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Technical Report

Report on the University of Kansas PRISM Research Group Activities at the NorthGRIP Field Site: Summer 2003

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I. SUMMARY

The PRISM (Polar Radar for Ice Sheet Measurements) research team conducted a series of tests at the North Greenland Ice Sheet Project (NorthGRIP) during the summer of 2003. The objectives of these field tests were to evaluate the performance of radar systems, communication sub-systems, and the rover and its associated sensors, and to identify any problems. Significant accomplishments were made in five of the six primary research areas: radar sensors, communications, robotics, intelligent systems, outreach, and science. Using a network analyzer-based bistatic radar operating over the frequency range from 50 to 500 MHz, we measured specular scattering response with antennas separated by a distance of 1 km. We collected sample wideband radar and identified interference problems related to the digital system. Using a prototype of the accumulation radar, we collected data on near-surface internal layers in conjunction with detailed snow pit studies and ice cores. We conducted extensive tests of a communication system developed with multiple Iridium modems to transmit data, video and audio from the field to the University of Kansas. We investigated the radio propagation environment over the flat terrain of the Greenland ice sheet. We developed a long-distance wireless communication link and evaluated its performance and collected data for developing a radio propagation model for Wireless Local Area Network communication over the ice sheet. We performed tests to evaluate the functionality of the rover and its components in the polar environment and collected data on sensor and control system performance for autonomous rover operation on the ice sheet. Because of a computer failure, the field team could not troubleshoot and test the intelligent system in the field during this season. As a part of project's outreach program, we documented the preparation necessary for polar field work, logged daily experiences of the field team and reported the progress of the experiments to students and the general public in an innovative and timely manner.

This report presents objectives, results, lessons learned and future activities for next year's campaign for each of the groups named above. It also presents the results obtained by the project's science group.

II. DUAL-MODE RADAR RESEARCH GROUP

A. Primary Group Objectives

Our primary objective was to develop and test a prototype of the dual-mode radar that can measure ice thickness and map near-surface and deep internal layers, and to collect data that will allow us to optimize the radar system. The radar system was actually split into two sub-systems: an ultra wideband radar that operates over the frequency range from 500 to 2000 MHz to map layers in the top 200 meters of ice and a wideband depth sounder that operates over the frequency range from 50 to 200 MHz to measure deep internal layers and ice thickness.

B. Results

The near-surface layer mapping radar was installed in one of the NGRIP tracked vehicles and connected to two horn antennas mounted on either side of the vehicle. We collected data while at a few selected spots in stationary mode and along various traverses around the camp with the vehicle moving at speeds between 5 and 15 km/hr. Some of these traverses were selected so that they passed over snow pits and drill sites. Figure 1 shows an example of the data collected with the system both in stationary and non-stationary mode.

The flat bands at the beginning and the end are where the tracked vehicle was stopped; the band at the end shows a dip because the vehicle stopped on a small snowdrift and made measurements from there. This figure shows that the radar has a resolution of approximately 50 cm in the internal layers of the ice sheet.

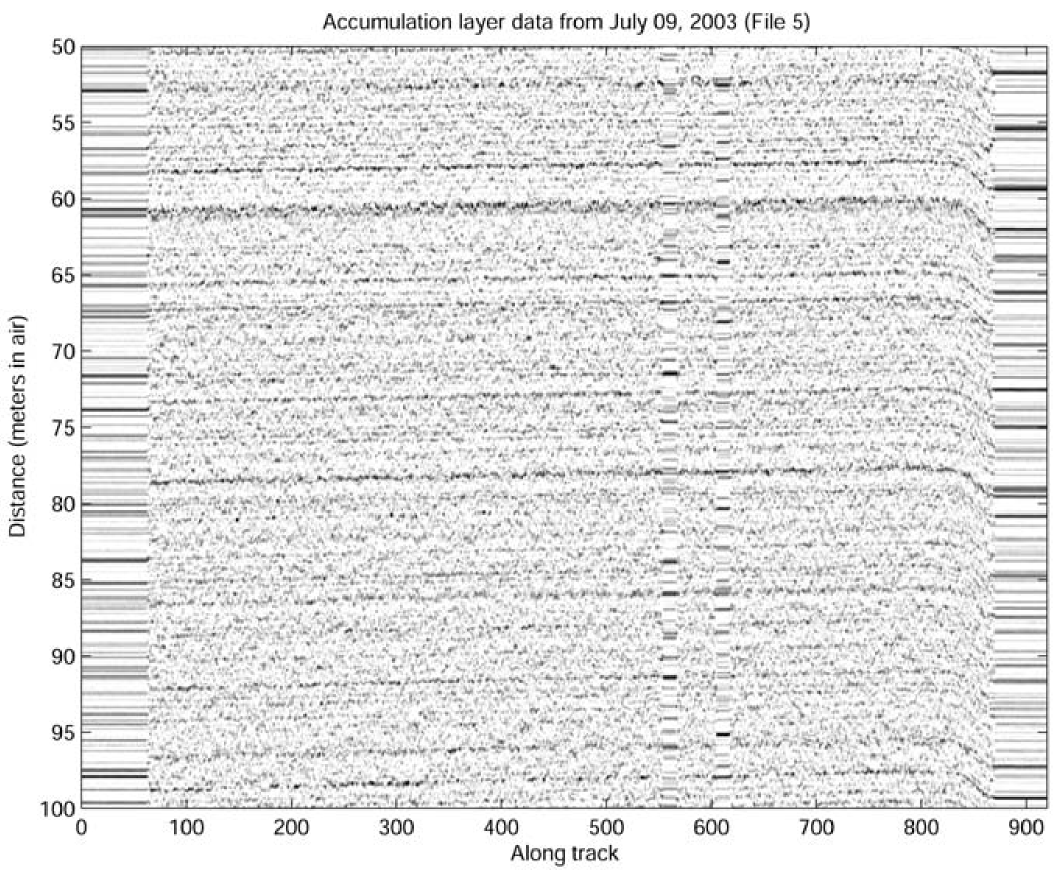


Figure 1: Accumulation Layer Data

We also tested the wideband depth sounding radar. We were only able to collect data at a few selected spots with this system. We used commercial off-the-shelf hardware for digitizing and integrating the data. This off-the-shelf data acquisition system didn't perform averages in hardware, which forced us to use a very low-pulse repetition frequency. This, combined with the fact that we required several thousand pulses to be averaged, meant that we had to remain stationary for several seconds. The data collected at these points were examined in the field. We were able see near-surface layers (<500m) with a resolution of approximately 1 m. We did not detect the deeper internal layers. This was due to the fact that when the depth sounder's receiver was connected to the antenna, the noise floor of the system rose substantially. This behavior had not been seen during laboratory tests because television and radio broadcasts restricted us from doing tests with the antennas connected to the system. When the receiver was connected to an antenna, the system sensitivity was reduced by as much as 30 dB because of interference signals. The reduced system sensitivity limited our ability to obtain good quality ice thickness data. At this point, we believe the interference signals were generated and radiated by the digital system. We are doing further tests to completely understand and correct this problem.

C. Lessons Learned

The prototype ultra wideband near-surface layer mapping radar performed reasonably well. We are redesigning a few assemblies to improve the radar's performance. We will also study the motion effects of both the tracked vehicle and the vibration of the antennas. This is to ensure that the received signal does not decorrelate over the integration period because of vehicle motion or antenna vibration.

The radiated digital noise coupled into the depth sounder's receiver through its antenna reduced the system sensitivity. While we were able to see some internal layers at an improved resolution, the system did not provide ice thickness information with high signal-to-noise ratio. After we fully understand the nature of the problem, we will redesign and/or shield the digital system to eliminate this problem before the next field season.

D. Next Year's Activities

We are optimizing the designs of both radar systems. For the layer mapping radar, we are improving the YIG driver circuit and redesigning the IF amplifier to reduce the noise level. We are redesigning parts of the wideband depth sounder's RF subsection to reduce the transients introduced by the receiver's front-end switches. Both sections of the dual-mode radar will be miniaturized and repackaged into a compact PCI RF enclosure. Also, we are developing a data acquisition system for the depth sounder to perform hardware averages at a fast rate for operating the radar with high pulse repetition frequency.

Next year this system, as well as the SAR, will be integrated onto the rover and the tracked vehicle. This will allow the system to be tested as an integrated unit next summer in Greenland.

III. BISTATIC SYNTHETIC APERTURE RADAR RESEARCH GROUP

A. Primary Group Objectives

We are developing a wideband VHF/UHF monostatic/bistatic synthetic aperture radar for measuring the basal properties of the polar ice sheets. As many parameters critical to the system design are not well known, we assembled a network-analyzer-based bistatic radar to measure these parameters directly. The parameters of interest included forward scatter power versus scattering angle, direct path signal attenuation between two distant antennas placed directly on the ice sheet, and finally external background signal strength. Data on ice sheet attenuation versus frequency (50-500 MHz) and polarization are also of interest. In addition, collection of forward-scattered signal data using a rudimentary synthetic-aperture configuration would be useful during the development of image processing algorithms.

B. Results

We successfully measured the direct and forward scattered signal with a 1-km separation between our transmitter and receiver. Figure 2 gives a sample of the forward-scattered signal from the ice-bed interface using biconical-log antennas (50-500 MHz). The signal-to-noise ratio (SNR) of the bedrock reflection for a single measurement is just over 20 dB, and after preliminary SAR processing the SNR is about 30 dB. The bedrock is at approximately 3080 m in this plot, which corresponds well with the depth given by the NGRIP ice core located about 2 km away of 3084.99 m (unadjusted for slant angle of core). The basal echo-free zone occurs just before the bedrock reflection. At this spot, the bedrock reflection decays slowly, implying that there may be a fair amount of energy scattered from regions away from the specular point. The signal strength from these other regions is significantly weaker (13 dB) than the specular portion of the reflection.

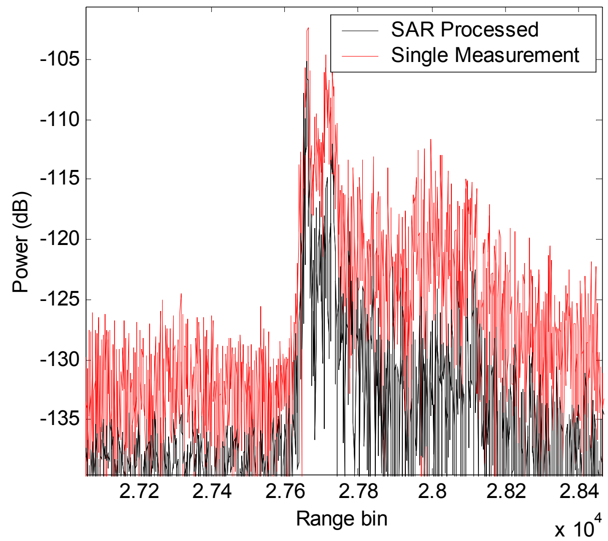


Figure 2: Forward-scattered signal from the ice-bed interface at NGRIP.

Analyzing the NGRIP bottom echo along the SAR aperture will offer us an understanding of the bedrock scattering. Using SAR processing, the specular nature of the bedrock surface can be investigated by focusing the energy from specific points on the bedrock. The pulse shape of the bedrock reflection indicates that there may be a fair amount of energy scattered from areas of the bedrock away from the specular point. In addition, these data provide information regarding attenuation as a function of frequency across our entire band of interest, which will help us optimize the radar operating frequency. We can also compare the results with data collected from the KU radar depth sounder (142.5-157.5 MHz) at the same location. Finally, we found that the direct path signal for two bowtie antennas placed directly on the ice sheet with 1000 m separation is attenuated by 60 dB more than that for two antennas in free space. This is important as we will be using the direct signal to synchronize the two systems.

Figure 3 shows the background signal strength as measured with the spectrum analyzer using a 10-kHz resolution bandwidth. We noted that most of the RF noise emanated from the camp's main dome, where nearly all of the radio equipment operates. We took measurements with the biconical-log pointed toward the main dome and away from the main dome to help identify the background noise that would be present anywhere on the ice sheet. From these data we can design our system to operate reliably in the presence of these external RF signals.

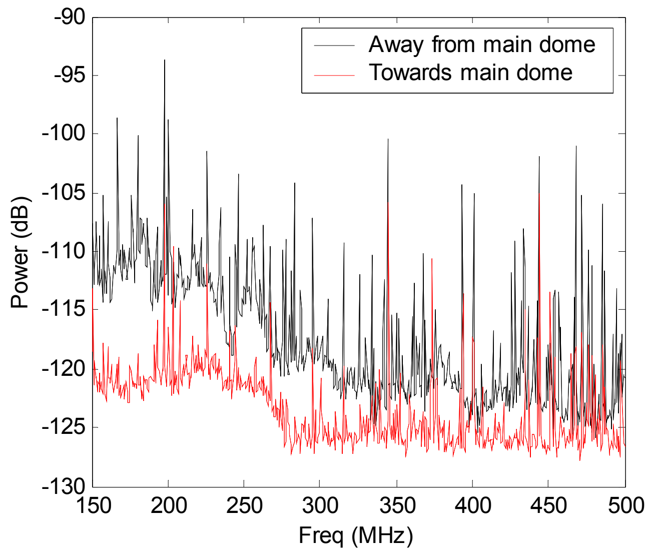


Figure 3: Measured background noise.

C. Lessons Learned

We encountered a few problems and challenges during this field experiment. By learning from these challenges, we hope to design and deploy a more robust system in the next field season.

When specifying a power generator, a minimum amperage rating at a preferred voltage should be provided. The power generator that was provided did not furnish sufficient current at 110 V, and no adapters existed in camp to convert the available 220-V generator output to 110 V.

Liquid crystal displays (LCDs) should be avoided when the screen will be exposed to freezing temperatures while in operation. While heating pads can be used to heat the screen, even with a battery heater and medical hot pad (total of 100 W), it took about thirty to sixty minutes to preheat the display on a cool day (-10° C). LCDs with internal heating may be a reasonable solution. The temperature range of the LCD down to –40° C could be verified in our temperature chamber.

Fiber-optic cables can be used in the cold, and no problems were found with fiber breakage due to flexure in cold temperatures. However, the connectors on the fiber-optic cables that we used were easily pulled off because of low tensile strength. Since replacing a connector on a fiber-optic cable is a significant challenge in the field, either fiber-optic cables specially designed to provide strain relief (high tensile strength between connector and cable) should be used or fiber-optic cables should be restricted to applications where they will not be subject to significant pulling forces (e.g., internal applications).

D. Next Year's Activities

Using information obtained from the summer 2003 field experiment, we will complete the design of the SAR system (radar and antennas), and then build and test it. The software control system for the SAR will be implemented, which includes bistatic mode synchronization issues. The SAR processor and EM model will be completed so that we can view processed data during the upcoming field season. The next field season will be used to test the SAR system as well as to collect a more complete set of data for improving the SAR processor and EM model.

IV. COMMUNICATIONS RESEARCH GROUP

A. Primary Group Objectives

The goal of the summer 2003 field experiments was to determine the performance of an Iridium-based data communication system in a polar environment and to examine the performance of the wireless communications/telemetry link between the autonomous rover and the tracked vehicle.

1. The Iridium Link

The objectives of the Iridium experiments included evaluating the performance of a multi-link point-to-point protocol (MLPPP) communication system over the Iridium satellite system. Further, the goal was to obtain quantitative network performance data from the field, including 24-hour access, call drops, packet drops, delay and jitter; this data will be used to evaluate the consistency and reliability of a multi-link connection using the Iridium satellite in polar regions. The objectives also included evaluating the suitability of the link for the transfer of large files, e.g., non-real-time video, and real-time video/audio communications.

2. The Telemetry Link

The objective of the wireless link experiments was to characterize the communications link between the rover and tracked vehicle and to gather performance data over a variety of operating conditions. The performance of the communications/telemetry link was to be evaluated while passing radar, rover sensory and outreach (videos, photographs) data over distances that may be as much as 8 km. Another objective for this summer was to establish a wireless network to provide members of the camp with connectivity to the Iridium-based Internet connection in order for polar researchers to exchange real-time information while working anywhere within the camp.

B. Results

1. The Iridium Link

To provide communications connectivity, we investigated various satellite services; the two feasible options were Iridium, with its low-bit-rate service (2.4 kb/s) and Inmarsat/Intelsat with broadband service. We selected the Iridium option because it provided coverage in both Antarctica and Greenland. To achieve higher capacity communications, the multilink point-to-point protocol (MLPPP) was configured to operate efficiently over the Iridium satellite system. MLPPP combines multiple channels to obtain a seamless data connection with a capacity equal to the sum of the individual link rates. We used four Iridium modems to obtain an aggregate capacity of about 9.6 kb/s. Standard Internet protocols, TCP/IP, were then used to provide end-to-end connectivity. The MLPPP system was implemented in Linux. New link management software was developed and implemented to automatically detect and then recover from modem call drops. The physical system architecture is shown in Figure 4, the protocol architecture is given in Figure 5, while the end-to-end network architecture developed for this field experiment is shown in Figure 6. Overall, the MLPPP communications system performed in the field as expected based on laboratory experiments conducted at KU.

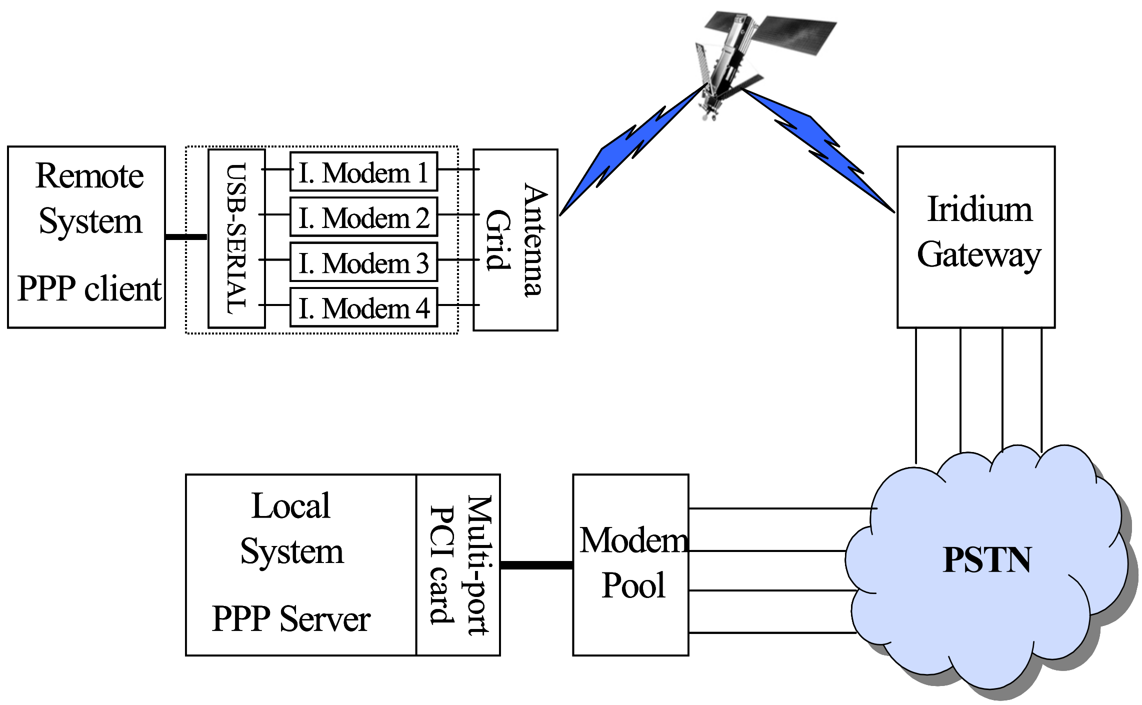


Figure 4: Physical Network Architecture

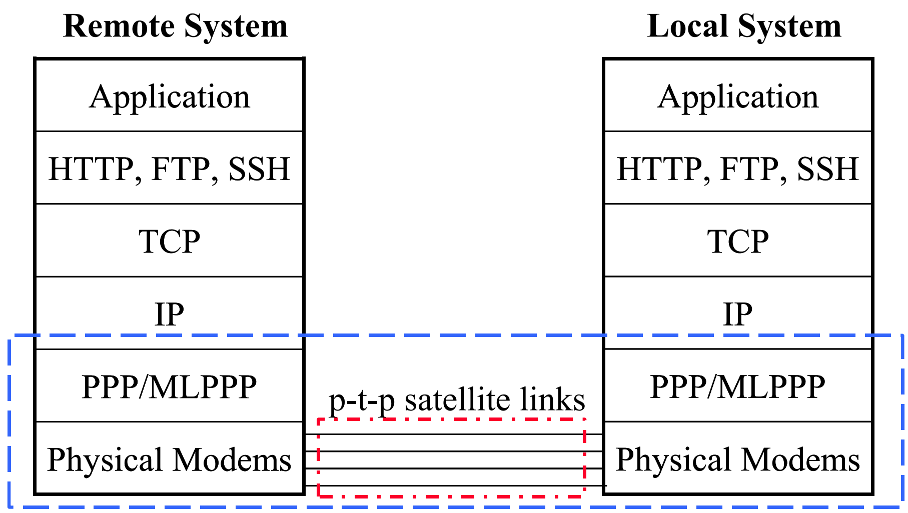


Figure 5: Protocol Architecture

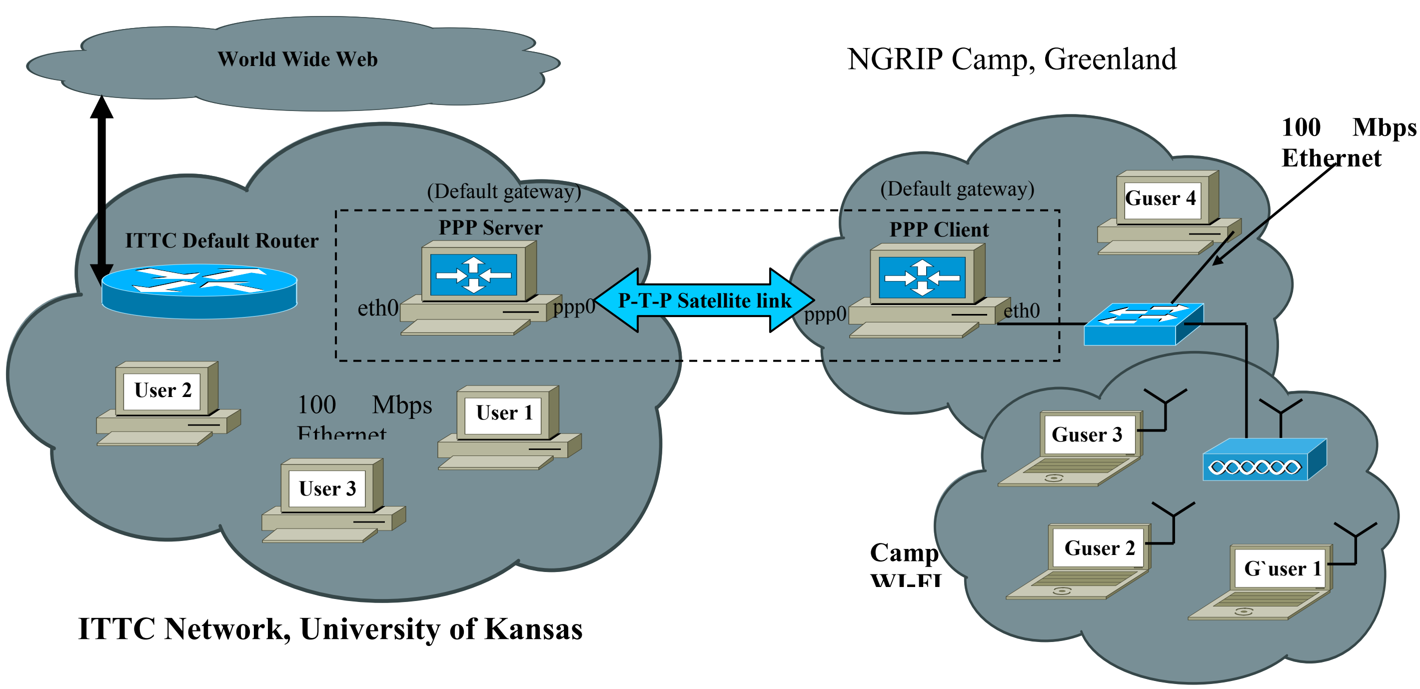


Figure 6: End-to-End Network Architecture

a. Delay and Loss Performance

Table 1 shows the system round trip time (RTT) and loss performance. Note that the one-way propagation delay is about 49 msec and the transmission time for a 64-byte packet at 2.4 kbps is 213 msec; thus the minimum theoretical RTT is 524 msec. The average RTT was observed to be about 1.8 seconds. The additional delay could be attributed to the inter-satellite switching and processing at the gateway.

TABLE 1. DELAY AND LOSS PERFORMANCE

Packets sent	Packets received	% Loss	RTT (sec)			
			Avg	Min	Max	mdev
50	50	0	1.835	1.347	4.127	0.798
100	100	0	1.785	1.448	4.056	0.573
100	100	0	2.067	1.313	6.255	1.272
200	200	0	1.815	1.333	6.228	0.809

b. Throughput Performance

Figure 7 displays the throughput as a function of the number of modems. These results were obtained using the TTCP and IPERF tools. The system was thus about 96% efficient. The system was also used to download large video files, ranging in size from 0.75 MB to 3.2 MB. The results of these transfers are shown in Table 2. Modem call drops resulted in the throughput being less than expected in some cases. However, it is important to note that these large files were successfully transferred automatically even in the presence of call drops, indicating that the new link management software properly executed.

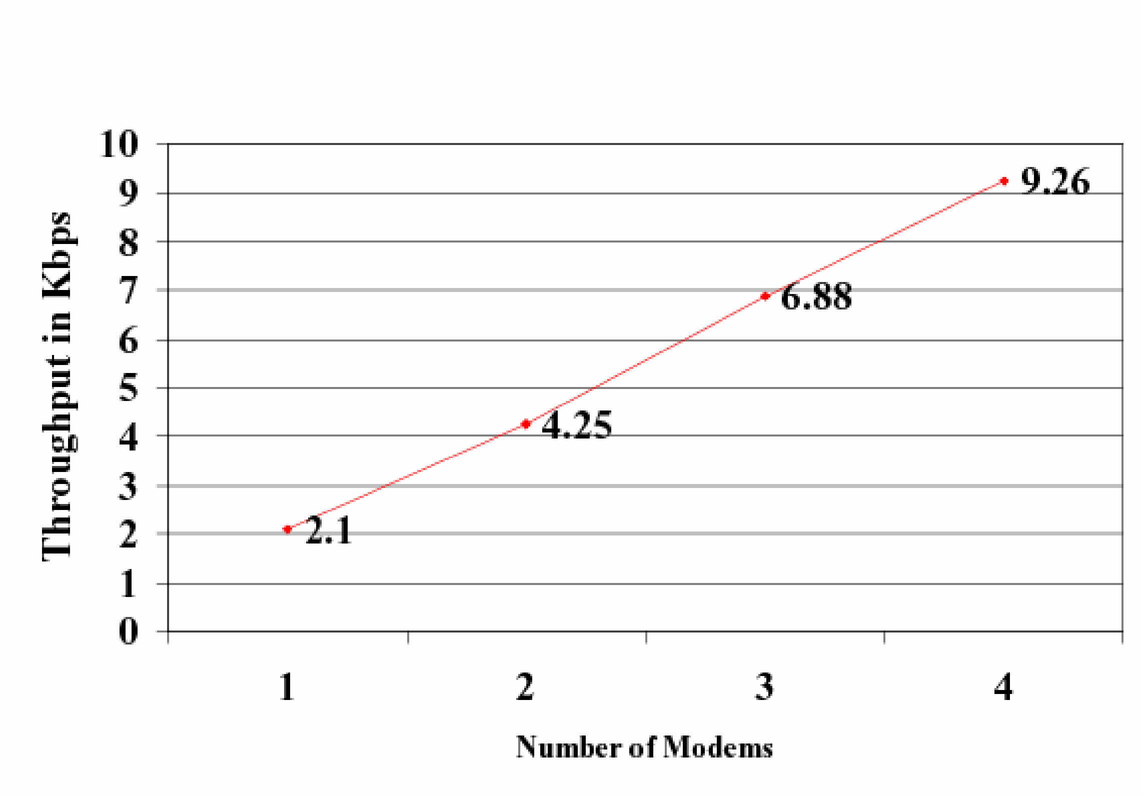


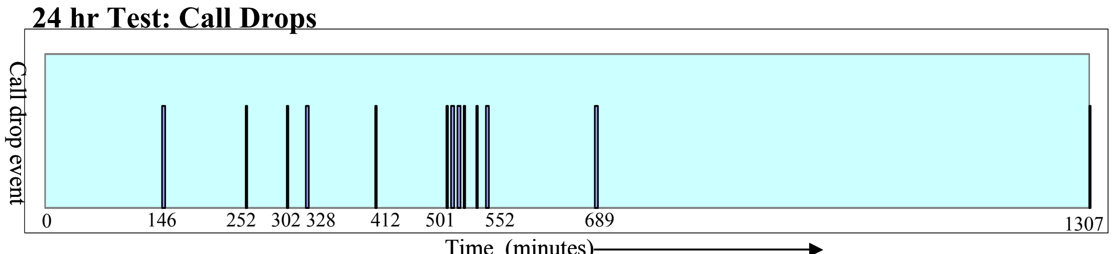
Figure 7: Measured throughput versus number of modems

TABLE 2. LARGE FILE TRANSFER PERFORMANCE

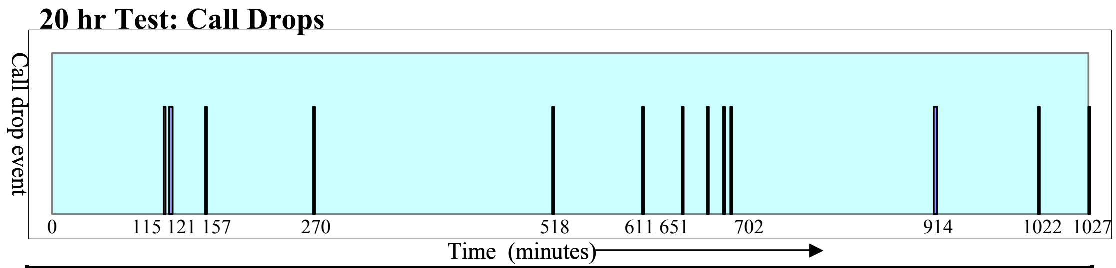
File Size (MB)	Download Time (min)	Throughput (b/s)
0.75	11	9091
3.2	60	7111
1.6	23	9275
2.3	45	6815
1.5	28	7143
2.5	35	9524

c. Reliability- Modem Call Performance

Combining the results from a 24-hour and a 20-hour test, the average connection time between call drops (modem up time) was measured to be 95.5 minutes with up time of about 90%. The longest up time observed was 618 minutes. The pattern of call drops is shown in Figure 8. The typical time to make a connection is 1 minute, while the average number of retries after a call drop is 2.



24hr Test – Up Time	146	106	50	26	84	89	8	7	8	17	11	137	618



20hr Test – Up times	115	6	36	113	248	93	40	27	16	8	212	108	52

Figure 8: Call Drop Performance

d. System Performance in Motion

The system was tested while the communications system, the four modems and their antennas, was in motion. The platform was transported at speeds of up to 32 km/h. The system's performance levels with and without motion were comparable. However, the number of attempts to complete a connection increased with the system in motion.

e. Qualitative Performance

The communications system was used for the transfer of large files to support the general activity of the NGRIP camp. Table 3 shows specific files that were downloaded from the web and the ITTC network. The size of these files and their importance (on a scale of 1-10, based on user survey) are also shown. In combination with a modified Wi-Fi deployment, the system provided Internet access for the entire NGRIP camp; this was the first time the camp had such a capability and it was very well received. The NetMeeting software was used to test the real-time video/audio capabilities of the system. As expected, the latency made real-time interactions difficult.

TABLE 3. LARGE FILE TRANSFERS IN SUPPORT OF NGRIP CAMP ACTIVITIES

	Title	Downloaded/uploaded	Size	Imp
1	Spectrum Analyzer programmer's manual	Download from Agilent.com	7.2 Mb	9
2	Matlab programs	Download from ITTC	500 kb	7
3	Voltage regulator data sheet	Download from Fairchild.com	226 kb	9
4	GPS software	Download	800 kb	9
5	Proposal submission	Upload	600 kb	8
6	Access point manager software	Download from Orinoco.com	4.66 MB	7
7	Drawing of machine parts to order	Upload to University of Copenhagen	1 Mb	9
8	Video of ice core, datasheet	Upload for press release	2 Mb	8
9	Pictures, press release of longest ice core in Greenland	Upload to Kangerlussuaq for press release	500 kb	6

2. The Telemetry Link

The experimental setup consisted of a rugged laptop with an Orinoco 802.11b card. The external antenna connector on the card was connected to a bi-directional amplifier, which was then connected to a high gain 15-dBi antenna. This antenna was tested using the KU antenna range project on the rooftop of Nichols Hall, and it was discovered that the measured gain was only about 8.5 dBi in the frequency range of interest. The bi-directional amplifier connected to the 802.11b transceiver is used to amplify the signals in both the transmit and receive directions. When operating in the transmit mode, the amplifier used an automatic gain control (AGC) to provide a power output of 1 W for any input power to the range of 5-800 mW. In the receive mode, the amplifier had a fixed gain of 17 dB. The antenna used to provide ubiquitous coverage had a horizontal beamwidth of 360° and a vertical beamwidth of 7°. The manufacture-specified gain was 15 dBi and it was designed to operate over a frequency range of 2400-2500 MHz. However, as stated earlier, the gain of the antenna measured using the KU antenna range project was determined to be only 8.5 dBi. This antenna was used at both ends of the peer-to-peer link.

The above-mentioned hardware was installed both at the stationary base station as well as on the snowmobile on the ice and is shown in Figure 9. A Garmin GPS12 receiver with a built-in antenna was connected to the RS-232 port of the rugged laptop on the snowmobile. The latitude, longitude and altitude information from the GPS with the corresponding time stamp was logged every 2 seconds. The coordinates of the base station were noted in order to determine the distance from the base station as the mobile vehicle moved along a traverse of 8 km. The Orinoco client manager software was used to log the received signal strength, noise level and SNR from the 802.11b card. These parameters were logged every 2 seconds along with their corresponding time stamp.

The experimental procedure involved fixing the antenna at a particular height on both sides and carrying out the propagation measurements along three different tracks of 8 km each surrounding the base station. Data transfer tests were also performed with field videos being exchanged between the two stations. These experiments were repeated for four different antenna heights of 1, 2, 3 and 5 m on both the base and the mobile station. Also, measurements and tests with the base station antenna higher than the antenna on the mobile station were performed. Transmission Control Protocol (TCP) as well as User Datagram Protocol (UDP) performance at various distances along the 8-km track were taken and are shown below. The throughput measurements were taken every 0.5 km along the track using the Netiq Qcheck software. An additional experiment involved providing wireless Internet to the researchers at the NorthGRIP camp using an 802.11b access point. The basic Internet connection was provided using Iridium modems, and wireless access to the Internet was implemented using the 802.11b technology.

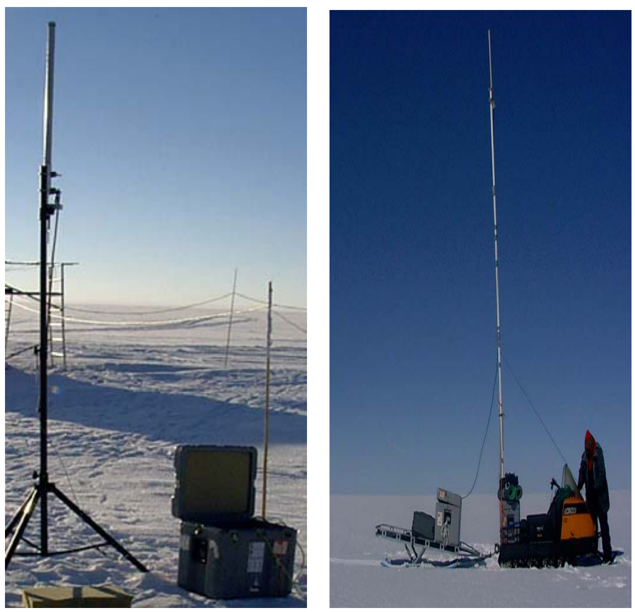


Figure 9: Base station setup and snowmobile

The 802.11b link worked seamlessly over a distance of 8 km, and video files with sizes of 5 MB were exchanged between the two stations when they were separated by 8 km. The 802.11b cards support a variable bit rate scheme, and it requires the following SNR's in order to achieve those data rates.

TABLE 4: DATA RATES AND SNRS

Data Rate	1 Mbps	2 Mbps	5.5 Mbps	11 Mbps
SNR Req	4 dB	7 dB	11 dB	16 dB

Measurements for a particular antenna height were performed on several different tracks around the base station. The plots of the signal-to-noise ratio for four different antenna heights are shown in Figure 10.

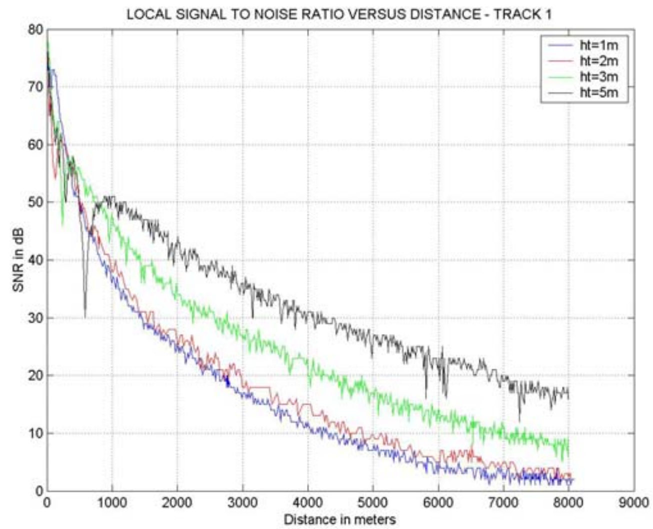


Figure 10: SNR versus distance for antenna heights of 1, 2, 3 and 5 m

C. Lessons Learned

1. The Iridium Link

From this field experiment, we learned that standard Internet protocols combined with MLPPP and Iridium modems could provide Internet access for polar expeditions at useful data rates. The 4-modem configuration was observed to be over 90% efficient, e.g., a 2.5 MB video file was transferred in 35 min at 9.524 kb/s. The system had an average up time of over 90% and thus is stable and suitable for autonomous operation. Mobile tests showed performance very similar to that of a stationary system at speeds of up to 32 km/h. The end-to-end network architecture developed to provide Internet access worked. PPP level data compression did not provide any significant improvement in the throughput. Further, interactions of PPP level compression caused "unclean" modem termination, resulting in large packet losses. The system round trip time is significant, ~ 1.8 seconds, which is an impediment to real-time interactions, and there are large (random) variations in the system RTT. Also, a call drop on the first modem connected results in a complete loss of connection. This is a known issue with the current version of the PPP code, and it may be fixed in future releases of the software.

Even with these connectivity issues and such low data rates, the response of the camp to having a wireless network/life line Internet connection was very positive. Overall, the system provided the first Internet access at NGRIP and proved very useful to both the PRISM and ice-core teams.

2. The Telemetry Link

The 802.11b wireless link worked seamlessly over 8 km. The SNR and hence the data rate were dependent on the antenna height. It would be feasible to use an antenna height of 3 m above the ground and achieve throughputs of the order of 2.5 Mbps at distances close to 8 km. Although there were no problems with the wireless link as such, we encountered some trouble with the rugged laptops that were used during this field experiment. These laptops had batteries that drained very quickly in the cold and they did not charge very easily in the cold. The rest of the hardware functioned without the slightest of problems in the harsh polar environment.

The 802.11b wireless link was established between the two stations and data was exchanged with bit rates of the order of 2-3 Mbps at 8 km. This link was used to provide wireless Internet access to the participants of the NGRIP camp from virtually anywhere around the camp. Throughput measurements using data sizes of the order of 1 Mbytes were taken, and it was clear that there was sufficient bandwidth to exchange video and other data between the two rovers continuously over distances of up to 8 km.

D. Next Year's Activities

Additional research is needed to expand and refine the capabilities of the Iridium-based communications system. Increasing the data rate is a priority, thus the system needs to be expanded to use additional modems. The goal would be to expand the system to 8-12 modems. This presents several problems, since as the number of modems increases so does the number of antennas and associated hardware. It is possible to have multiple modems share one antenna, e.g., NAL Research Corp. (http://www.nalresearch.com/) claims to have a system to allow four modems to share one antenna. Thus, research is needed into packaging larger systems for polar experiments, including allowing multiple modems to share one antenna and reducing the spacing between antennas. The software will also need to be modified to support additional modems.

V. INTELLIGENT SYSTEMS RESEARCH GROUP

A. Primary Group Objectives

The goal during the trip to Greenland this summer was to test our code over the wireless network while running on Remote Method Invocation (RMI). Our code is designed to have independent "wrappers" running on various machines connected over a network. The wrappers are meant to encapsulate a data source such as the SAR, depth sounder, etc. A "matchmaker" agent keeps track of the location of the wrappers and assists them in connecting with each other when needed. The user interface agent is the current means of testing the system by requesting information from the data wrappers.

To keep our tests simple, we installed our code on two of the laptops going to Greenland. The plan was to run the matchmaker agent and the user interface agent on one computer and run a dummy data wrapper on the other. If all went well, the user interface agent and the data wrapper would both register with the matchmaker, and then the user interface would request information from the data wrapper. This would verify that our basic system was working.

B. and C. Results and Lessons Learned

Although we do not have field results to report, the code was successfully tested in Lawrence before the field deployment. A major problem with the intelligent system field tests this year was the failure of two of the rugged laptops on which the code was installed. After the field team returned to Lawrence, they tested these laptops in a temperature chamber and they failed at about -20°c. These computers were returned to the manufacturer for a refund.

Because of time constraints and other commitments of the field team as well as the shortage of computers, the field team could not reinstall the code on other computers and complete tests as planned. We plan to perform additional experiments and test all computers in our temperature chamber before field deployment during the next season.

D. Next Year's Activities

By the time of the second Greenland experiment, we expect to have complete wrappers for as many different data sources as possible. We will be collecting any experimental results from the trip that will be similar to the output of data sources such as the depth sounder and the SAR. If none is available for a particular source, we will try to come up with some mock data to use for testing. Additionally, a new agent will be designed to control the high-level movements of the "Bob" robot. All the wrappers and the new agent will then be integrated into our system and tested on Bob.

We will also have codified expert knowledge to make decisions and issue control instructions to the various independent entities like the radar sensor, rover, etc. In this direction, we are to first classify and map quantitative information that will provide us with some prior knowledge about the ice sheet. We also need to develop suitable data/image processing techniques and algorithms to interpret real-time data from the dual-mode wide-band radar and SAR processed two-dimensional reflectivity gray-scale images. In addition, we need to gather health information from the rover and codify our expert database accordingly. We have identified Bayesian Network Models as the appropriate decision-making model for the project's intelligent radar and rover control.

During the second Greenland trip we will investigate the functionality of all code components and study whether the agents are issuing the correct instructions to the radar and rover given the conditions of the bedrock.

VI. ROBOTICS RESEARCH GROUP

A. Primary Group Objectives

The primary objectives of the robotics group were (1) to perform preliminary field experiments in order to test the functionality of the mobile rover and its components in harsh polar regions, and (2) to collect sensor and control data while operating in the field to be used to design an autonomous system for the rover.

The field experiments were divided into three main tasks of: (1) rover and automation testing, (2) sensor testing, and (3) data collection. For testing the rover and its automation, the goal was to ensure that the vehicle and its components could survive and function properly in the cold temperatures and high altitude of the polar region. This involved evaluating the mobility of the rover on snow/ice, its power, and its winterization. This task also involved testing the automation of the rover. The actuation of the steering and throttle mechanisms was placed under computer control through the use of linear motors. The rover was also equipped with a remote control system where its movements were controlled using a joystick. Testing involved operation of the rover on various types of terrain under computer control.

We also tested and evaluated a variety of sensors that will be placed on board the rover. These sensors include the GPS (Global Positioning System), laser range finder, temperature sensors, weather station, tilt sensor, etc. Each of the sensors was tested individually to ensure its proper operation in the cold environment and evaluate its accuracy. The GPS tests were more extensive in order to determine its relative accuracy, as the precision requirements were much higher for the GPS system. Extensive collection of data from the actuators and sensors occurred while the rover was in operation. These data will be used when rover autonomy is implemented. The rover will process its sensory data and use the resulting information to function autonomously. Data from both the sensors and the control system were integrated and logged for processing upon return to Kansas. The testing involved various natural and human-made obstacles.

Figure 11: Photograph of the GPS base station

B. Results

Rover Operation: From the onboard generator, which functioned with little difficulty, the rover had sufficient power to operate the motors, laptop, sensors, and rack mountable equipment. The rover and its onboard equipment required thawing by the heat generated from the generator for at least 30 minutes. After warming up, the rover started without any problems. The rover's engine was modified in order to work in the cold climate. The rover was capable of operating on nearly all terrain with the exception of going up a slope of 50° on loose snow, i.e., a snowdrift from a snow blower.

Winterization: The rover operated without snow accumulating in it, and if properly closed and sealed at night, no additional snow entered the vehicle. Certain seals were replaced or removed due to glue failure. The onboard equipment was protected from the harsh climate conditions due to the winterization of the rover.

Automation: The vehicle's actuation system operated properly. The main throttle's actuator will be replaced with a larger actuator, to increase the top speed of the rover. Joystick control was successful.

Remote Control: Once local tests of the automation were completed, remote control was tested using 802.11b wireless and Java RMI. The vehicle was successfully controlled remotely via a joystick.

Sensor Performance: All of the sensors utilized performed properly in the polar climate. When integrated, there was no change in performance with any of the sensor modalities. The GPS base station batteries drained quickly and required frequent recharging and replacement.

GPS Accuracy: The accuracy of the GPS equipment was tested by taking measurements within a 100-m radius of the base station. Twenty points approximately 5 m apart were selected. Multiple measurements were collected at these points (see Figure 12). The standard deviation for each position was then calculated. The maximum standard deviation was 1.4 mm.

C. Lessons Learned

Shipping: The rover had been loaded on the C-130 aircraft for the return flight from Greenland, but was then combat-offloaded (i.e., pushed out of the cargo bay onto the ice sheet) so that the aircraft would be able to gain enough speed to take off from the skyway. The rover has to be able to sustain drops of about half a meter from a moving aircraft. The rover's shipping, including the pallet, strapping, and packaging, should be designed with that possibility in mind and be able to survive the drop. The ability to ship the rover in modules should also be given consideration in the future.

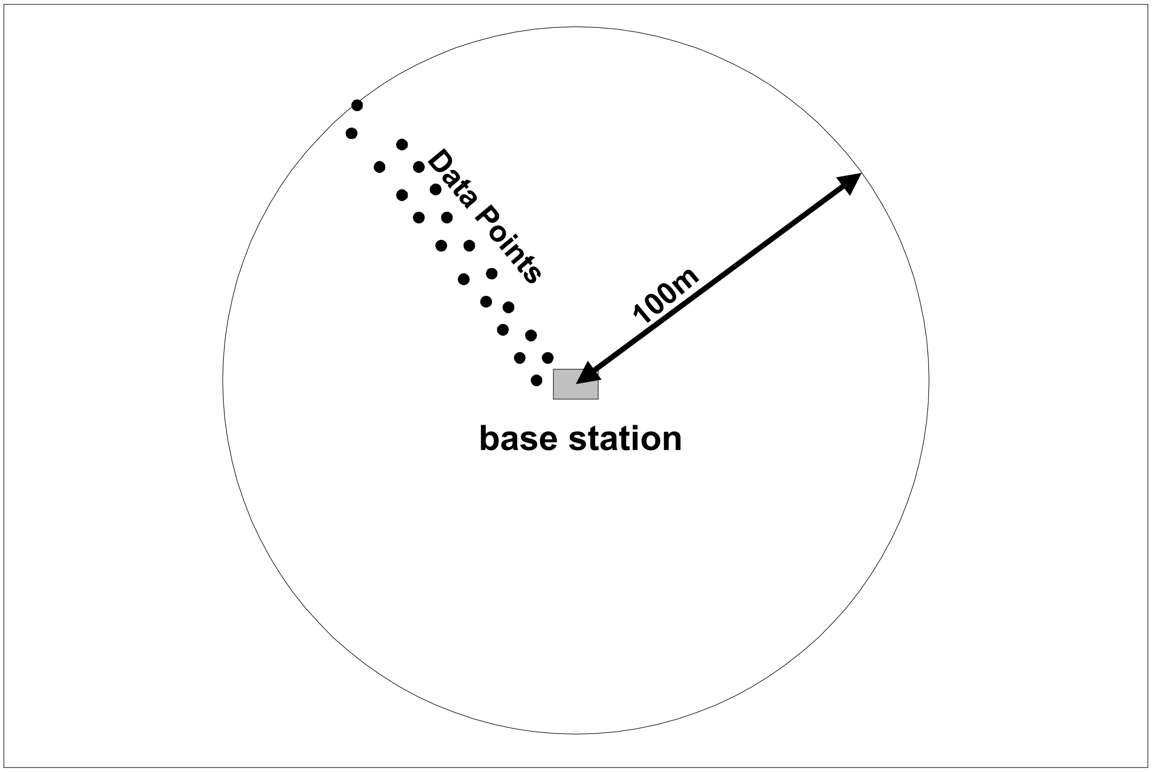


Figure 12: GPS accuracy test configuration

Rover Power: Although the rover was able to function while carrying its payload and towing antennas, larger engines should be considered for future missions.

Electric Power: It is not feasible to rely on the power sources provided by the camp. The camp's power was running higher than 220 V, and this resulted in the loss of several surge protectors and voltage converters. The group should provide its own power.

Laptops: A number of rugged laptops failed, and resulted in a shortage of laptops and groups having to share them. Laptops should be purchased in advance and their operation, charging, discharging, and other functions should be tested in the temperature chamber. A few additional laptops should be taken just in case of failures.

Batteries: Batteries can be ineffective in the cold, and their charging can be unreliable. Some batteries drained at rates twice as fast (if not faster) when they were cold.

Glue: Electrical tape, duct tape, etc. failed easily due to the cold and was unable to retain its adhesive properties. Glues should be replaced with fasteners whenever possible.

D. Next Year's Activities

The activities next year will focus on (1) improving and enhancing the rover's functionalities; (2) integrating the rover with other components, namely, radar, communication, and intelligence modules; and (3) automating the rover so that it can function on its own.

Improvements: Redesign the rover doors, which were broken during the drop from the aircraft. The new doors should be improved to allow better access to internal components of the rover. Replace the throttle actuator with a more powerful one. Replace the throttle cable with one that can handle the cold better. Replace taped weather seals with bolted weatherproofing. Move proven equipment into rackmount boxes, and replace the testing shelves with more space for rackmount equipment. Build power supplies for equipment that run only on batteries. Leave the current batteries in place for possible, though unlikely, generator failure.

Integration: Place the radar equipment and communication equipment on board the rover and fully evaluate the integrated system.

Autonomy: Have the rover perform waypoint navigation incorporated with obstacle avoidance. This will require full integration of the sensors and drive system. The vehicle will then perform patterned movement as per the requirements of the radar system.

Figure 13: A photograph of the rover taken during the field experiments.

VII. OUTREACH RESEARCH GROUP

A. Primary Group Objectives

The outreach objectives for the 2003 field season were to: 1) document the preparation necessary for polar field work; 2) convey the experiences of the field team and the progress of the experiments to students and the general public in an innovative and timely manner; and 3) to set up and test a "virtual dashboard" into which data from the field could be placed, making it easy for a teacher to download selected data. Before heading to the field, our objectives were to take many digital pictures and video of the various stages of instrument and equipment preparation, the packing of all the miscellaneous items into shipping boxes, and palletizing the cargo for shipment. On the journey to the field and while in the field, our objectives were to write daily entries to a field journal that would be maintained on the web, and to take digital pictures and video clips of the experiments and general camp conditions. The "virtual dashboard" was set up for presenting data arriving from the field, but it required a great deal of hand-selection of the data. We also brought along two small "Geobears" to photograph in different situations for later development as a picture story detailing the PRISM field experience for younger students (K – 6). The outreach group and the communications groups had a common objective of transmitting text, video, audio, and images back to KU over the Iridium data link to provide daily updates for presentation on the PRISM web page. An additional objective of this field season was to test the coordination and protocol of the outreach team at KU to handle the bits and pieces of information (text, video, etc.) that arrived from the field, and to present this material on the PRISM web page in a professional and timely manner.

B. Results

All the objectives for this summer's campaign were achieved. We documented the field preparation activities with digital pictures and video, which resulted in an adequate amount of material. We chronicled events in the field by posting a daily field log on the PRISM web page (http://ku-prism.org/). By 8:00 a.m. each day, the daily journal entry was e-mailed from the field to KU, where it was edited and posted on the PRISM web page. For visually impaired students, the journal was converted to audio as well. The whole process was usually completed by early afternoon. The entire field log was available for viewing on the PRISM web page for the duration of the campaign.

PRISM web page content included an introduction on the field work being conducted by the PRISM team, a section on the web page that provided updates on the ice core drilling, such as the point when the ice core became the longest ever drilled in Greenland and when the drilling team hit bedrock, and four video segments with audio.

The "virtual dashboard" was set up, but at this point it requires hand-selection of data. There was no data transferred from the field. The data were delivered to the outreach team after the field team returned to KU. The only data provided were latitude/longitude and time. On the next campaign we will need to ensure that the rover team provide other sensor data such as air temperature and wind speed coordinated with lat/long.

For the Bears On Ice in Greenland feature, the rover team took responsibility for taking pictures of the Geobears in different situations. We have approximately 25 pictures of the bears, but the number of pictures, the picture quality, and the number of situations photographed were all lower than expected. The outreach team is developing a narrative from the pictures.

The interaction between the outreach and communications groups was excellent, and the transfer and transmission of text, video clips and pictures worked very smoothly. We were even able to record an interview over the Iridium telephone and put it on the web site. We also obtained more than three hours of video and two CDs of more than a thousand digital pictures. These CDs contain digital pictures taken by everyone in the camp. Currently, the pictures are being sorted and captions are being added. The video has been cataloged and is now being developed into several production segments.

C. Lessons Learned

For the field journal, we need to discuss the text reading level. The entries produced this year would have been difficult for elementary students to read. We should also plan on having at least two photos sent to illustrate each daily journal entry. This would greatly enhance the user experience (particularly for students) if the journals had pictures as well as text each day.

The quality of the audio in the movies was often poor and we should look into clip-on microphones. The resolution and compression of the transmitted video need to be examined. An option to offer different video formats on the web page should be explored. The field team should be able to edit video clips and do voice-overs to eliminate ambient noise such as wind and generator noise. A suggestion is to train one person on the field team to use StudioDV software so we can capture and edit video in the field before it is sent to KU. Also, the field team member responsible for outreach should have the capability to download pictures from all the digital cameras (personal or project) brought along by his or her colleagues.

For Bears on Ice, someone with a fair amount of creativity and with good photography skills is needed for this assignment. There needs to be feedback with the outreach team while in the field – sending back pictures and descriptions every few days, and receiving directions on additional pictures that are needed to make an effective story.

D. Next Year's Activities

The plan for next year will generally be a more refined version of this year's activities, and an operational version of the virtual dashboard. We will work towards incorporating some of the ideas that came out of this year's outreach efforts. These include:

- Provide an itinerary of the tasks to be accomplished by the field teams on the front page of the PRISM web page. Check off items as they are completed.
- Provide a map of the camp where someone can click on a location and see pictures inside and outside.
- Include a funny (or strange) quote of the day from the field team or others in the camp.
- Include as many personal touches as possible – such as what we're eating, and how we relax at the end of the day.

- Improve the quality of the audio in the video clips and develop the capability to edit video clips in the field.

VIII. SCIENCE GROUP

A. Primary Group Objectives

An important step in testing the accumulation rate radar is to investigate what the near-surface radar reflections represent. They might represent annual layers, but also temporally variable dust layers or wind crusts. The presence of ice pipes, lenses and depth hoar will also have a distinct effect on radar backscatter.

One of the objectives of the science group was to investigate sources of near-surface radar scattering and reflection and to measure recent accumulation rates. In order to do this, we completed a detailed snow pit study at several locations along the radar tracks. In addition, the field team extracted a 15-m core for isotope analysis. Isotopic samples were also acquired from two other pits where there are coincident isotope and stratigraphy/density data. The results of these investigations will be compared and correlated with acquired radar profiles and meteorological data.

B. Results

The first couple of days at NGRIP were spent on setting up extra tents at camp and investigating the deepest snow pit, which was doubled so the adjoining wall could be backlit (Figure 14). Also, the hand auger was tested, but this proved very difficult and the core fell apart. Therefore, it was decided to use an automatic drill available in the camp. On July 3 we set up the system and started the drilling up to 8.5 m. The cores were cut into 5-cm pieces and put into bags to melt. The water was afterwards transferred to plastic lab bottles. On July 5 we drilled another 6 m. On July 8 investigations started at snow pit 2, and locations for three more sites (snow pits 3, 4, and 5) were selected with the help of the radar team (Figure 15).

Figure 14: Snow pit wall of pit 1

TABLE 5: LOCATION AND DEPTH OF SITES DISCUSSED IN TEXT

Location name	Latitude	Longitude	Elevation	Depth	Distance to camp
Pit 1	N 75.1055	W 42.3388	2923 m	2.90 m	1 km
Core 1	N 75.1058	W 42.34	2924 m	14.45 m	1 km
Pit 2	N 75.1108	W 42.3813	2935 m	2.05 m	2.45 km
Pit 3	N 75.1203	W 42.3633	2919 m	2.00 m	2.94 km
Pit 4	N 75.1242	W 42.3282	2928 m	2.20 m	3.06 km
Pit 5	N 75.1212	W 42.2883	2931 m	2.10 m	2.81 km

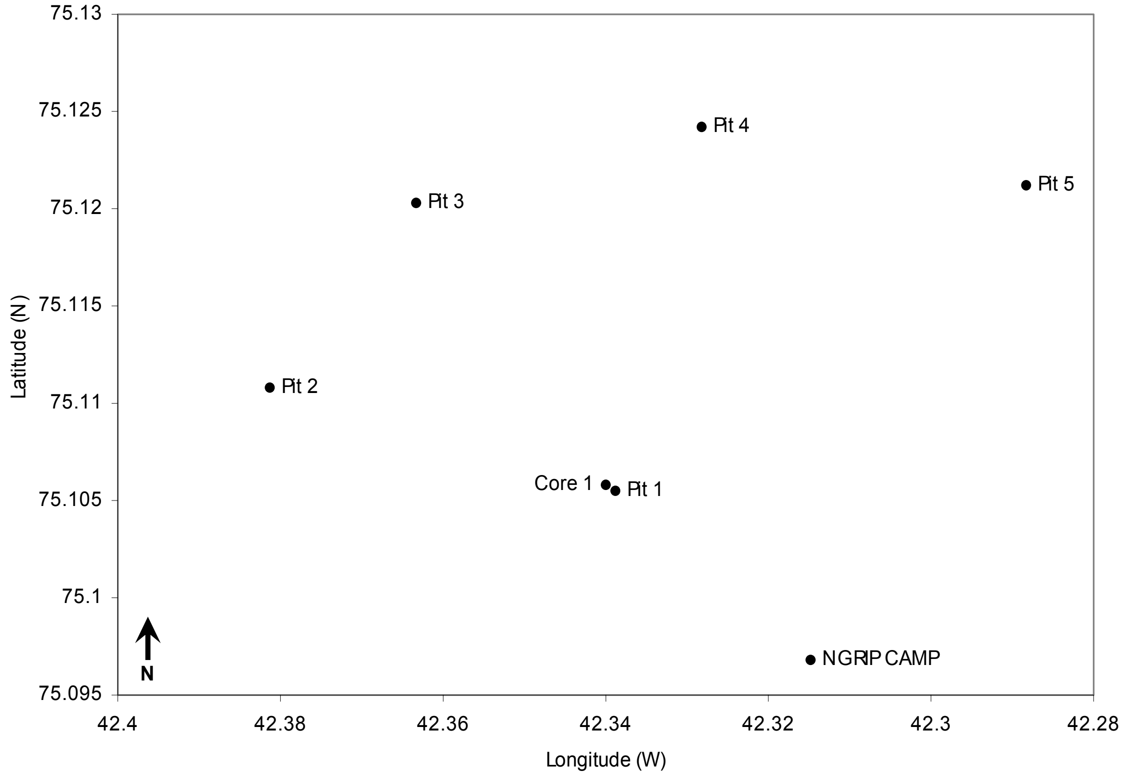


Figure 15: Map showing locations of sites discussed in text relative to the camp.

A total of five different pits were investigated, ranging in depth from 2 m to 2.90 m (Table 5). Pit locations were selected in the vicinity of the NGRIP camp (Figure 15). Before digging a pit, location, altitude (GPS), date, time and weather conditions (temperature) were recorded. Each site was marked with an accumulation pole with flags, for potential future re-examination. The vehicle with the accumulation radar mounted on it circled around all these sites.

At each site we investigated stratigraphy and checked for the presence and thickness of annual layers, ice pipes, ice lenses, wind crusts and depth-hoar layers. Thicknesses of individual layers were measured and grain orientation, size and shape of the snow crystals were determined using coated graph paper and a magnifying lens (Figure 16). Other characteristics such as snow strength and hardness were also recorded. A photograph was made of the pit walls (Figure 14). In general, the stratigraphic data of the different pits very much agreed with each other. Between 50 and 60 cm below the surface in all the pits, a depth-hoar layer was observed, and just below that a 5-mm-thick ice crust, with intermittent ice lenses and an occasional ice pipe. This ice crust was also reported at GRIP 300 km away (SSE) and is believed to reflect a widespread melt event during the summer of 2002. Accumulation since that time is approximately 60 cm (snow).

Using both digital and dial stem thermometers, the temperature was recorded at 10-cm intervals. This was done on the wall shaded from the sun immediately after digging the pit, so that outside influences would not affect the temperature profile. In this way we determined the temperature profile within the upper layers of the snow pack (Figure 17). Preliminary observation of the data showed that all temperature profiles were more or less similar except for the upper 50 cm, which is highly influenced by daily/hourly surface temperature fluctuations.

We also determined the temperature in a drill hole. After the core was taken out, a thermometer was put into the hole at a depth of 10 m and left there for 24 hours with a lid on top of the hole. This temperature is an approximation of the average annual surface temperature, and was found to be -29.5 ºC.

The density profile of the snow was also determined at 10-cm intervals. For this we used density tubes of which the volume was measured beforehand with a graduated cylinder. In the field it was decided not to leave the lid on the density tube to avoid compressing the snow too much; because of this there is a small volume change of the tube that has yet to be determined due to the absence of a graduated cylinder in the field. Contents of the tubes were emptied into a Ziploc bag (of known weight) and the weight was determined using a scale. Figure 18 shows preliminary results of the weight of the samples; density must still be determined.

From two pits we took isotope samples. In one the sampling interval was 5 cm, in the other 10 cm. The samples were put into small plastic bottles for oxygen-isotope analysis back at the Ohio State University. This is necessary to get a better estimate of the age of the layers.

In addition to the snow pit samples, we also retrieved a 14.45-m core using an automatic drill. The core was extracted very close (20 m) to the deepest pit, 2.90 m deep (pit 1). We only have stratigraphy and density for the pit due to time constraints. Based on recommendations from other investigators in the field, the core was sampled at 5-cm intervals, filling 300 sample bottles. Analysis of these samples will give us an oxygen-isotope record of perhaps more then 20 years.

In summary, preliminary observation of the snow-pit data shows a fairly uniform stratigraphy that might reasonably be extrapolated to a larger area around NGRIP. Radar measurements were done around all sites, making the snow-pit studies of high value for calibration/validation purposes. In addition, snow samples were taken from two pit walls and a 14.45-m-deep core for oxygen-isotope analysis. Over the next few months, the data will be reduced and a report on the derived products prepared for use by the team.

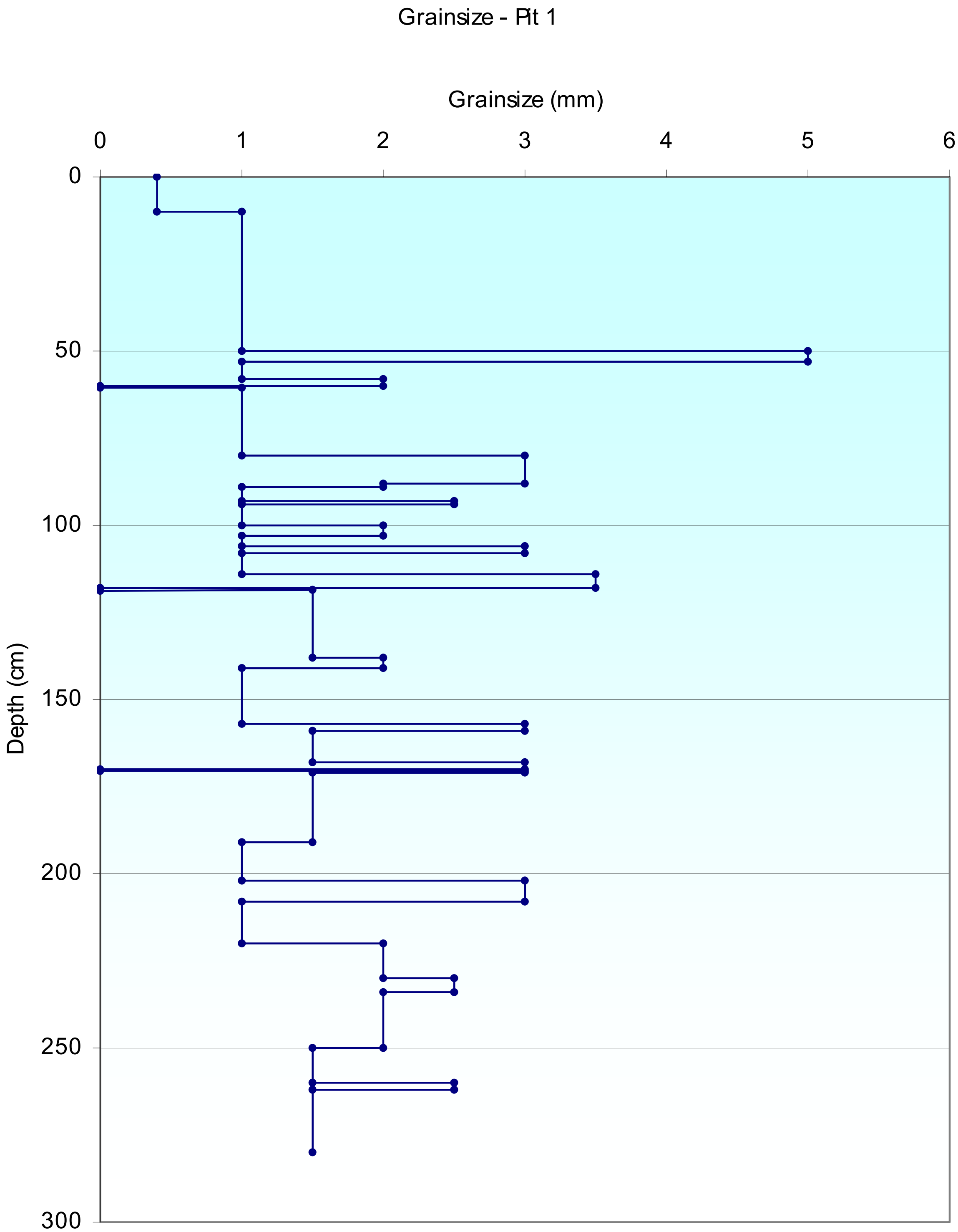


Figure 16: Grain size profile of snow pit 1. The coarse grain size at 50 cm depth reflects a 3-cm-thick depth-hoar layer; grain size 0 reflects ice crusts.

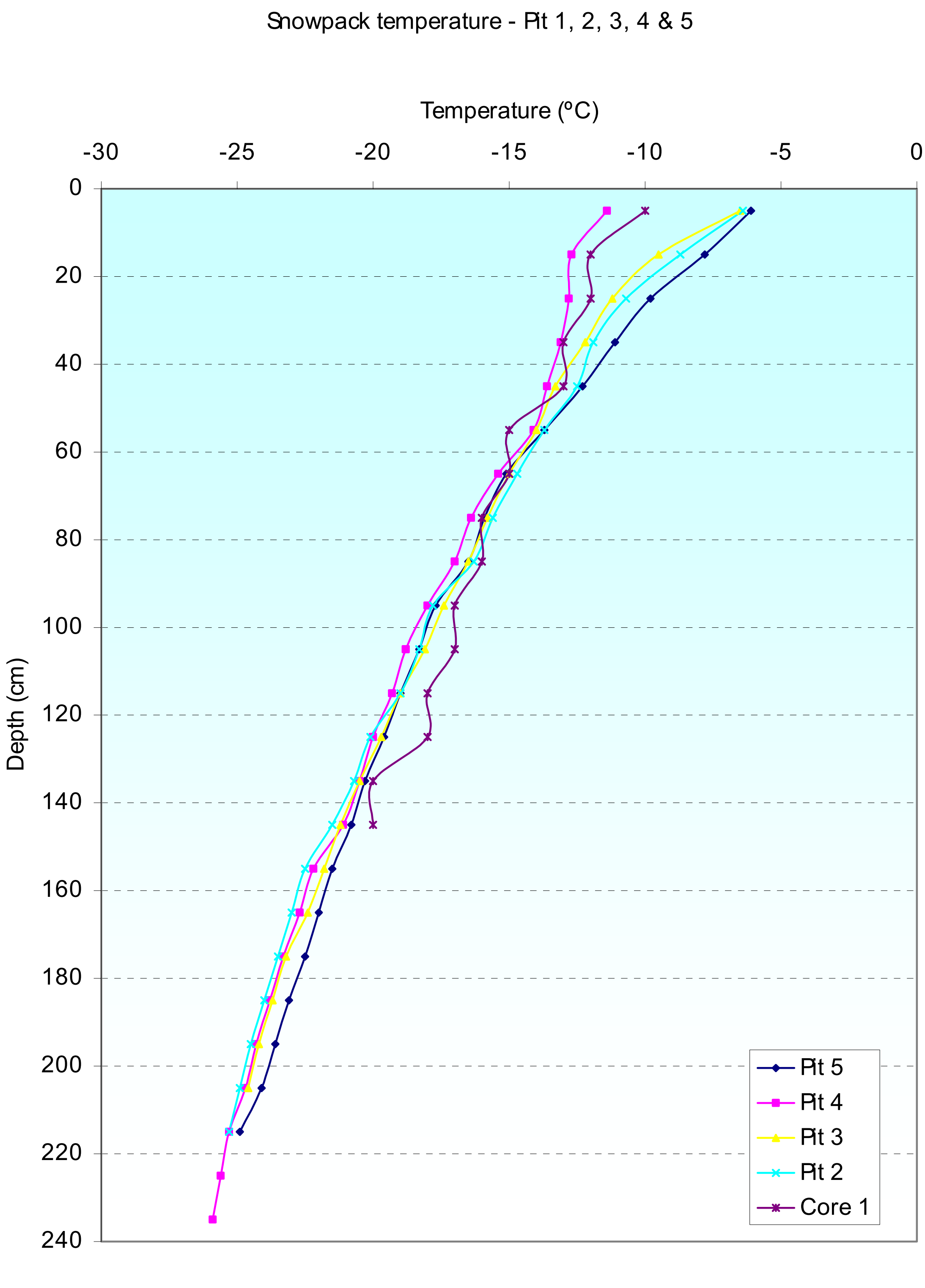


Figure 17: Temperature within the upper layers of the snow pack. Except Core 1, all measurements were made with a digital thermometer.

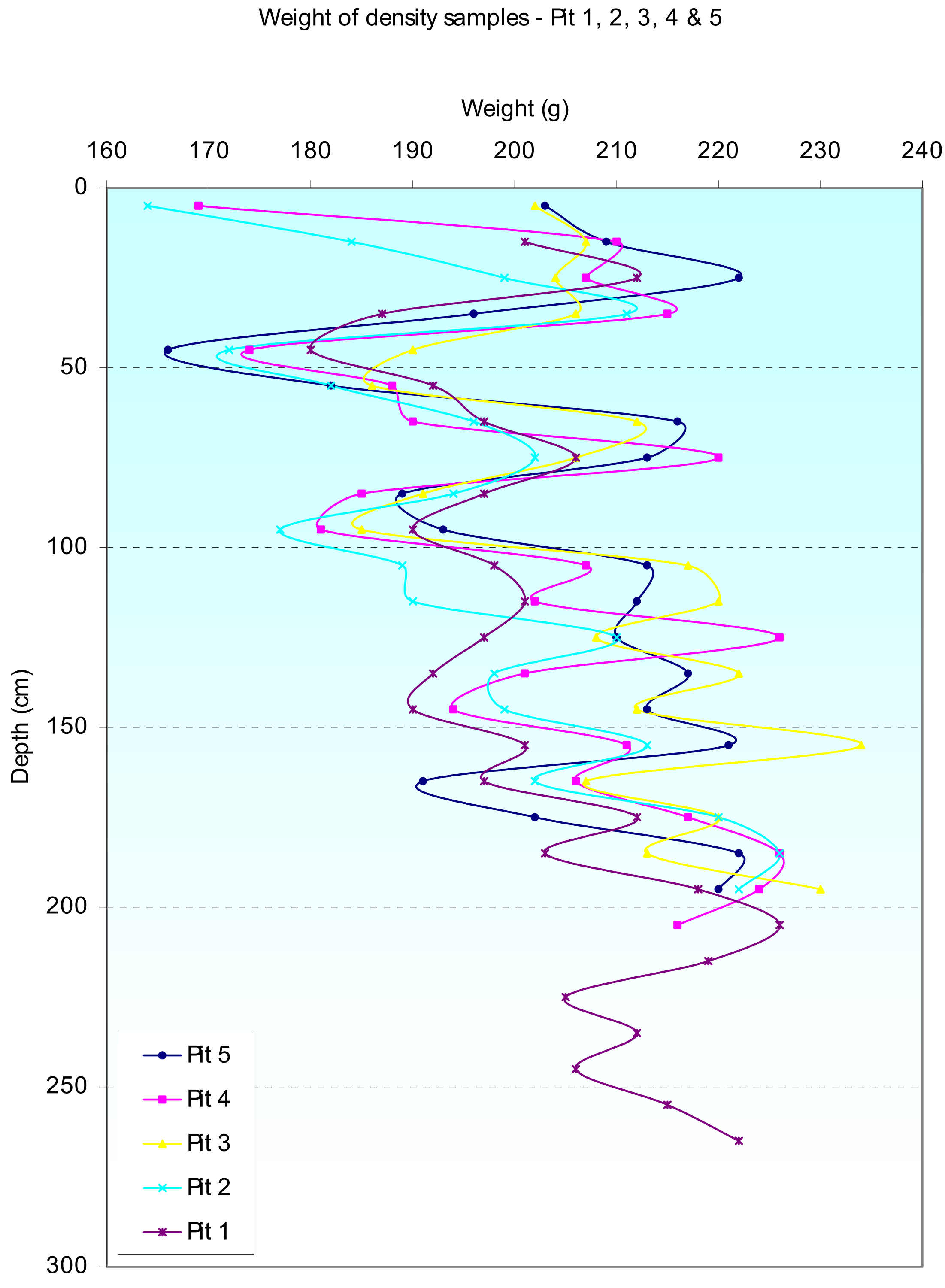


Figure 18: Weight of density samples vs. depth in the various snow pits. Especially in the upper part there is a very good agreement. Density and error bars must still be determined.