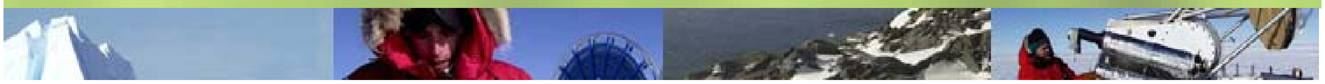

U.S. Antarctic Program, 2004–2005

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OCEAN AND CLIMATE SYSTEMS

The U.S. icebreaking research ship Laurence M. Gould is used by U.S. Antarctic Program scientists to support research including oceanography and marine biology. It is also used to transport personnel from Punta Arenas, Chile, to Palmer Station. (*NSF/USAP photo by Jeffrey Kietzmann, Raytheon Polar Service Corp.*)

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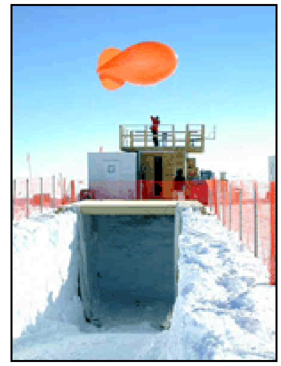
Overview

Though it borders the world's major oceans, the Southern Ocean system is like no other in the world, with 4 times more water than the Gulf Stream and 400 times more than the Mississippi River. It is a sea where average temperatures do not reach 2 °C in the summer, where even the water itself is so distinctive that it can be identified thousands of miles away in currents that originated here. These Antarctic Bottom Waters provide the major source of cooling for the world's oceans. In fact, if the Earth is a heat engine, Antarctica should be viewed as its circulatory cooling component.

The climate in Antarctica is also unique, linked as it is to the extreme conditions of the land, ice, and sea below the troposphere (the inner region of the atmosphere, up to between 11 and 16 kilometers). This ocean/atmosphere environment defines and constrains the marine biosphere and in turn has a dynamic relationship with the global ocean and with weather all over the planet. Few major energy exchanges on Earth can be calculated without factoring in these essential antarctic phenomena. As such, they are both an indicator and a component of climate change.



A researcher attaches an instrument to a tethered balloon to measure the characteristics of water vapor in the lower two kilometers of the atmosphere at Amundsen–Scott South Pole Station, Antarctica. (*NSF/USAP photo by Jeff Ingles, Raytheon Polar Services Corp.*)

The Ocean and Climate System Program sponsors research that will improve understanding of the high-latitude ocean environment, including the global exchange of heat, salt, water, and trace elements; there is also an emphasis on sea-ice dynamics, as well as the dynamic behavior and atmospheric chemistry of the troposphere. Major program elements include the following:

- **Physical oceanography:** The dynamics and kinematics of the polar oceans; the interaction of such forces as wind, solar radiation, and heat exchange; water-mass production and modification processes; ocean dynamics at the pack-ice edge; and the effect of polynyas on ventilation.
- **Chemical oceanography:** The chemical composition of sea water and its global differentiation; reactions among chemical elements and compounds in the ocean; fluxes of material, within ocean basins and at their boundaries; and the use of chemical tracers to map oceanic processes across a range of temporal and spatial scales.
- **Sea-ice dynamics:** The material characteristics of sea ice, from the level of the individual crystal to the large-scale patterns of freezing, deformation, and melting.
- **Meteorology:** Atmospheric circulation systems and dynamics, including the energy budget; atmospheric chemistry; transport of atmospheric contaminants to the antarctic; and the role of large and mesoscale systems in the global exchange of heat, momentum, and trace constituents.

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Antarctic Troposphere Chemistry Investigation (ANTCI).

Fred Eisele, Douglas Davis, Yuhang Wang, David Tan, and L. Greg Huey, Georgia Institute of Technology; Richard Arimoto, New Mexico State University; Detlev Helmig, University of Colorado-Boulder; Manuel Hutterli and Roger Bales, University of Arizona; Jack Dibb, University of New Hampshire; Donald Blake, University of California-Irvine; and Richard Shetter and Roy Mauldin, National Center for Atmospheric Research.

We will study sulfur chemistry in the antarctic atmosphere to enhance our understanding of the processes that control tropospheric levels of reactive hydrogen radicals, reactive nitrogen, sulfur, and other trace species for the further purpose of improving the climatic interpretation of sulfur-based signals in antarctic ice-core records. Specifically, we will be making observations of reactive hydrogen radicals, sulfuric acid and its sulfur precursors, and the flux of ultraviolet radiation. The results we derive will lead to a far more comprehensive understanding of antarctic atmospheric chemistry, as well as the factors that influence the levels and distributions of climate proxy species in antarctic ice cores.

Our major science objectives include:

- evaluating the processes that control spring and summer levels of reactive radicals in the atmospheric surface layer at the South Pole,
- assessing how representative previously obtained South Pole and coastal

measurements are in the larger context of polar plateau processes, and

- investigating the relative importance of the oxidative processes involved in the coast-to-plateau transport of reduced sulfur and determining the principal chemical transition regions.

Secondary objectives include investigating snow/firn chemical species that undergo extensive exchange with the atmosphere and assessing the different chemical forms of the trace elements and their relationships to levels of ozone and other oxidants.

Atmospheric sulfur chemistry is important in climate change because both naturally and anthropogenically emitted sulfur compounds form minute particles in the atmosphere (so-called aerosols) that reflect solar radiation, produce atmospheric haze and acid rain, and affect ozone depletion. These sulfate particles may also act as condensation nuclei for water vapor and enhance global cloudiness. The primary natural sources of sulfur are volcanic emissions and dimethylsulfide production by oceanic phytoplankton.

On the millennial time scale, the variability and background level of atmospheric aerosols can be reconstructed from ice cores. It is, however, necessary to understand how the physical and chemical environment of the process affects the relative concentrations of the oxidation products that become buried in the ice. (O–176–M/S; NSF/OPP 02–30246, NSF/OPP 02–29633, NSF/OPP 02–29605, NSF/OPP 02–30046, NSF/OPP 02–30051, NSF/OPP 02–30117, and NSF/OPP 02–30178)

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Solar radiation processes on the east antarctic plateau.

Stephen G. Warren and Thomas C. Grenfell, University of Washington.

This project is an experimental study of solar radiation processes near the surface at Concordia Base at Dome C, the French-Italian station in East Antarctica. It will be carried out in cooperation with the Laboratoire de Glaciologie et Geophysique de l'Environnment in Grenoble, France. The emphasis is on the reflection of sunlight by snow and the transmission of sunlight through clouds. The observations we gather will be relevant to climate, remote sensing, and the physics of ice and snow.

Observations of the angular pattern of solar radiation reflected from the snow surface will allow us to validate information from satellite-derived radiances. Using radiative transfer modeling through the atmosphere, we will reconcile measured surface-reflection functions with the empirical functions obtained from the Advanced Very-High-Resoution Radiometer on the polar orbiting satellites of the National Oceanic and Atmospheric Administration. (O–201–M; NSF/OPP 00–03826)

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Antarctic Meteorological Research Center (2002–2005).

Charles R. Stearns, University of Wisconsin-Madison.

The Antarctic Meteorological Research Center (AMRC) was created in 1992 to improve access to meteorological data from the Antarctic. The AMRC's mission is to conduct research in observational meteorology and the stewardship of meteorological data, along with providing data and expert assistance to the antarctic community to support research and operations. The AMRC fulfills its mission by

- continuing to maintain and expand, as appropriate, the long-term record of all meteorological data on Antarctica and the adjacent Southern Ocean and make these data available to the scientific community for multidisciplinary use (special attention will be given to obtaining data not normally or readily available by other means);

- continuing to generate satellite products, specifically, but not limited to, antarctic composite imagery, and expand and improve on them as much as possible;

- conducting research in observational meteorology, especially with regard to climatological analyses and case studies; and

- continuing to conduct and expand, as appropriate, educational and public outreach activities associated with antarctic meteorology and related fields.

Using available meteorological interactive processing software and other standard computing tools, we will collect data from all available sources for processing, archiving, and distribution. The mission of the AMRC not only includes the opportunity to advance the knowledge of antarctic meteorology, but with the free availability of its data holdings, the AMRC gives others the opportunity to advance the frontiers of all antarctic science.

Continuing educational outreach activities on meteorology and the Antarctic, an important component of this work, have the potential to raise the science literacy of the general public, as well as the level of K–12 science education. (O–202–M/P/S; NSF/OPP 01–26262)

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Measurements of variations in atmospheric oxygen/nitrogen and argon/nitrogen ratios in carbon dioxide concentration in relation to the carbon cycle and climate.

Ralph F. Keeling, Scripps Institution of Oceanography, University of California–San Diego.

Oxygen, the most abundant element on Earth, comprises about a fifth of the atmosphere. But much of the Earth's oxygen resides in other chemical species (in water, rocks, and minerals) and, of course, in the flora and fauna that recycle it (both directly and as carbon dioxide) through photosynthesis and respiration. Thus, scientists are interested in measuring the concentration of molecular oxygen and carbon dioxide in air samples; our project includes a subset of sample collections being made at a series of baseline sites around the world.

These data should help improve estimates of the processes whereby oxygen is cycled throughout the global ecosystem, specifically through photosynthesis and atmospheric mixing rates, and also improve predictions of the net exchange rates of carbon dioxide with biota, on land and in the oceans. An important part of the measurement program entails developing absolute standards for oxygen-in-air to ensure stable long-term calibration. In addition, we are conducting surveys of the oxidative oxygen/carbon ratios of both terrestrial- and marine-based organic carbon, hoping to improve the quantitative basis for linking the geochemical cycles of oxygen and carbon dioxide.

These results should help enhance our understanding of the processes that regulate the buildup of carbon dioxide in the atmosphere and of the change processes, especially climate change, that regulate ecological functions on land and sea. (O–204–P; NSF/ATM 00–00923)

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Processes driving spatial and temporal variability of surface pCO_2 in the Drake Passage.

Taro Takahashi, Columbia University, and Jorge L Sarmiento, Princeton University.

The Southern Ocean is an important component of the global carbon budget. Low surface temperatures with consequently low vertical stability, ice formation, and high winds produce a very active environment for the exchange of gaseous carbon dioxide between the atmospheric and oceanic reservoirs. The Drake Passage is the narrowest point through which the Antarctic Circumpolar Current and its associated fronts must pass and is the most efficient location for the measurement of latitudinal gradients of gas exchange.

We will expand the measurement suite and lengthen the time series of dissolved carbon dioxide gas (pCO_2) along with occasional total carbon dioxide (TCO_2) in surface waters on transects of Drake Passage. This expanded suite will include the addition of an oxygen probe to the pCO_2 system, as well as the addition of nutrient and carbon-13 measurements to the discrete TCO_2 samples now collected on regularly scheduled transects on the U.S. Antarctic Program research ship *Laurence M. Gould*.

Two short cruises (4 to 5 days) will also be dedicated to providing a baseline for surface measurements with water column profiles of TCO_2, pCO_2, nutrients, oxygen, and carbon-13. The continuation and expansion of the Drake Passage time series will contribute to achieving two main goals:

- quantifying the spatial and temporal variability and trends of surface pCO_2, TCO_2, oxygen, nutrients, and carbon-13 in four major regimes in the Drake Passage between March 2002 and June 2007 and

- understanding the dominant processes that contribute to variability in surface pCO_2 and the resulting air-sea flux of CO_2 in the Drake Passage.

We will test the hypothesis that the mean annual surface water pCO_2 in the Drake Passage is determined by the degree of winter mixing. This has special significance in light of two scenarios that may affect the ventilation of deep water in the Southern Ocean:

- a decrease in water-column stratification with observations of higher zonal winds or

- an increase in stratification due to higher precipitation and global warming.

If winter mixing determines the mean annual pCO_2 in the Drake Passage, the increase in atmospheric pCO_2 will have little effect on sea surface pCO_2. Because the Southern Ocean is a sink for anthropogenic carbon, further studies to understand the processes that determine this uptake and its response to climate change are needed. Our time series studies represent the highest concentration of pCO_2 measurements ever made both temporally and spatially in the Southern Ocean and so are an essential first step. Moreover, our study will make high-quality surface pCO_2 and discrete measurements of nutrients and carbon-13 available to help validate biogeochemical modeling efforts, as well as provide baseline data for studies throughout the Southern Ocean. (O–214–L/N; NSF/OPP 03–38248 and NSF/OPP 03–38155)

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AnSlope—Cross-slope exchanges at the Antarctic Slope Front.

Arnold L. Gordon, Stanley S. Jacobs, Martin Visbeck, William M. Smethie, and Peter Schlosser, Lamont-Doherty Earth Observatory, Columbia University; Alejandro H. Orsi and Thomas Whitworth, Texas A&M University; R. Dale Pillsbury, Oregon State University; and Laurence Padman, Earth and Space Research.

The importance of cold water masses originating in the Antarctic to the global ocean circulation and climate is now understood, but the processes by which these water masses enter the deep ocean circulation are not. Our program will address this issue.

Our primary goal is to identify the principal physical processes that govern the transfer of shelf-modified dense water into intermediate and deep layers of the adjacent deep ocean. At the same time, we seek to understand the compensatory poleward flow of waters from the oceanic regime. The upper continental slope is the critical gateway for the exchange of shelf and deep ocean waters. Here the topography, velocity, and density fields associated with the nearly ubiquitous Antarctic Slope Front (ASF) must strongly influence the advective and turbulent transfer of water properties between the shelf and oceanic regimes.

We will join the research icebreaker *Nathaniel B. Palmer* for three transects over a 12- to 14-month period beginning in austral summer 2003 and use an integrated observational and modeling program to achieve four objectives:

- determine the mean structure and principal scales of variability of the ASF and estimate its role on cross-slope exchanges and mixing of adjacent water masses;

- determine the influence of slope topography on frontal location and outflow of dense shelf water;

- establish the role of frontal instabilities, benthic boundary layer transports, tides, and other oscillatory processes on cross-slope advection and fluxes; and

- assess the effect of diapycnal (shear-driven and double-diffusive) mixing, lateral mixing, and nonlinearities on the rate of descent and fate of outflowing, near-freezing shelf water.

Our measurements will focus on the outer continental shelf and upper slope of the northwestern Ross Sea. We will also take benthic float measurements and develop the techniques for parameterizing cross-front exchanges in regional and global models. Ongoing studies by Italian and German researchers will complement our work and provide a test-bed for our parameterizations of cross-front exchange. Synergistic projects will sample for geochemical tracers, nutrients, and oxygen isotopes; make casts to measure ocean microstructure; investigate surface-water properties during transects to and from New Zealand; and survey the near-surface environment, including elements of its ecosystem and sea ice field.

AnSlope cruise III (NBP04-08), the final cruise of this project, is the "late winter" component. We plan to occupy as many CTD/LADCP (Conductivity Temperature Depth/Lowered Acoustic Doppler Current Profiler) stations as possible across and along the ASF in the Ross Sea. These include a transect near previously deployed bottom-moored arrays of current, temperature, conductivity, and pressure sensors. Synergistic projects will sample for geochemical tracers, nutrients, and oxygen isotopes; make casts to measure ocean microstructure; investigate surface water properties during transects to and from New Zealand; and survey the near-surface environment, including elements of its ecosystem and sea ice field. (O–215–N; NSF/OPP 01–25172, NSF/OPP 01–25521, NSF/OPP 01–25523, NSF/OPP 01–25084, NSF/OPP 01–25431, and NSF/OPP 01–25602)

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In situ measurements of halogen oxides in the troposphere.

Linnea M. Avallone, University of Colorado–Boulder.

The phenomenon of sudden and complete boundary-layer ozone loss has been observed at many northern high-latitude sites and more recently in Antarctica. Simultaneous observations of other species indicated that ozone loss was often tied to increases in pollutants, suggesting a relationship to the transport of polluted air from the northern continents into the more pristine arctic environment. However, subsequent studies showed that the ozone loss phenomena in the Arctic are tightly linked to catalytic gas-phase halogen chemistry similar to that responsible for Antarctica's ozone hole. Although the exact mechanism for the sudden boundary-layer ozone losses remains uncertain, it is clearly linked to active bromine. Modeling studies suggest that the ultimate source of bromine is sea salt, which undergoes transformation when it is airborne in particulate form or dissolved in surface snow.

Snow is both an important source and sink for reactive bromine. Widespread bromine activation in coastal regions seems to coincide with the average edge of the annual sea ice. Previous measurements of halogen oxides, ozone, and nitrogen oxides have revealed that McMurdo Station does indeed see some significant ozone loss events, many directly related to local pollution (perhaps power plant emissions). There were also a number of low ozone periods during and immediately after large southern storms. These bear further study.

We will attempt to answer three questions:

- How often is surface ozone at McMurdo Station affected by local pollution?

- What reactive bromine compounds are present and can we identify their source (s)?

- How much is the snow surface directly affecting ozone?

The relatively clean antarctic environment, far from most sources of anthropogenic sources of nitrogen oxides and hydrocarbons, will allow us to better constrain the natural role of snow- and ice-covered surfaces on the boundary-layer ozone budget. As sea-ice coverage changes in response to a changing climate, the frequency and duration of boundary-layer ozone loss related to the availability of bromine gases derived from sea

We will investigate the breakup of antarctic sea ice in McMurdo Sound in light of recent findings indicating that the fracture strength of first-year ice is strongly dependent on size, that the deformation and fracture on the scale of tens of meters is influenced by microstructural variation (or anisotropy), and that the characteristic flaws of sea ice (such as brine drainage features) give rise to length scales relevant to transitions in fracture behavior.

We will investigate the following topics:

- coupled deformation-diffusion influences on the fracture of sea ice (due to fluid transport within the ice matrix),
- the influence of loading rate versus specimen size on fracture behavior,
- fractal descriptions of the failure surfaces, and
- a new cyclic loading geometry that should benefit the constitutive measurements.

The direct tensile cyclic loading geometry we will use will allow constitutive testing to be conducted independent of fracture testing and at significantly higher stress levels than were previously attained. We will make combined acoustic emission (AE), pore fluid pressure, crack-opening-displacement, and fracture surface roughness measurements for each test, thereby enabling quantitative comparison between deformation and AE-deduced fracture energy and the fractal dimension. The ability of sea water and brine to be transported within the ice matrix will be examined both theoretically and experimentally to formulate a suitable poroelastic fracture mechanics model.

Our findings will give important insight into the underlying mechanisms of ice breakup and will significantly improve the reliability of models of this process. In addition, our work will improve the understanding of and ability to model the deformation and fracture of antarctic sea ice at scales applicable to the breakup of ice sheets.

We will involve two graduate students, and every effort will be made to recruit them from underrepresented groups. These students will participate in Clarkson University's K–12 Project-Based Learning Partnership Program. CDs will be produced, and a Web page will be maintained to broaden the dissemination of research and educational material. Moreover, a different K–12 teacher will be invited for each of the three trips planned. (O–316–M; NSF/OPP 03–38226)

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