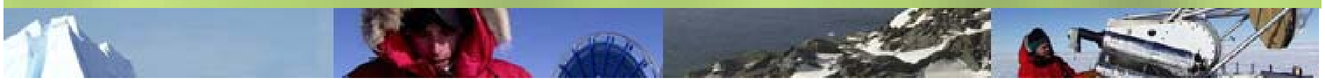

GLACIOLOGY

Icebergs near the Antarctic Peninsula. (*NSF/USAP photo by Jeffrey Kietzmann, Raytheon Polar Service Corp.*)

On this page:

Overview

A science team loads equipment on to a ski-equipped C-130 air transport (LC-130). USAP's LC-130 airplanes, flown by the Air National Guard of Schenectady, New York, support remote field research throughout Antarctica and provide essential support to Amundsen-Scott South Pole Station. (*NSF/USAP photo.*)

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;
- investigating the physics of fast glacier flow with emphasis on processes at glacier beds;
- investigating ice-shelf stability; and
- identifying and quantifying the relationship between ice dynamics and climate change.

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Mechanics of dry-land calving of ice cliffs.

Bernard Hallet and Erin Pettit, 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 a combination of strain gauges, tilt sensors, thermistors, and a global positioning system surface strain network to measure ice deformation and temperature near the cliff face at three sites. 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)

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Airborne geophysical survey of the Amundsen Sea embayment, Antarctica (AGASEA).

John W. Holt, David L. Morse, and Donald D. Blankenship, Institute for Geophysics, University of Texas-Austin.

The West Antarctic Ice Sheet, the only marine ice sheet remaining from the last glacial period, has been the subject of intensive study since it was recognized to be a potential source for a rise in sea level of up to 5 meters, possibly on a short time scale. The West Antarctic Ice Sheet has three primary drainages; the Ross Sea and Weddell Sea embayments have been the primary focus of attention, while the Amundsen Sea embayment has been studied comparatively little, primarily because it is so remote. However, satellite remote-sensing studies, combined with limited data on ice thickness, indicate that the Amundsen Sea embayment discharges the largest ice flux in West Antarctica; furthermore, of all the major antarctic drainage basins, it is the only one to exhibit significant change in elevation over the period of recent satellite observations.

At present, we lack the knowledge of the ice thickness and subglacial boundary conditions needed to understand the evolution of this embayment or its sensitivity to climatic change. We therefore intend to perform comprehensive aerogeophysical surveys of the two major drainage basins within the Amundsen Sea embayment: the Thwaites Glacier Basin and the Pine Island Basin. We will analyze the data we gather and generate maps of laser surface elevation, radar surface elevation and ice thickness, ice accumulation rate from shallow radar layer interpolation, internal layer preservation depth, crevasse classification, gravity and magnetic anomalies, detailed basal morphology and roughness statistics, and coherent radar echo strength and scattering characterization.

Our surveys and analyses will be achieved through collaboration with the British Antarctic Survey and will include graduate students in all phases of the project. Undergraduates and high school apprentices will also be fully integrated into data analysis. Given the substantial public and scientific interest that recent reports of change in West Antarctica have generated, we expect fundamental research in the Amundsen Sea embayment to have a widespread impact. (I–141–M; NSF/OPP 02–30197)

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Late Quaternary history of Reedy Glacier.

John O. Stone and Howard B. Conway, University of Washington, and Brenda L. Hall, University of Maine.

The stability of the marine West Antarctic Ice Sheet remains an important, unresolved issue for predicting future changes in sea level. Studies indicate that the mass balance of the ice sheet today could be negative or positive. The apparent difference could stem in part from short-term fluctuations in flow. By comparison, geologic observations provide evidence of behavior over much longer time scales. Recent work suggests that deglaciation of both the Ross embayment and coastal Marie Byrd Land continued into the late Holocene (about the past 2,000 years) and leaves open the possibility of ongoing deglaciation and grounding-line retreat. However, previous work in the Ross embayment was based on data from just three locations that are all far north of the present grounding line. Additional data from farther south are needed to determine whether the recession has ended or whether the rate and pattern of deglaciation inferred from our previous study still apply.

We will therefore reconstruct the evolution of Reedy Glacier, in the southern Transantarctic Mountains, since the last glacial maximum. Because the glacier emerges from the mountains above the grounding line, its surface slope and elevation should record changes in the thickness of grounded ice in the Ross Sea up to the present. The deglaciation chronology of Reedy Glacier can thus indicate whether the Holocene retreat of the West Antarctic Ice Sheet ended thousands of years ago or is still continuing.

We will map, date, and correlate moraines at sites along the length of the glacier over two field seasons and make radar and global positioning system measurements to supplement existing ice thickness and velocity data. We will also construct a model of glacier dynamics and use it to relate geologic measurements to the grounding-line position downstream. Ultimately, we will integrate the mapping, dating, and ice-modeling components of the study into a reconstruction that defines changes in ice thickness in the southern Ross Sea since the last glacial maximum and relates these changes to the history of grounding-line retreat.

Our work directly addresses the key goals of the West Antarctic Ice Sheet Initiative, which are to understand the dynamics, recent history, and possible future behavior of the West Antarctic Ice Sheet. (I–175–M; NSF/OPP 02–29314 and NSF/OPP 02–29034)

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West Antarctic Ice Sheet stability: The glacial

geologic record from the Ohio Range of the Horlick Mountains in the Bottleneck.

Harold W. Borns, University of Maine, and Sujoy Mukhopadhyay, Harvard University.

We will study the West Antarctic Ice Sheet at the Ohio Range near the head of Mercer Ice Stream; this is located in the Bottleneck, a unique, relatively narrow passage in the Transantarctic Mountains connecting the West and East Antarctic Ice Sheets.

We will map glacial deposits and erosion features and combine these with cosmogenic surface-exposure dating on Ohio Range nunataks to determine the chronology of past ice sheet levels and glacier fluctuations. Exposure ages of fresh glacial erratics, up to 60 meters above the present level, will be used to constrain the timing of the last high stand and draw-down of the ice sheet in this sector, while exposure ages of debris bands on the surface will constrain the duration of continuous ice cover near the present elevation. A complementary local proxy climate record will also be obtained from a chronology of local glacier moraines.

These glaciers are sensitive to changes in snow accumulation and predominant wind direction. When compared with the record of the fluctuations of the adjacent ice sheet, the timing of alpine glacier advance will yield information that can be used to test climate reconstructions based on antarctic ice core records. Our data will contribute to the development of time-dependent, nonequilibrium models since the last glacial maximum 20,000 years ago. Moreover, such data are critical to testing and calibrating the models necessary to predict the behavior of the ice sheet in response to climate changes.

The behavior of this ice sheet is significant because of its link to sea levels. Melting would raise sea levels, negatively affecting the large portion of the population living near the coasts. Because the West Antarctic Ice Sheet is largely grounded below sea level, it is subject to gravitational collapse that could be ongoing or triggered by global warming.

In addition, the glacial record in the Bottleneck will reflect the history of the interaction of the West Antarctic and East Antarctic Ice Sheets, which could be used to test hypotheses on the collapse of the former during the Pleistocene (10,000 to 1.8 million years ago). (I–187–M; NSF/OPP 03–38189)

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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)

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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)

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Tidal modulation of ice stream flow.

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

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)

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

Helen A. Fricker and Jean-Bernard Minster, Scripps Institution of Oceanography, University of California–San Diego.

Antarctic ice sheets lose mass primarily by iceberg calving from the front of the fringing ice shelves. This mass contributes to the freshwater flux of the Southern Ocean, but does not cause a change in sea level, since the ice was already floating. However, ice shelves can influence the discharge of inland ice via the streams that feed them; in particular, a reduction in ice shelf could increase the discharge rate. Furthermore, any changes in the mass lost by calving could be an indicator of regional effects of climate change and could modify freshwater mass production rates, which might have global consequences. Therefore, it is important not only to monitor the frequency of calving, but also to understand the mechanisms behind it.

Icebergs calve when rifts—crevasses that penetrate from the ice shelf surface to its base—propagate far enough that a part of the shelf becomes detached. Because this process is not well understood, we will combine *in situ* and remote-sensing data with numerical modeling to study rift growth on the Amery Ice Shelf, an active rift system combining two longitudinal-to-flow rifts that originated at the ice shelf front in the suture zones between merging flowbands and two transverse-to-flow rifts that formed at the tip of the western longitudinal rift about 7 years ago. The propagation of the two transverse rifts is not independent, and the longest of them is growing at around 8 meters a day.

When this rift meets the eastern longitudinal rift, which we expect to occur in mid-2006, a huge iceberg will calve. Once it does, we will examine the effects on the dynamics of the ice shelf and on previously inactive rifts.

Iceberg calving has a history of sparking a great deal of media and public interest, especially since the recent large calving from the Ross and Ronne Ice Shelves and the break-up of the Larsen Ice Shelf. We intend to report our results widely at conferences and in the scientific literature, and we will display our results to local faculty and researchers, undergraduate and graduate students, and school children and their teachers. (I–277–E; NSF/OPP 03–37838)

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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, Jet Propulsion Laboratory, National Aeronautics and Space Administration; 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 the past 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)

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Investigating atmospheric chemistry through oxygen and sulfur isotopes in volcanic sulfate from South Pole ice cores.

Jihong Cole-Dai, South Dakota State University, and Mark H. Thiemens, University of California–San Diego.

It is well known that large, sulfur-rich volcanic eruptions can influence the radiative budget of the atmosphere and the global climate. Less understood is the direct impact on atmospheric chemical processes, especially the impact of massive eruptions that alter the composition of the entire atmosphere.

We will use mass-independent isotope chemistry, which has been shown to be an effective tool in understanding a variety of gas-phase atmospheric processes. Preliminary results of oxygen and sulfur isotope measurements in samples from several eruptions indicate that the isotopic composition of volcanic sulfate in antarctic snow and ice contains valuable information on atmospheric chemical and dynamic processes that have not been previously investigated. For example, mass-independently fractionated sulfur isotopes demonstrate that atmospheric photolysis (chemical decomposition induced by light) of sulfur compounds occurs at longer ultraviolet (UV) wavelengths than those in the Archean atmosphere (Precambrian era), possibly reflecting atmospheric ozone or oxygen concentration (or both). This suggests that the isotopic composition of atmospheric sulfate may be used to track the evolution (oxygenation) of the atmosphere and the origin of life on Earth.

Using tested methodology, we will:

- locate and isolate known volcanic events in six shallow South Pole ice cores,
- extract volcanic sulfate from at least five major eruptions (Pinatubo, Tambora, Unknown 1809, Kuwae, Unknown 1259) from these samples,
- use established isotope analytical procedures to determine oxygen and sulfur

isotopes, and

- interpret the data we gather.

These steps will help us address a number of important questions:

- What impact do massive volcanic eruptions have on the oxidative capacity of the atmosphere?
- What oxidants and mechanisms are involved in the oxidation or conversion of volcanic sulfur dioxide to sulfate in the stratosphere?
- What isotopic criteria could be used to differentiate ice core signals of stratospheric eruptions from those of tropospheric eruptions?
- What is the role of UV radiation in sulfur dioxide conversion in the atmosphere?
- Does the photo-oxidation mechanism of volcanic sulfur dioxide depend on and reflect ozone/oxygen levels in past atmospheres? (I–355–S; NSF/OPP 03–37933)

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