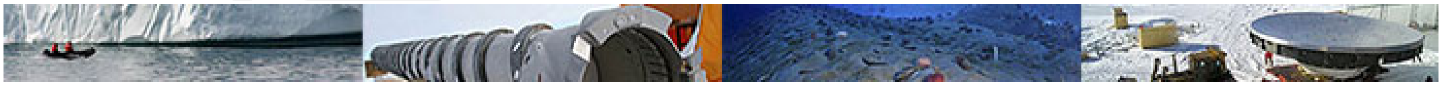

GLACIOLOGY

An ice core drill lies on a table revealing the scoop cutters and collet (the metal ring just inside the drill). Both features are new to ice core drilling and were tested at WAIS in 2006–2007. For more information on this research, read the January 7, 2007, issue of *The Antarctic Sun* at: http://antarcticsun.usap.gov. (*NSF/ USAP photo by Steven Profaizer*)

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 thick, that is larger than most countries, that rises over 2,000 meters 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 meters. 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. Efforts have begun 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.

Fluctuations of the West Antarctic Ice Sheet in relation to lake history in Taylor Valley, Antarctica, since the last glacial maximum.

Michael L. Prentice, Plymouth State University; Ronald S. Sletten, University of Washington; and Steven A. Arcone, U.S. Army Cold Regions Research & Engineering Laboratory.

This study examines the stratigraphy of near-surface sediments in Taylor Valley, Antarctica. Two contrasting hypotheses proposed for surface sediments in this region have important and different implications for how the West Antarctic Ice Sheet (WAIS) responded to the sea-level rise of the last deglaciation and Holocene environmental changes. One hypothesis holds that the sediments directly reflect more than 10,000 Carbon-14-years of WAIS shrinkage in the Ross Sea during and perhaps driven by deglacial sea-level rise. The other hypothesis holds that the Taylor sediments have little significance for WAIS change during the deglaciation because this sediment was deposited in a large glacial lake, the surface level of which was not necessarily influenced by the WAIS.

These two hypotheses reflect fundamentally different interpretations of the sediment record. To test these two hypotheses, we will use glacial geology, geochemistry, ground-penetrating radar (GPR) and portable sediment coring. We will also study the geomorphology and stratigraphy of valley-floor sediment sequences and collect GPR profiles and 30 meters of sediment core in two separate locations that feature excellent conditions to test both models of sediment formation. The coring is vital to calibrating interpretation of the GPR results.

Understanding the glacial and lake history in the McMurdo Sound region has important implications for the role that the WAIS will play in future sea-level and global climate change. Moreover, the history of Taylor Valley has significance for the ecosystem studies currently being conducted by the Antarctica Long Term Ecological Research Project. Two graduate and undergraduate students will participate in the studies, and research will also feature prominently in our teaching. (I-133; NSF/OPP 05-40073, NSF/OPP 05-41054, and NSF/OPP 05-39983)

A Science Management Office for the U.S. Component of the International Trans Antarctic Expedition (US ITASE SMO): A collaborative program of research from Taylor Dome to the South Pole.

Paul Andrew Mayewski, University of Maine.

Changes in the antarctic environment have the potential to exert significant controls on the global climate system. The International Trans Antarctic Scientific Expedition (ITASE) is a long-term, multinational, multidisciplinary field research program with the broad aim of understanding the recent 200-year environmental history of Antarctica. The U.S. component of the project is focused on ice core investigation and data collection from the Taylor Dome to the South Pole region in East Antarctica.

The sum of the traverses in this region will provide environmental data on temperature change and atmospheric circulation, ice accumulation rates, ice thickness, and internal radio-echo horizons for ice entering the Ross Sea embayment from the south and west through a series of large outlet glaciers, including Beardmore, Nimrod, Byrd, Mulock, and Shackleton glaciers.

This project and US ITASE activities thus far will provide important focus to determine the significance of environmental change in both West and East Antarctica. The overall program has integrated the disciplines of meteorology, remote sensing, geophysics, dynamical glaciology, ice core glaciology, and atmospheric chemistry.

Outreach activities planned include annual workshops to discuss logistics and science; maintenance and expansion of a public website; a virtual exhibit at the Museum of Science in Boston; and numerous lectures for K– students, the public, and professionals. (I-153; NSF/OPP 04-40679)

Grounding line forensics: The history of grounding line retreat in the Kamb Ice Stream outlet region.

Ginny Catania, University of Texas, Austin; and Christina Hulbe, Portland State University.

Understanding ice streams' unique geologic setting and associated dynamics is a long-standing objective of West Antarctic glaciology. Comprehending such processes has important influence over our ability to accurately predict mass balance changes in this region. Currently, Kamb Ice Stream is quiescent and Whillians Ice Stream is slowing in its downstream reaches. The Kamb shutdown appears to have begun at its downstream end but beyond that simple observation, it is not yet possible to draw meaningful comparisons between these two adjacent streams. We do not know whether current events on Whillians Ice Stream are similar to what transpired during the Kamb shut-down. Using radio-echo sounding and global positioning, this study will to bridge that gap by exploring past grounding line migration and the relationship between that process and ice stream shutdown.

This study will contribute to the hotly debated possibility that the West Antarctic ice streams might be grinding to an interglacial halt. We intend it to also have a broader impact of training the next generation of scientists and engineers and encouraging women to pursue scientific or engineering careers. (I-159; NSF/OPP 05-38120 and NSF/OPP 05-38015)

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.

At McMurdo Station, we will calibrate and test our ice-penetrating radar system. When these tests are complete, we will travel by LC-130 aircraft to the WAIS Divide field camp in West Antarctica. Using snowmobiles, we will take detailed radar measurements of the ice at 21 sites within a 60 kilometer by 150 kilometer area. We will also measure the strain grids that were installed at these sites last season. We will use the global positioning (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 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)

Spatial variability in firn properties from borehole optical stratigraphy at the inland WAIS core site.

Edwin D. Waddington, University of Washington.

Ice core records provide details about the climate, atmospheric chemistry, and accumu-lation that are essential to our understanding of the Earth's history. Yet ice cores measure the snow from only a tiny piece of the ice sheet present millennia ago and cannot account for spatial variations in accumulation or in snow-metamorphic processes that can change ice core chemistry. Thus ice core records may contain spurious apparent climatic variations brought about when spatial patterns of accumulation change over decades. It is particularly critical to understand variations of this type near the proposed inland West Antarctic Ice Sheet (WAIS) core, because this core site is thought to have good resolution of decadal climate variations.

Using Borehole Optical Stratigraphy (BOS), we will study the patterns of accumulation variation and microstructural properties near the WAIS core site in a 2.5-kilometer array of 20-meter boreholes. The BOS detects layers in firn that result from changes in firm microstructure, giving annual-scale records of how accumulation varied across the array over the past 40 to 50 years.

Statistical analysis of the layer data will let us predict the following:

- the expected level of variability in layer thickness due to interannual accumulation vari-ability
- the expected level of variability in layer thickness at decadal scales due to changing spatial patterns in accumulation and
- the expected level of variability in microstructure-driven metamorphism due to changing spatial patterns of microstructure.

With these statistics in hand, a scientist measuring climatic shifts found in the inland WAIS core will be able to determine the fraction by which signals they measure exceed the signal due to background accumulation variations.

The results of this field experience will be incorporated into an undergraduate seminar as well as a middle school science and math class. (I-171; NSF/OPP 05-38639)

Ice dynamics and surface glaciology along U.S. ITASE traverse routes in East Antarctica.

Gordon S. Hamilton, University of Maine.

Global sea level rise is accelerating and poses a substantial threat to society. Complete melting of the West Antarctic Ice Sheet would raise sea level by approximately 5 meters. The much larger East Antarctic Ice Sheet contains the sea level equivalent of 65 meters of water. Small ongoing changes in these ice sheets might account for some of the unexplained contribution to observed sea level rise, but there are too few direct measurements of the ice sheets to test this hypothesis. A better understanding of ice sheet changes is therefore necessary to assess their current contribution to global sea level and to model future contributions.

This work will be conducted along the traverse route from Taylor Dome to South Pole. Its objectives are to take advantage of the overland traverse logistics framework provided by the U.S. component of the International TransAntarctic Scientific Expedition (US ITASE) and to collaborate with other US ITASE investigators to:

- calculate rates of ice sheet thickness change (mass balance) on domes, along elevation contours, and along flow lines in East Antarctica using precise global positioning system methods;
- assess variability in snow accumulation rates using shallow ice cores and ground-penetrating radar profiling, and provide a way to deduce true past climate variation in accumulation rates from 200-year-long ice core records by measuring ice motion and upglacier gradients in accumulation rate; and
- study patterns and causes of the onset of streaming flow in the catchments of selected large outlet glaciers draining through the Transantarctic Mountains.

The results of this project will lead to an improved understanding of the Earth system and provide a basis for sound planning and policy decisions. (I-178; NSF/OPP 04-40792)

Center for Remote Sensing of Ice Sheets (CreSIS)

S. Prasad Gogineni, University of Kansas–Lawrence; Richard B. Alley, Pennsylvania State University; David Braaten, University of Kansas; Kenneth C. Jezek, Ohio State University; and Glenn E. Prescott, University of Kansas.

CreSIS will study the present and future contributions of the polar ice sheets to sea-level change. The problems of determining ice-sheet mass balance and creating predictive models of ice-sheet dynamics are scientifically and technologically complex, gauged by the intricacy of the ice sheet processes themselves. Ice accumulation and loss rates are affected by seasonal and interannual variations in snowfall, snow drift, radiation, temperature, and other weather and climate variables. Ice sheets contain ice streams, ice shelves, and glaciers whose dynamics and interaction with the ocean and atmosphere are imperfectly understood. A multidisciplinary team of scientists and engineers will address these issues through technical innovation, data collection, and data analysis over a span of years.

To determine the mass balance of polar ice sheets, data will be gathered from satellite and airborne platforms and in situ observations. To gather more comprehensive data over areas undergoing significant changes, technologically innovative sensors, platforms, and cyberinfrastructure are necessary. Furthermore, new analytical models and algorithms to interpret the data must be developed to predict long-term ice-sheet behavior from measurements such as ice flow rates, current ice thickness, and average seasonal temperatures for the ice sheet.

Sea-level rise is a serious issue that requires long-term, multidisciplinary collaborations that can be accomplished effectively through a science and technology center where university scientists and engineers work collaboratively with counterparts in industry. The Center for Polar Research and Remote Sensing will serve as a headquarters for current work and a forum for planning future work in an environment where scientists and engineers routinely meet to discuss problems and share solutions in the areas of ice-sheet dynamics and remote sensing, and where they have access to the newest technology and data. Investigations in this area will be more productive by ensuring that ideas, information, and data are readily exploited, technology is effectively developed in response to emerging needs, and contradictions in the data are quickly resolved. (I-189, NSF/OPP 04-24589)

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 (e.g., 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 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.

Furthermore, 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 World Wide 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)

Characterizing Lake Amundsen-Scott, South Pole: A ground geophysical program.

Sridhar Anandakrishnan, Pennsylvania State University.

This project is a study of Lake Amundsen-Scott using seismic and radar methods. Radar imaging and satellite altimetry work have been used to identify a catalog of over 100 subglacial lakes in Antarctica, which have the potential to harbor novel life forms. Lake Amundsen-Scott is typical of many of the subglacial lakes in its radar signature and subglacial morphology. However, temperature modeling and radar reflection strength modeling have cast doubts on the presence of free water at the base of the ice sheet near the South Pole. Reconciling these contradictory results is crucial to establishing the validity of the subglacial lake catalog.

This study will foster a cross-disciplinary pollination of ideas, techniques, and tools between the seismic and marine acoustics communities. In addition to traditional seismic techniques, new methods of data analysis that have been developed by acousticians will be applied to this problem as an independent measure of lake properties. (I-205; NSF/OPP 05-28097)

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)

Major chemical composition of the West Antarctic Ice Sheet Divide ice core.

Jihong Cole-Dai, South Dakota State University.

This project will contribute to the U.S. West Antarctica Ice Sheet Ice Divide ice core (WAIS Divide) project by determining the concentrations of the major ions present in all ice cores. To measure the chemical concentrations, we will use a melter-based, continuous-flow, multi-ion-chromatograph technique and newly developed instrumentation (CFA-IC). The fast analysis speed of the CFA-IC system, at approximately 10 meters per day, will permit the high-resolution analysis of the entire core (about 3,300 meters) to be completed within one year of the completion of the deep core drilling.

Annual layer counting using the CFA-IC and other high-resolution measurements will contribute significantly to the project's goal of producing precisely dated climate records for the past 40,000 years. In addition, longer (more than 100,000 years) records of ice core chemistry will be produced, as well as the longest volcanic record from antarctic ice cores. The volcanism-climate connection will also be studied.

The complete continuous, high-resolution chronological records of snow chemistry will be available to the research community to investigate the dynamic history of atmospheric chemistry and its relationship with climate variations, the biogeochemical cycles of important elements, and anthropogenic impact on atmospheric chemical composition. (I-355; NSF/OPP 05-38553)

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

Kendrick C. Taylor, University of Nevada 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.

This season, the project has two phases. First, one field team member will fly aboard an LC-130 airplane to the WAIS Divide field camp and will work with an Ice Core Drilling Services team to drill and extract a 130-meter ice core as close as possible to the main borehole location. Afterward, the crew will drill and extract a 100-meter core from the main borehole. The ice cores will be shipped to the University of Nevada Desert Research Institute for analysis. Second, one field team member from the National Ice Core Laboratory (NICL) will travel later in the season to the WAIS Divide field camp to conduct a site review of the WAIS Divide facility, particularly the core storage and processing areas within the arch. (I-477-M; NSF/OPP 04-40817)