates the weather data and/or photographs from the gallery.
- Complete the story lines and post "Bears On Ice - Greenland 2004."
- Make and post 4-5 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.
- Continue with Polar News - updating every two weeks.
- Continue to tape and convert special summer lectures to our collection of web-accessible video lecture series.
- Continue to organize, caption and upload video and photos from the 2004 Greenland expedition.
- Track of the traffic to the outreach components of the PRISM webpage.
- Implement link checking software on the outreach components of the PRISM webpage.

6.0 Publications

Note: This list shows only publications not included in previous annual reports.

Allen, C., S. Mozaffar and T. Akins, "Suppressing coherent noise in radar applications with long dwell times," *IEEE Transactions on Geoscience and Remote Sensing*, in press.

Braaten, D., J. Holvoet and S. Gogineni, "Virtual PRISM – on the ice via the web with the Polar Radar for Ice Sheet Measurements project," International Geoscience and Remote Sensing Symposium (IGARSS'04), Anchorage, Alaska, September 21-24, 2004.

Bueler, E., C. S. Lingle, J. A. Kallen-Brown, D. N. Covey and L. N. Bowman, "Exact solutions and verification of numerical models for isothermal ice sheets," *Journal of Glaciology*, in review.

Gogineni, S. P., C. Allen, D. Braaten, T. Akins, P. Kanagaratnam, A. Agah, E. Akers, I. Bhattacharya, D. Dunson, V. Frost, H. Harmon, K. Jezek, K. Mason, A. J. Mohammad, R. Parthasarathy

Harmon, H. P., "Design and construction of a robot for polar region navigation," MS Thesis, Department of Electrical Engineering and Computer Science, University of Kansas, 2004.

Kuchikulla, A., S. P. Gogineni, P. Kanagaratnam and T. L. Akins, "A wideband radar depth sounder for measuring the thickness of glacial ice," International Geoscience and Remote Sensing Symposium (IGARSS'04), Anchorage, Alaska, September 21-24, 2004.

Mohammed, A., V. Frost, G. Prescott and D. Braaten, "Multi-channel Iridium Communication System for Polar Field Experiments," International Geoscience and Remote Sensing Symposium (IGARSS'04), Anchorage, Alaska, September 21-24, 2004.

Paden, J. D., C. T. Allen, S. Gogineni, D. Dahl-Jensen, L. B. Larsen and K. C. Jezek, "Wideband measurement of ice sheet attenuation and basal scattering," *IEEE Transactions on Geoscience and Remote Sensing Letters*, vol. 2, no. 2, pp. 164-168, 2005.

Paden, J., S. Mozaffar, D. Dunson, C. Allen, S. Gogineni and T. Akins, "Multiband multistatic synthetic aperture radar for measuring ice sheet basal conditions," International Geoscience and Remote Sensing Symposium (IGARSS'04), Anchorage, Alaska, September 21-24, 2004.

Parthasarathy, R., P. Kanagaratnam, T. Akins, S. Gogineni and K. Jezek, "A compact high-resolution radar for determining snow accumulation rates," International Geoscience and Remote Sensing Symposium (IGARSS'04), Anchorage, Alaska, September 21-24, 2004.

Paul, S., "Database and Web Application to View Echograms and Ice Sheet Thickness Plots of Greenland Ice Sheet Data," Technical Report ITTC-FY2005-TR-27640-06, January 2005.

Sivashanmugam, S., and C. Tsatsoulis, "Bayesian Network for Autonomous Sensor Control during Polar Ice Sheet Measurements," International Geoscience and Remote Sensing Symposium (IGARSS'04), Anchorage, Alaska, September 21-24, 2004.

Stansbury, R. S., "Integration and evaluation of sensor modalities for polar robots," MS Thesis, Department of Electrical Engineering and Computer Science, University of Kansas, 2004.

Tsatsoulis, C., S. Sivashanmugam and S. Perry, "Intelligent Matchmaking for Polar Ice Sheet Data Collection and Delivery," International Geoscience and Remote Sensing Symposium (IGARSS'04), Anchorage, Alaska, September 21-24, 2004.

7.0 Internet dissemination

http://ku-prism.org/

This site is the home page for the project. It is aimed at the general public as well as educators and students with an interest in climate change issues, polar regions or polar exploration, and related areas. It also includes a "Team Connection" where people working on the PRISM project may upload papers or presentations and review data.

8.0 Contributions

8.1 Contributions within discipline:

The ice sheets are undergoing rapid changes unseen in human history. To understand and explain why these rapid changes are taking place, we need information about the basal conditions. The sensors developed and demonstrated as a part of this project will contribute to unambiguously determining the basal conditions. We designed these sensors in such a way that they can be operated from either surface-based or airborne platforms. They can be used to make a variety of geophysical measurements as a part of the International Polar Year.

8.2 Contributions outside discipline:

Developing a communication system for remote field operations in polar regions both for safety and transfer of data is an important goal of the Office of Polar Programs. This is an especially difficult problem because communication satellites constitute the only effective way to transfer data from the polar regions. Unfortunately, most commercial communication satellites that carry high data-rate traffic cannot be accessed from the polar regions. A few specialized polar orbiting satellites, such as Iridium, are the only candidates for use in these regions, and these satellites are mostly narrow-band systems intended for voice communications. We developed and demonstrated a parallel voice-band modem system for transferring data out of the polar regions via the Iridium satellite system. By managing voice-band modems in parallel and properly conditioning the data through a demultiplexing and remultiplexing process, much higher data rates of about 18 Kbps were achieved using the Iridium system than ever before realized in the field.

8.3 Contributions to human resources development:

Four Ph.D. students in Electrical Engineering and Computer Science, and two Ph.D. students in Geography, are being supported by this project and being trained in the interdisciplinary aspects of polar research. Five students have received their M.S. degrees within the last year. Three of these students are employed by US industries. The other two are pursuing doctoral education. The project also was successful in involving high school students in research and encouraging them to pursue careers in science and engineering. PRISM faculty mentored two local high school students with an interest in engineering (Ying Niu and Satyanarayana Telikkepalli). Ms. Niu entered MIT to study engineering in fall 2004. Mr. Telikkepalli entered the engineering program at the University of Kansas in summer 2005.

Three Haskell students served as student hourly workers in the Haskell GIS laboratory during academic year 2004-2005. Student workers provided technical and computer support for the GIS laboratory and worked on miscellaneous GIS projects for various departments on the Haskell campus. The students are mentored and advised in the fields of mathematics, science and technology and are assisted in the pursuit of their academic goals. Chris Jefferson enlisted in the U.S. Navy and is receiving training in computer technology. Gamaliel Hood is working with 2 KU faculty mentors over the summer months, Lorne Maletsky and Sara Wilson. He will be working in mechanical engineering on spinal and knee joint centered research. Pemy Fleuker will be working with an emeritus professor Dr. Tom Armstrong who will be working with Pemy on projects that are centering on solar energy path's into Earth's atmosphere and its potential global impact. Gamaliel and Pemecewan Flueker will be returning to the lab in the fall.

PRISM has been successful in attracting underrepresented students to work on research projects during the past year. Professor Gogineni worked with undergraduate electrical engineering major and McNair Scholar Cora Kalukuta, and Prof. Braaten is currently working with undergraduate atmospheric science major and McNair Scholar Kirby Mullenberg. The McNair Scholar Program, funded by the U.S. Department of Education, is designed to provide support and research opportunities to students from groups traditionally underrepresented in graduate education for doctoral study. PRISM has also hosted two students from Elizabeth City State University (ECSU) during summer 2004, and three ECSU students during summer 2005.

8.4 Contributions Beyond Science and Engineering:

Through our web page activities, our work with K-12 educators and students, and our interactions with students and faculty at Haskell Indian Nations University during the past year, this project has had an impact that goes beyond science and engineering. Specific contributions include:

- Hosting a GIS workshop for American Indian tribes through Haskell Indian Nations University.
- Developing a variety of web-based lessons for K-12 using TrackStar.
- Developing and refining “Graphic Sleuth,” an online utility that allows teachers to make web lessons for student use. The lessons guide the student through the process of using bibliographic citations to help them analyze photographs.