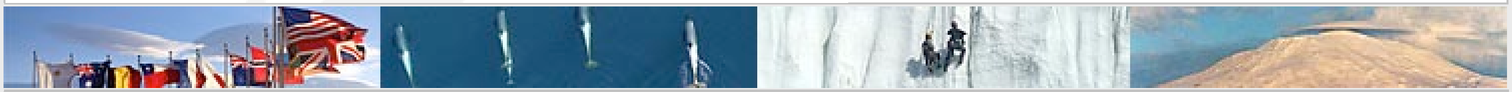

GLACIOLOGY

Undergraduate researcher Erin Whorton and mountaineer Susan Detweiler approach the top of Taylor Glacier, while a mountaineer monitors their ropes from above. Researchers must climb the glacier to place instruments that will record its temperature, movement and melting. Scientists hope to determine why polar glaciers create shear cliffs unlike glaciers in more temperate regions. (*NSF photo by Kristan Hutchison*)

In this section:

- Overview
- Mechanics of dry-land calving of ice cliffs.
- Using polarimetric radar methods to detect crystal orientation fabrics near the Ross/Amundsen Sea ice-flow divide and at the Siple Dome ice core site.
- Gases in firn air and shallow ice at the proposed West Antarctic Ice Sheet divide drilling site.
- Investigating iceberg evolution during drift and breakup: A proxy for climate-related changes to antarctic ice shelves.
- A mobile sensor web for polar ice-sheet measurements.
- Earth's largest icebergs.
- Dry Valleys Late Holocene climate variability.
- Tidal modulation of ice stream flow.
- Monitoring an active rift system at the front of Amery Ice Shelf, East Antarctica.
- Is Kamb Ice Stream Restarting? Glaciological investigations of the Bulge-Trunk transition on Kamb Ice Stream, West Antarctica.
- High-resolution ice thickness and plane wave mapping of near-surface layers.
- A hyperinsulated instrumentation system to support year-round research in polar regions.
- Using a deep ice core from the West Antarctic Ice Sheet ice divide to investigate climate, ice dynamics, and biology.

Overview

Ice is indisputably the defining characteristic of Antarctica. The entire continent (with a few exceptions such as the McMurdo Dry Valleys and some lakes and mountains) is covered by ice sheets that have been laid down over eons, if the term "sheets" can be used to describe a dynamic mass that is several thousand meters (m) thick, that is larger than most countries, that rises over 2,000 m above sea level (and peaks in an ice dome nearly twice that high in the east), and that is heavy enough to depress the bedrock beneath it some 600 m. Actually, the continent has two distinctly different sheets: the much larger East Antarctic Ice Sheet, which covers the bedrock core of the continent, and the smaller, marine-based West Antarctic Ice Sheet, which is beyond the Transantarctic Mountains and overlays a group of islands and waters.

The Antarctic Glaciology Program is concerned with the history and dynamics of the antarctic ice sheets; this includes research on near-surface snow and firn, floating glacier ice (ice shelves), glaciers, ice streams, and continental and marine ice sheets. These species of ice facilitate studies on ice dynamics, paleoenvironments (deduced from ice cores), numerical modeling, glacial geology, and remote sensing. Current program objectives include the following:

- correlating antarctic climatic fluctuations (from ice-core analysis) with data from arctic and lower-latitude ice cores;
- integrating the ice record with terrestrial and marine records;
- documenting the geographic extent of climatic events noted in paleoclimatic records and the extension of the ice core time series to provide information on the astronomical forcing of climate;
- establishing more precise dating methodologies for deep ice cores;
- determining the Cenozoic history of antarctic ice sheets and their interaction with global climate and uplift of the Transantarctic Mountains and the response of the antarctic ice sheets to the Pliocene warming;
- investigating the physics of fast glacier flow with emphasis on processes at glacier beds;
- investigating ice-shelf stability; and

- identifying and quantifying the feedback between ice dynamics and climate change.

Ice cores from Antarctica are important for determining whether the rapid climate changes recorded in Northern Hemisphere ice cores, such as those obtained from Summit, Greenland, in the Greenland Ice Sheet Project II (GISP2), are global in extent. Plans are underway to drill a deep ice core at a site that has both thick ice and high annual accumulation and is located on the ice divide in West Antarctica. This is the only antarctic site where scientists can obtain an ice core capable of providing a long, annual resolution history of Southern Hemisphere climate in which compressed snow layers are thick enough to allow absolute dating. This ice core will provide a Southern Hemisphere equivalent to the GISP2, GRIP (the European Greenland Ice Core Project), and North GRIP ice cores and will allow a detailed comparison of environmental conditions between the Northern and Southern Hemispheres. The ice cores will also complement those already under study from Byrd Station and Siple Dome in West Antarctica and Taylor Dome and Vostok Station in East Antarctica. Ice cores are unique in that they contain continuous, or nearly continuous, records of annual precipitation, atmospheric temperature, and components of the atmosphere, including gases as well as soluble and insoluble aerosol particles from a variety of sources (biogenic, terrestrial, solar, marine, volcanic, anthropogenic).

Ice cores collected under the Antarctic Glaciology Program are stored at the National Ice Core Laboratory (NICL), a government-owned facility for storing, curating, and studying cores recovered from the ice-covered regions of the world. NICL is supported through an Interagency Cooperative Agreement with the U.S. Geological Survey (USGS) and provides researchers funded by the National Science Foundation and the USGS with the capability to examine and measure ice cores while preserving the integrity of these cores in a protected environment.

Mechanics of dry-land calving of ice cliffs.

Bernard Hallet, University of Washington, and Andrew G. Fountain, Portland State University.

We will perform a comprehensive study of land-based polar ice cliffs. Through field measurements and modeling, we will identify the physics underlying the formation of ice cliffs at the margin of Taylor Glacier in the McMurdo Dry Valleys.

Preliminary modeling suggests that horizontal velocity peaks one-third the distance up the cliff face and that the highest shear strain rates are at the base. We hypothesize that the displacement field of the glacier is more important than the local ablation pattern in maintaining ice cliffs and that the timing of calving is controlled by rapid temperature fluctuations that cause transient stress fields to develop in the thermal skin of the cliffs.

We will use strain gauges, tilt sensors, thermistors, and a global positioning system surface strain network to measure ice deformation and temperature at three sites near the cliff face. An ablation stake network will augment existing energy balance data, and a small seismic network will monitor local ice quakes associated with cracking and calving. Ultimately, the field data will be used to validate a model that will enable us to explore the sensitivity of ice cliff evolution to basal sliding rate, ice temperature, and angle of incident solar radiation. Finally, we will determine the slope, aspect, and height of ice cliffs using a model derived from a laser altimetry survey conducted by the National Aeronautics and Space Administration.

Our work will provide insight into calving and glacier terminus evolution and will shed light not only on other land- and water-based glacier termini on Earth, but also possibly on the Martian ice caps. Moreover, a better grasp of ice cliff processes will improve predictions of glaciers' response to climate change. A better understanding of moraine formation at polar ice cliffs will contribute to more precise interpretation of paleoglacier margins in the McMurdo Dry Valleys and their correlation with paleoclimatic events derived from the Taylor Dome ice core.

This research will have student involvement and will be incorporated into the curriculum of a wilderness science education program for high school girls, as well as several classroom science workshops for middle and high school girls in the Seattle area. (I–139–M; NSF/OPP 02–30338 and NSF/OPP 02–33823)

Using polarimetric radar methods to detect crystal orientation fabrics near the Ross/Amundsen Sea ice-flow divide and at the Siple Dome ice core site.

Charles F. Raymond and Kenichi Matsuoka, University of Washington.

The alignment of ice crystals, called crystal-orientation fabrics (fabrics), has an important effect on ice deformation. As ice deforms, anisotropic fabrics are produced; these in turn influence further deformation. Consequently, fabric variation measurement can reveal how the ice was deformed and indicate how it will deform in the future. Ice cores can determine a vertical fabric profile, but not horizontal variation. Examining variation over large areas requires remote sensing with ice-penetrating radar. We will therefore use ground-based radar measurements to investigate fabrics near the Ross/Amundsen Sea ice-flow divide, where a deep core will be drilled.

When fabric is not rotationally symmetrical around a vertical axis, vertically propagating radio waves are affected by bulk birefringence related to the fabric's axis. Polarimetric methods can detect the degree of horizontal anisotropy and the orientation of fabrics, even when they are nearly vertical. To understand secondary effects on radar-echo anisotropy, we will make radar measurements at Siple Dome and use fabric information from the ice core to study radio wave propagation.

We will do radar measurements at 10 sites for each of two 300-kilometer lines crossing the divide and at about 5 additional sites. We will use the latter to investigate a ridge-like high elevation that could be transient. In conjunction with polarimetric radar measurements at these 25 sites, we will take ice strain measurements with a global positioning system (GPS) and perform radar profiling to connect all sites. We will use the GPS data, together with depth variation of radar-detected isochrones, to derive modern strain rate configuration and to simulate fabrics for shallow depths (about 1,000 meters). Using the simulated fabrics as a reference, we will examine mismatches between simulated and measured fabric azimuths and strengths, and their horizontal variation, to infer divide migration in the past.

Our work will help evaluate the impact of the West Antarctic Ice Sheet on the rise in global sea level, provide further interpretation of the Siple Dome ice core, and support collaboration between the United States and Japan. Moreover, our measurements may lead to new designs for polarimetric radio-wave sensors for ice on Earth and Mars. (I–163–M; NSF/OPP 04–40847)

Gases in firn air and shallow ice at the proposed West Antarctic Ice

Sheet divide drilling site.

Todd Sowers, Pennsylvania State University; James White, University of Colorado–Boulder; Mark O. Battle, Bowdoin College; Eric Saltzman, University of California–Irvine; Edward Brook, Oregon State University; and Jeffrey Severinghaus, University of California–San Diego, Scripps Institution of Oceanography.

Records of changes in atmospheric composition are essential to understanding how the global biosphere influences, and is influenced by, global climate and environmental change. Moreover, changes in atmospheric composition over the past few centuries provide crucial information on how anthropogenic activities have altered the atmosphere. The best way to reconstruct these changes is from air naturally archived in the polar ice sheets.

We will focus on the composition of firn air and occluded air in shallow boreholes and ice cores from the West Antarctic Ice Sheet divide site, the location of a planned deep ice coring program. We have three primary objectives:

- to establish the nature of firn air movement and trapping at the site to interpret gas data from the deep core,
- to expand atmospheric trace gas species that can be measured in ice and replicate existing records of other species, and
- to intercalibrate all collaborating laboratories to ensure that compositional and isotopic data sets are comparable.

We will initiate the project with a shallow drilling program that will recover two 300-meter cores and firn air samples representing more than 700 years of atmospheric history. These will allow us to address a number of important questions related to atmospheric change over this period.

Having a team drawn from six U.S. laboratories has a number of advantages:

- We will be able to coordinate sample allocation to maximize the resolution and overlap of records of interrelated species.
- Sample registration will be exact, allowing us to compare all records directly.
- We will produce a coherent data set to ensure that we have the best possible understanding of gas records at the site.
- The collaborative structure of the project will encourage laboratories to share techniques, equipment, and ideas.

We will identify the impact of various industrial/agricultural activities and help distinguish them from natural variations. Moreover, we will include species for which there are no long records of anthropogenic impact. Trace records from ice cores provide fundamental data for quantifying anthropogenic perturbations of atmospheric composition, and our work will thus help predict future atmospheric loadings. (I–177–M; NSF/OPP 04–40759, NSF/OPP 04–40498, NSF/OPP 04–40509, NSF/OPP 04–40602, NSF/OPP 04–40615, and NSF/OPP 04–40701)

Investigating iceberg evolution during drift and breakup: A proxy for climate-related changes to antarctic ice shelves.

Theodore A. Scambos, University of Colorado–Boulder.

We will place automated instruments on one of two large icebergs off the east coast of the Antarctic Peninsula. Logistical support will be provided by the Instituto Antártico Argentino, and fieldwork will be conducted by a joint U.S.–Argentine team. Icebergs in this area characteristically drift north toward South Georgia Island and then disintegrate in the subpolar climate. Recent study of a series of large icebergs traversing this track has provided a background of remote-sensing-based information on breakup. The two targets are likely to be the last large icebergs in this position for several years.

To derive our observations, we will install an automated weather station, digital cameras, and an iridium data uplink. Getting the observation station set up as soon as possible will provide baseline measurements before the iceberg's rapid drift northward into warmer conditions.

In contrast to icebergs in other sectors of Antarctica, icebergs in the northwestern Weddell Sea drift northward along a relatively predictable path and reach climate and ocean conditions that lead to breakup within a few years. During this northward drift, rapid changes in surface temperature, surface melt, firn density, and basal melt rate occur. As surface melting increases, firn densification can lead to surface melt ponding, which induces rapid fracturing. It has recently been recognized that the end stages of iceberg breakup can imitate the rapid disintegration observed for the Larsen A and Larsen B Ice Shelves. However, basal melting may also play a significant role in shelf breakup. Resolving these two processes (surface ponding/fracturing versus basal melt) and observing iceberg drift and breakup *in situ* will answer fundamental questions about iceberg evolution and provide other highly relevant data.

Understanding ice-shelf disintegration is an important part of understanding the future climate-related evolution of the Antarctic Peninsula and the antarctic ice sheet in general. Shelf removal has a significant effect on glacier flow and mass balance. Glacier mass balance and the shelf stability of the antarctic ice sheet are critically important to changes in sea level. Our work will further the understanding of ice-sheet dynamics by investigating ice-shelf-related processes. (I–186–E; NSF/OPP 05–40915)

A mobile sensor web for polar ice-sheet measurements.

S. Prasad Gogineni, University of Kansas–Lawrence.

We will use synthetic aperture radar (SAR) carried on ground-level rovers to map polar ice sheets and bedrock. Ground-level radar of this type will provide a two-dimensional picture and more details than have previously been available from satellite imagery and airborne SAR. To produce the detail needed by glaciologists, the radar we will use will be able to operate in either monostatic or bistatic mode.

Much of this project will focus on developing the new technologies needed to carry out the project. These include an intelligent and collaborative radar system—one that can look at the data it is generating in real-time, determine whether these data indicate that an area should be studied in more detail, and then send that information to another radar system that is taking similar measurements only a few kilometers away.

PRISM (Polar Radar for Ice Sheet Measurements) engineers also need to design and build a semi-autonomous ground rover capable of

- withstanding the rigors of the polar environment,
- towing the radar safely and accurately,
- providing power for the radar systems and data analysis systems as well as the rover, and
- keeping track of the exact position of the radar units at all times.

In addition, PRISM scientists will be developing a wireless communication system that operates in harsh polar environments to allow the rover and radars to communicate with one another, as well as transmit near-real-time data back to other researchers and educators in distant locations. (I–188–M; NSF/OPP 01–22520)

Earth's largest icebergs.

Douglas R. MacAyeal, University of Chicago; Emile A. Okal, Northwestern University; and Charles R. Stearns, University of Wisconsin–Madison.

Icebergs released by the antarctic ice sheet represent the largest movements of fresh water within the natural environment. Several of these icebergs, B–15, C–19, and others calved since 2000, represent over 6,000 cubic kilometers of fresh water—an amount roughly equivalent to 100 years of the flow of the Nile River.

We will study the drift and breakup of the Earth's largest icebergs, which were recently released into the Ross Sea as a result of calving from the Ross Ice Shelf. We will attempt to ascertain the physics of iceberg motion within the dynamic context of ocean currents, winds, and sea ice, which determine the forces that drive iceberg motion, and the relationship between the iceberg and the geographically and topographically determined pinning points on which it can ground. In addition, we will study the processes by which icebergs influence the local environment (sea ice near Antarctica, access to penguin rookeries, air-sea heat exchange and upwelling at iceberg margins, nutrient fluxes), as well as the processes by which icebergs generate globally far-reaching ocean acoustic signals that are detected by seismic-sensing networks.

In addition, we will attempt to deploy automatic weather stations, seismometer arrays, and global positioning system tracking stations on several of the largest icebergs presently adrift, or about to be adrift, in the Ross Sea. Data generated and relayed via satellite to our home institutions will lead to theoretical analysis and computer simulation and will be archived on a Web site (http://amrc.ssec.wisc.edu/iceberg.html) that scientists and the general public can access.

A better understanding of the impact of iceberg drift on the environment, and particularly the impact on ocean stratification and mixing, is essential to understanding the abrupt global climate changes witnessed by proxy during the Ice Age and future greenhouse warming. More specifically, the study will generate a knowledge base useful for the better management of antarctic logistical resources that can occasionally be influenced by the adverse effects icebergs have on sea ice (the shipping lanes to McMurdo Station, for example). (I–190–M; NSF/OPP 02–29546, NSF/OPP 02–29492, and NSF/OPP 02–30028)

Dry Valleys Late Holocene climate variability.

Karl J. Kreutz and Paul A. Mayewski, University of Maine.

We will collect and develop high-resolution ice-core records from the Dry Valleys in southern Victoria Land and provide interpretations of interannual to decadal climate variability during the past 2,000 years (late Holocene). We will test hypotheses related to ocean/atmosphere teleconnections (e.g., El Niño Southern Oscillation, Antarctic Oscillation) that may be responsible for major late Holocene climate events such as the Little Ice Age in the Southern Hemisphere.

Conceptual and quantitative models of these processes in the Dry Valleys during the late Holocene are critical for understanding recent climate changes. We plan to collect intermediate-length ice cores (100 to 200 meters) at four sites along transects in Taylor and Wright Valleys and analyze each core at high resolution for stable isotopes, major ions, and trace elements. A suite of statistical techniques will be applied to the multivariate glaciochemical data set to identify chemical associations and to calibrate the time-series records with available instrument data.

Broader impacts of the project include

- contributions to several ongoing interdisciplinary antarctic research programs;
- graduate and undergraduate student involvement in field, laboratory, and data interpretation activities;
- use of project data and ideas in several University of Maine courses and outreach activities; and
- data dissemination through peer-reviewed publications, University of Maine and other paleoclimate data archive Web sites, and presentations at national and international meetings. (I–191–M; NSF/OPP 02–28052)

Tidal modulation of ice stream flow.

Sridhar Anandakrishnan, Richard B. Alley, and Donald Voigt, Pennsylvania State University; Robert Bindschadler, National Aeronautics and Space Administration, Goddard Space Flight Center; and Ian Joughlin, National Aeronautics and Space Administration, Jet Propulsion Laboratory.

We will investigate the newfound, startling sensitivity of major west antarctic ice streams to tidal oscillations to learn the extent and character of the effect and its ramifications. Ice streams D, C, and Whillans (B) all show strong but distinct tidal signals. The ice plain of Whillans is usually stopped outright, forward motion being limited to two brief periods a day, at high tide and on the falling tide. Motion propagates across the ice plain at seismic wave velocities. Near the mouth of D, tides cause a diurnal variation of about 50 percent in ice-stream speed that propagates upglacier more slowly than on Whillans, and seismic data show that C experiences even slower upglacier signal propagation. Tidal influences are observed more than 100 kilometers (km) upglacier on C and more than 40 km upglacier on D and may be responsible for fluctuations in basal water pressure reported 400 km upstream on Whillans.

During the first year, five coordinated seismic and global positioning system (GPS) instrument packages placed 100 km apart on each stream measured Whillans and ice stream D. These packages were deployed at sites selected by satellite imagery and operated autonomously for two lunar cycles to study the sensitivity of the streams to spring and neap tides. Also, we examined existing data sets for clues to the mechanisms involved and developed preliminary models.

During the second and third seasons, we will examine in greater detail the tidal behavior of Whillans and D. We will focus especially on at least one source area for Whillans, assuming that areas inferred from preliminary data remain active. Vertical motions have not yet been detected, but differential GPS will increase sensitivity. Seismic instrumentation will greatly increase temporal resolution and the ability to measure the propagation speed and any spatial heterogeneity.

Improved knowledge of ice-stream behavior will contribute to assessing the potential for rapid ice-sheet change affecting global sea levels. Results will be disseminated through scientific publications and talks at professional meetings, as well as contacts with the press, university classes, visits to schools and community groups, and other activities. (I–205–M; NSF/OPP 02–29629 and NSF/OPP 02–29659)

Monitoring an active rift system at the front of Amery Ice Shelf, East Antarctica.

Helen A. Fricker, University of California–San Diego, Scripps Institution of Oceanography.

Iceberg calving from the front of fringing ice shelves is the primary mechanism by which the antarctic ice sheets lose mass. A single large iceberg can remove a large fraction of the mass gained through years of accumulation and thus can be a significant component in the overall mass balance. This mass contributes to the freshwater flux of the Southern Ocean but does not lead to a change in sea level, since the ice was already floating. However, the presence of ice shelves can influence the discharge of inland ice via the ice streams that feed the shelves; in particular, a reduction in the extent of the ice shelf could increase the rate of discharge. Further, any changes in mass caused by calving could be an indicator of the regional effects of climate change and could modify freshwater mass production rates, which could have global consequences. Therefore, it is important not only to monitor the frequency of iceberg calving, but also to understand the mechanisms that govern it.

Icebergs calve when "rifts," crevasses that penetrate from the surface of the ice shelf to its base, propagate far enough that part of the ice shelf becomes detached. The mechanics are not well understood. We will therefore examine an active rift system—a combination of two longitudinal-to-flow rifts and two transverse-to-flow rifts—that formed at the tip of the western longitudinal rift on the Amery Ice Shelf about 7 years ago. We will use instruments to study the latter two rifts. Their propagation is not independent, and the longer of them is propagating at around 8 meters per day. When this rift meets the eastern longitudinal rift, an iceberg (roughly 30 kilometers by 30 kilometers) will calve. Once calving has occurred, we will examine its effects on the dynamics of the ice shelf and previously inactive rifts.

Calving sparks a great deal of media and public interest. We will report our results widely at conferences and in the scientific literature, and we will use the Visualization Center at the Scripps Institution of Oceanography to display our results. (I–277–E; NSF/OPP 03–37838)

Is Kamb Ice Stream Restarting? Glaciological investigations of the Bulge-Trunk transition on Kamb Ice Stream, West Antarctica.

Slawek M. Tulaczyk, University of California–Santa Cruz; Ian Joughlin, National Aeronautics and Space Administration, Jet Propulsion Laboratory; and Robert W. Jacobel, St. Olaf College.

The West Antarctic Ice Sheet contains enough ice to raise the global sea level by several meters, and concerns have been raised about its possible retreat or collapse. However, measurements have shown that the Ross Sea sector of this ice sheet is in a positive mass balance. This is surprising, because geologic and glaciologic data indicate that the ice sheet has been retreating for about 10,000 years. It is possible that the observed positive mass balance is a result of a short-term (decadal- or century-scale) oscillation in ice discharge, rather than an indication of a long-term shift in ice-sheet behavior. In particular, the Ross Sea sector of the West Antarctic Ice Sheet could return to neutral or negative mass balance if the Kamb Ice Stream (formerly called "Ice Stream C"), which has stopped, restarts and begins flowing at ice-stream–like velocities. Because the tributaries of this stream are still active, a massive ice bulge is building up where they run into the locked-up trunk of the Kamb Ice Stream, near the site of the former Upstream C Camp. On mountain glaciers, buildup of ice bulges is associated with a sharp increase in ice velocity in a relatively short time.

We will test to see whether the Kamb Ice Stream may already be in the process of restarting. If so, we will establish what the rate of reactivation is and what mechanisms are controlling it. If not, we will determine what physical controls are preventing surging and what the alternative scenarios for the evolution of the stream are. One scenario is an increase in ice diversion toward neighboring Whillans Ice Stream; this could prevent a complete stoppage of the stream, which has been slowing down for almost 25 years.

Our work will have two components:

- field observations of bed properties, geometry of internal radar reflectors, surface strain rates, and velocity/topography changes using ice-penetrating radar and differential global positioning systems, and
- numerical modeling of the evolution of the Kamb Ice Stream over the next 100 to 1,000 years.

This project is a collaboration of scientists from three different types of U.S. institutions—a liberal arts college (St. Olaf College), a public research university (University of California–Santa Cruz), and a National Aeronautics and Space Administration research laboratory (the Jet Propulsion Laboratory). We will make project results available to the public and educators through downloadable graphics and animations posted on the research Web site. Field data resulting from the project will be shared with other investigators through the Antarctic Glaciological Data Center. (I–345–M; NSF/OPP 03–38295 and NSF/OPP 03–37567)

High-resolution ice thickness and plane wave mapping of near-surface layers.

Pannirselvam Kanagaratnam, University of Kansas–Lawrence.

We will build and operate two compact, low-power radar systems along the planned traverse route of the U.S. International Trans Antarctic Scientific Expedition (ITASE). The first is a step-frequency depth sounder operating over a wide frequency range of 50 to 200 megahertz for measuring ice thickness, deep internal layers with high resolution, and basal conditions. The second is a wide-band radar operating over a frequency range of 12 to 18 gigahertz for detecting near-surface internal firn layers to a depth of approximately 7 meters with better than 10-centimeter resolution. These measurements will allow us to determine the spatially continuous snow accumulation rate along the route, which is of critical importance to the validation of satellite missions aimed at assessing the current mass balance of the polar ice sheets. The antenna systems are relatively compact and will be located on the sledge carrying the radar systems.

Our broad scientific focus will be to investigate processes relevant to glacier dynamics and ice-sheet mass balance. Our objectives are to

- obtain high-resolution characterization of internal layering in deep ice to provide a history of past glacier deformation,
- obtain ice-thickness measurements to assess the driving stress of the major ice streams traversed,
- use measurements to validate theoretical models,
- determine basal conditions, whether the bed is wet or frozen, and relate them to glacier flow fields, and
- characterize with high depth resolution the spatial variability of the snow accumulation rate along the traverse route to use in validating satellite mission data.

As part of this project, we will institute a strong outreach program involving K–12 education and a minority institution of higher learning (Haskell Indian Nations University, with which we have an existing collaboration). We also work closely with the Advanced Learning Technology Program at the University of Kansas to develop online, interactive, resource-based lessons for use by students at all grade levels, and we will develop new lessons related to this project. (I–346–M; NSF/OPP 02–30378)

A hyperinsulated instrumentation system to support year-round research in polar regions.

Anthony D. Hansen, Magee Scientific Company.

Year-round scientific research is seriously challenged by the ambient environment in polar regions. Extremely low temperatures, 6 months of darkness, high winds, and icing create substantial problems for the unattended operation of remote instrumentation stations for a year or more. Further, the risks and logistical costs of accessing a remote site even once a year can be considerable. Consequently, many research projects experience loss of data or the inability to acquire data over extended areas or periods of time, leading to temporal and geographical gaps in our knowledge. The ability to deploy an instrumentation package that could survive these conditions and gather data unattended for a year or more would help fill these gaps. This type of system could also support year-round research at locations that have well-developed summer camps but are unoccupied and inaccessible during the winter.

The system we will create synthesizes in an innovative manner many recent developments in other areas. When buried in a shallow snow pit at –60°C, the system will provide a warm, powered environment for an instrumentation payload with a passive design endurance of 10,000 hours. Insulation will be provided by a large-capacity metal Dewar flask like the ones used to preserve samples in liquid nitrogen. Thermal storage will be provided by the latent heat of fusion from 150 liters of specially formulated paraffin oil; electrical energy will come from lithium-ion batteries recently developed for military applications. Solar panels will provide multiyear operation by recharging the system electrically and thermally during the summer. An iridium modem will allow reporting on system status and transmit summaries of scientific data stored on solid-state memory.

The system is designed to be transported to remote field sites by helicopter or Twin-Otter aircraft and to be set up by no more than two people. We will develop and test the system during two year-long deployments at existing camps on the Antarctic Plateau. For testing purposes, we will equip it with an array of temperature probes like the ones used for glaciology research, but the system will be explicitly designed to accommodate almost any payload of data-gathering equipment. (I–414–S; NSF/OPP 03–37737)

Using a deep ice core from the West Antarctic Ice Sheet ice divide to investigate climate, ice dynamics, and biology.

Kendrick C. Taylor, Desert Research Institute.

The U.S. ice core research community will collect a deep (3,400 meters) ice core from the West Antarctic Ice Sheet ice-flow divide and integrate approximately 15 separate projects to develop, analyze, and interpret a series of interrelated climate, ice dynamics, and biological records in order to understand the interactions among global systems.

The most significant characteristic of this program will be the development of climate records with an absolute annual-layer-counted chronology for the past 40,000 years (approximately). Lower temporal resolution records will extend to roughly 100,000 years ago. These records will enable us to compare environmental conditions in the Northern and Southern Hemispheres and to study greenhouse gas concentrations in the paleoatmosphere in more detail. The themes of the program are as follows:

- **Climate forcing by greenhouse gases:** This research will provide a record of greenhouse gases with unprecedented time resolution during the rapid climate changes that occurred at the end of the last glacial period. The relative timing of changes in greenhouse gases and other environmental parameters will be determined.
- **The role of Antarctica in abrupt climate change:** We will develop high-time-resolution records that can be used to infer the interaction of the southern oceans and atmosphere with each other and with their northern counterparts. This will allow a precise investigation into the role of the Antarctic in abrupt climate changes.
- **The relationship among northern, tropical, and southern climates:** Small differences in the age of the ice versus the age of the gas in the ice will allow us to investigate the relative timing of Northern Hemisphere Dansgaard-Oeschger events and corresponding Southern Hemisphere climate excursions.
- **The stability of the West Antarctic Ice Sheet:** We will determine how the West Antarctic Ice Sheet responded to previous climate changes, thereby improving predictions of how the ice sheet and sea level will respond now and in the future.
- **Biological signals in deep ice cores:** This research will yield information about biogeochemical processes that control and are controlled by climate, as well as lead to new insights about life on Earth. (I–477–M; NSF/OPP 04–40817)