

# *Witness The* **ARCTIC**

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## **Arctic Research at the Desert Research Institute**

Established in 1959, the Desert Research Institute (DRI) is the nonprofit research campus of the University and Community College System of Nevada. Approximately 440 DRI research faculty and support staff conduct more than 100 environmental research projects each year. DRI's main campuses are in Las Vegas and Reno, with subsidiary campuses in Boulder City, Nevada, and Steamboat Springs, Colorado. DRI's environmental research programs are directed from three core divisions:

- Atmospheric Sciences,
- Earth and Ecosystem Sciences, and
- Hydrologic Sciences;

and two interdisciplinary centers:

- the Center for Arid Lands Environmental Management, and
- the Center for Watersheds and Environmental Sustainability.

Although the institute is located in an arid region and its name suggests the desert is the focus of its investigations, DRI scientists have worked on all of the world's continents, and not only in desert regions. DRI has a number of active research projects in the Arctic, much of which can, in fact, be classified as a desert. This insert provides an overview of several of these projects.

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### **Greenland Ice Sheet Projects**

#### **Summit Environmental Observatory**

Among the most influential glaciochemical records from the Arctic are the two nearly adjacent cores from Summit, at the highest point of the Greenland ice sheet ( $\sim 72^\circ\text{N}$ ,  $\sim 38^\circ\text{W}$ , elevation  $\sim 3200$  m; see *Witness* Spring 1997 and Autumn 1998). Completed in the early 1990s, the U.S. Greenland Ice Sheet Project 2 (GISP2) and the European Greenland Ice Core Program (GRIP) cores are each over 3000 m in length and have been analyzed for a broad range of chemical and physical parameters. The GRIP and GISP2 cores provide nearly replicate high-resolution environmental records spanning more than 250,000 years, with annual layering identified over the past 110,000 years.

Because multiple factors determine how chemical impurities are transported to a region, deposited in snow, and then preserved in ice, a number of recent studies seek to better understand ice core records through coordinated measurements collected at the sites of major ice core drilling activities. For over 10 years, investigators have gathered atmospheric,



*Graduate student Christine Kirick inspects the edge of the Greenland Ice Sheet. Photo by Todd Valentic.*

snow, and other geophysical measurements intermittently at Summit, which is currently the only high-altitude arctic site for atmospheric and related measurements. Beginning in summer 2003, a research team has continued and expanded the suite of core measurements at the Greenland Environmental Observatory at Summit (GEOSummit). The NSF Arctic Research Support and Logistics Program, with additional funding from NOAA and European agencies, is supporting DRI researchers led by Joe McConnell of the Division of Atmospheric Sciences, together with colleagues at the University of California at Merced and Davis and elsewhere, to collect long-term measurements of the arctic atmosphere, snow, and other components at Summit for a five-year period.

The project also provides for the continued operation of GEOSummit as a long-term site for year-round measurements and research. In addition to core measurements, GEOSummit staff will also carry out measurements initiated by individual investigators. Core measurements include meteorology, radiation, tropospheric chemistry, snow properties, and snow chemistry. The suite chosen is of broad interest to the research community and is aligned with the objectives of the World Meteorological Organization's Global Atmospheric Watch (GAW). Some measurements at GEOSummit will be made in cooperation with NOAA's Climate Monitoring and Diagnostics Laboratory (CMDL), including carbon cycle greenhouse gases, chlorofluorocarbons, radiation, and ozone.

### Elevation and Mass Balance

In 1995, NASA initiated the Program in Arctic Regional Climate Assessment (PARCA) with the goal of measuring and understanding the mass balance of the Greenland ice sheet. Understanding the current mass balance of the Greenland and Antarctic ice sheets is critical for predicting future sea level; the deposition and accumulation of water as snow on the ice sheets is a key component of mass balance. Collectively, PARCA investigators estimate changes in ice sheet mass by two methods:

- using repeat satellite and aircraft altimetry to measure elevation changes, and
- inferring mass balance from differences between total snow accumulation,

defined as precipitation minus evaporation, and total ice discharge.

Ice cores are the primary indicator of long-term average, year-by-year, and seasonal accumulation over the ice sheet. They are also used to calibrate and interpret ice-penetrating radar measurements of accumulation and to parameterize and validate meteorological model simulations of net precipitation on ice sheets and glaciers.

Ice cores also contribute directly to mass-balance estimates by providing ground truth for satellite altimetry measurements. Recently reported radar and laser altimetry studies of the Greenland ice sheet show little change in overall mass at higher elevations, although some areas have experienced significant thinning and thickening during the past few decades. Multiple factors, however, determine changes in ice sheet elevation over annual to decadal time scales. Using ice-core accumulation measurements together with firn densification modeling, Joe McConnell, in collaboration with Roger Bales at the University of California, Merced, found that much of the 1978–88 pattern in ice-sheet elevation change measured by repeat altimetry can be attributed to variability in snow accumulation. At higher elevations, this accumulation-driven elevation change likely masks any thickening and thinning associated with long-term changes in mass balance, and must be modeled and removed before repeat altimetry data can be used to understand long-term ice-sheet mass balance.

With support from NASA, McConnell and colleagues at the Ohio State University, the University of Arizona, the University of California, Merced, and the Woods Hole Oceanographic Institution have collected and analyzed approximately 80 shallow (20–30 m) and intermediate (50–150 m) depth ice cores since 1995 from all parts of the Greenland Ice Sheet, including 10 new cores in 2003. Recent developments in ice core chemical analyses at DRI mean that accurate measurements of annual net accumulation are now possible well below the dry snow zone, greatly expanding the role of ice core measurements in the study of temporal and spatial variations in precipitation in Greenland. DRI researchers are also involved in collaborative efforts to use ultra-trace glaciochemical and accumulation measurements to better understand

the mass balance of the ice sheet and the changes in atmosphere and ocean circulation that drive it.

### New Analytical Tools for Ice Cores

The application of ice-core chemical data in environmental, biogeochemical, and global change studies has been limited by:

- relatively coarse sample resolution in time, even for high-resolution studies,
- inexact co-registration in depth for different chemical measurements, and
- the limited number of chemical species, elements, and isotopes routinely measured in ice cores.

A novel analytical approach for ice-core analysis termed the Continuous Flow Analysis with Trace Elements (CFA-TE) method eliminates many of these problems in the development of very high-resolution, broad-spectrum glaciochemical records at relatively modest cost. Developed by Joe McConnell and colleagues with support from the NSF Office of Polar Programs, CFA-TE couples a continuous ice-core melter directly with a traditional continuous flow analysis (CFA) system and both a high-resolution inductively coupled plasma mass spectrometer (HR-ICP-MS) and an optical emission spectrometer (ICP-OES). The apparatus provides continuous, high-resolution, and exactly co-registered glaciochemical measurements of a broad spectrum of chemical species, trace elements, and isotopes.

In 2003, with funding from the NSF Arctic Natural Sciences Program, McConnell's group collected two new 150-m ice cores in west central Greenland in an area that is strongly influenced by large-scale changes in atmospheric circulation and anthropogenic pollution from North America. When analyzed with the CFA-TE system, these new glaciochemical records will extend from ~1750 A.D. to the present and will be the highest resolution, multi-century elemental and isotopic glaciochemical records ever produced from Greenland ice cores. Together with similar recently completed measurements from Summit, these data sets will open new avenues for using glaciochemical data to investigate environmental and global changes issues ranging from anthropogenic, volcanic, and biomass-burning-related trace element fallout to changes in hemispheric-scale circulation and rapid climate change events.

### Borehole Sonic Logging

Gregg Lamorey of DRI's Division of Hydrologic Sciences has a sonic logging project at the GISP2, GRIP, and North Greenland Ice core Project (NGRIP) boreholes. Funded by the NSF Arctic Natural Sciences Program, Lamorey is conducting his work during the 2002–04 field seasons.

Interpretation of paleoclimate records from ice cores depends on understanding the ice sheet flow to determine depth–age relationships and whether the ice has been affected by folding. The alignment of crystals in ice, called fabric, is an important factor in understanding ice sheet flow since preferentially aligned crystals cause the ice to flow more easily in certain directions

and less easily in others. Fabric is commonly determined by measuring the c-axis orientation of individual crystals in thin sections from an ice core.

Another method of determining fabric is sonic logging, where a probe is lowered into a borehole to measure the velocity of compressional (P) waves through the ice. This velocity is affected by the temperature, density, and crystal orientation of the ice. Temperature differences can be compensated for, and changes in density are minimal below 100 m. The sonic logging tool consists of a transmitter, a near receiver and a far receiver. The difference in the first arrival of the P wave between the two receivers yields the average sonic

velocity between receivers. The fluid path between the tool and the borehole wall is the same for P waves arriving at both receivers as long as the borehole diameter is constant.

The most common ice fabric feature is a vertical alignment of crystals described by a cone angle. The cone angle, defined as the cone containing 90% of the c-axis, can be related to the sonic velocity of the ice. Sonic logging is a valuable tool for understanding ice fabric because it provides a continuous profile of ice fabric and averages the alignment of ice crystals over a much larger volume than do thin sections and does not require samples from an ice core. ■

## Geochronological Research

Investigators have long sought a numeric dating method that would overlap with the radiocarbon ( $^{14}\text{C}$ ) technique (typically 0.2–35 ka range) and extend well back into the last few glacial–interglacial cycles (a few 100 ka). Luminescence methods have potential for this use through their capacity to determine the last exposure of siliclastic mineral grains (mainly quartz and feldspars) to daylight. Daylight “zeros” the clock, while exposure to low-level ambient ionizing radiations within sediments keeps the clock ticking at a constant rate after burial of mineral grains. Luminescence proportional in intensity to the burial age can be released in the laboratory and measured by photon-counting methods. This is a unique tool for establishing numeric time scales for a large variety of paleoclimatic proxies preserved in sediment matrices. Only within the past decade, however, have luminescence geochronometers been tested and proven in arctic regions. The testing and applications by Glenn Berger of DRI's Division of Earth and Ecosystem Sciences have included eolian silt as well as lake and marine sediments, with support provided by both the NSF Arctic Natural Sciences program and Directorate of Geosciences.

### Eolian Sediments

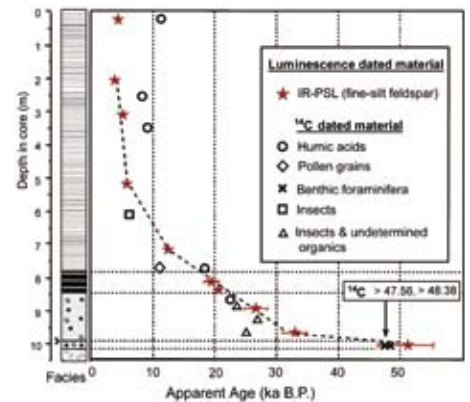
Loess is a globally widespread silt laid down by wind. In Alaska, loess has preserved buried forest beds and soils and random tephra layers; this record of paleoclimatic change reaches back about 2 Ma. Determining the

deposition age has been difficult or impossible for the 30–150 ka range, between the reliable upper limit of the  $^{14}\text{C}$  dating and the lower reliable limit of glass-fission-track dating. Berger successfully validated thermoluminescence (TL) dating of loess in the Fairbanks region of central Alaska during the 1990s by independently deriving tephrochronology of enclosed ash. Using TL dating, Berger has determined ages of loess and other sediments in the Noatak River valley in northwestern Alaska and the Yukon River valley in northeastern Alaska. Results are in preparation for publication with colleagues from Alaska and England.

### Lake Sediments

Arctic and near-arctic lakes can hold excellent records of paleoclimatic changes because the sediments can be preserved continuously and because many proxies are preserved that are often rare in other deposits (e.g., inter-paleosol loess). Such lakes can even be used to delimit the geographic extent of Pleistocene ice sheets. Following successful testing of TL dating procedures with arctic lakes from northwestern Alaska, Berger has applied the more sensitive infrared-photon-stimulated-luminescence (IR-PSL) procedures to lakes from the Russian High Arctic (Taymyr Peninsula), in collaboration with colleagues from Germany and with German financial support, as well as with NSF funding.

For example, in the 1990s a German–Russian project obtained a 10.4-m core



Plot of  $^{14}\text{C}$  dating results (uncorrected to calendar years) and IR-PSL ages for the composite core PG-1238 from Changeable Lake, with  $\pm 1\sigma$  error bars [modified from Raab et al., 2003, Quat. Sci. Rev., doi:10.1016/S0277-3791(03)00139-2].

from Changeable Lake (latitude  $79^\circ\text{N}$ , October Revolution Island, Severnaya Zemlya Archipelago). Subglacial till occupied the bottom ca. 40 cm of the core, overlain by nonglacial sediments (lake and marine). Radiocarbon dating of a variety of components produced a scattered set of results, but IR-PSL provides a clear age–depth profile in numeric ages. Thus, not only does the post-glacial paleoenvironmental record now have an accurate time scale, but the oldest IR-PSL ages (50–55 ka) provide the first clear evidence that the last regional glaciation occurred before ca. 55 ka and that the Eurasian ice sheet did not extend eastward to the Taymyr Peninsula during the Last Glacial Maximum. These results support the minimalist model of the extent of this Last Glacial Maximum ice sheet.

## Ocean Sediments

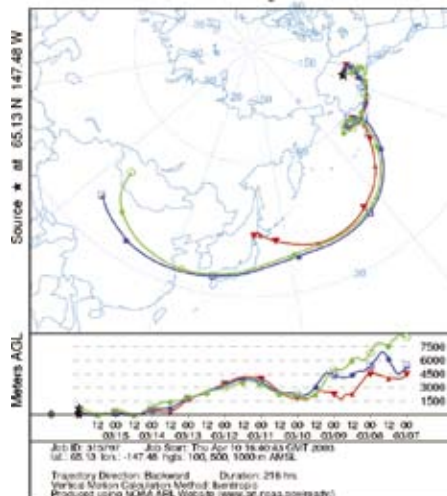
The paleo-oceanographic and paleoclimatic history of the Arctic Ocean remains unknown and uncertain for the time range ca. 30–800 ka, not least because this remains the last major ocean to be explored by modern geological and geophysical means, but also because the oxygen-isotope chronology developed for nonpolar oceans is ineffective in the Arctic. Foraminifera suitable for oxygen-isotope stratigraphy are preserved only sporadically at high latitudes. The first application of luminescence methods to arctic marine sediments demonstrated the potential of the TL approach, using cores from the western Arctic Ocean. Using IR-PSL, Berger's team has extended that work to sediments from across the Arctic Ocean, representing both basins and ridges. Some areas seem more favorable than others, but it is clear that luminescence dating is now applicable to sediments from this *mare incognita*. ■

## Atmospheric Studies

Funded by NOAA, Randy Borys and Melanie Wetzel of DRI's Division of Atmospheric Sciences are collaborating with Jim Slusser (USDA National UVB Monitoring and Research Program) and Glenn Shaw and Cathy Cahill (University of Alaska Fairbanks) to investigate interannual variability of ultraviolet (UV) irradiance, ozone, and aerosol chemistry in the Arctic.

Vertical profiles of several parameters, including ozone concentration, aerosol amount and composition, and cloud cover, change in response to seasonal circulation patterns, synoptic-scale air mass movement, and diurnal cycles in solar radiation and winds. While stratospheric ozone fluctuations are now closely monitored, mesoscale fluctuations in UV radiation at the surface are less well understood and yet have a more direct effect on UV exposure for humans and other biota.

Spectrometer and filter radiometer measurements of total UV irradiance have been made in the Arctic in the past, but to date no long-term studies of direct-sun UV radiation have been made. The geographic, seasonal, and inter-annual variability of UV irradiance is strongly controlled by the amount of ozone in the atmospheric vertical column. At the same time, variation



*Backward trajectories for air arriving to Poker Flat, Alaska, during the Asian Dust transport event at 00 UTC on 16 April 2001, showing the transport pathway from Asia during the Asian Dust episode. Although mineral dust dominated the aerosol composition, some industrial pollutants were also measured. Each tick is 6 hours. Lower plot is the height in meters of the air parcels as they traveled from Asia at three different levels in the atmosphere, beginning at ground level on the left.*

of UV irradiance and the resulting surface exposure is also significantly determined by local meteorological and surface physical conditions, including cloud cover aerosol extinction and albedo.

### Field Studies

To better understand the interrelationships between UV exposure and the controlling environmental conditions, the collaborators combined field measurements, satellite remote sensing, and radiative transfer modeling at a site near Fairbanks, Alaska. Observations included continuous measurements from a permanent monitoring site at Poker Flat Research Range, which began operations in September 2000, and results from additional sensor systems deployed in September 2000 and March–April 2001. The results indicated a relatively pristine environment, typical of the remote North American Arctic.

### Aerosol Classification

Observations indicated four primary aerosol-airmass types: Asian Dust, aged industrial pollution (Arctic Haze), cloud-processed air, and clean background conditions. The arctic region commonly experiences aerosol haze conditions caused by long-distance transport of pollution. The ongoing economic development of Northern Hemisphere countries is likely to continue these pollution sources.

Aerosol imported to central Alaska from outside the region produced frequent increases in UV optical depth calculated from direct-beam spectral extinction, but caused a limited reduction in transmittance at UV wavelengths, demonstrating the important role of aerosol scattering into the diffuse component of total irradiance. Chemical analysis was used to match aerosol composition to size distribution characteristics, and aerosol absorption was shown to be small in magnitude, even for the Asian Dust event.

### Infrastructure Improvement

A significant result of this project was the establishment of a new long-term monitoring site for providing multi-wavelength (UV through near-infrared) and broadband irradiances at the Poker Flat Research Range, Alaska. This new site will permit long-term assessment of the impacts of ozone, cloud, surface albedo, and aerosol conditions on trends in UV radiation climatology for central Alaska. Seasonal and interannual change in ozone column amount is large in this region, and the impact of variable cloud cover is enhanced by the spatial and temporal heterogeneity of snow cover. Aerosol effects are quite limited, but events such as Arctic Haze do cause measurable UV extinction.

### UV Variability

The overall variability in downward UV irradiance due to cloud-cover fluctuations is comparable to that caused by the observed seasonal and decadal trends in ozone column amount. By far the most important controlling influences on UV exposure were cloud cover, surface albedo, and ozone-column amount, while widely differing aerosol airmass sources had little impact on UV irradiance.

Future monitoring of exposure to UV radiation will be critical to understanding the link between global change and biological impacts. The downward irradiance of UV radiation typically increases as the total column amount of ozone decreases, but local enhancement in excess of clear-sky values can be caused by cloud reflection. Thus, long-term monitoring of these relationships will enhance our ability to predict UV exposure that will result from changes in weather as the climate changes. ■