Witness The
ARCTIC

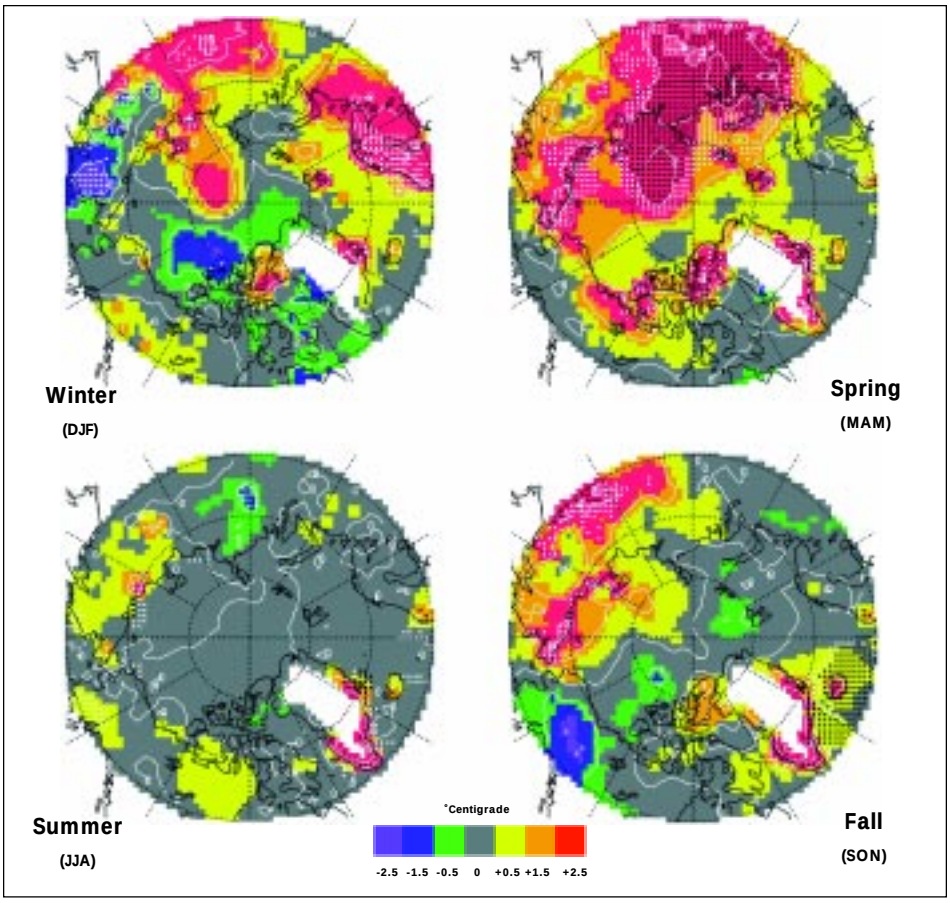
Arctic Research Consortium of the United States Member Institution Autumn 1998

Arctic Research at the University of Washington

The University of Washington (UW) in Seattle has a tradition of conducting research in polar regions. Diverse arctic research is conducted in various disciplines and is emphasized at the Polar Science Center and the Quaternary Research Center. Current arctic studies and related basic research in these centers and elsewhere at the UW are highlighted here.

Polar Science Center (PSC)

The PSC, a unit of the Applied Physics Laboratory, was established in 1978 following the multi-year Arctic Ice Dynamics Joint Experiment (AIDJEX). In this project, an international research team lived on an ice floe in the Beaufort Sea and collected atmospheric and oceanographic data to better understand natural processes in the remote Arctic. Today, PSC scientists are involved in studies of sea ice, polar oceanography, and meteorology, with a focus on observing and modeling the physical processes that control the nature and distribution of sea ice, the structure and circulation in high-latitude oceans, and the interactions among the air, ocean, and ice. Of particular interest is the relationship between polar regions and the global climate system. For more information see http://www.psc.apl.washington.edu/.



Seasonal surface air temperature trends from IABP/POLES data set for 1979-1997. Trends in grid cells that are significant at the 95% level are marked with small white dots; trends that are significant at the 99% level are marked with small black dots (I. Rigor, Journal of Climate, *submitted).*

SHEBA

The PSC spearheaded the ambitious Surface Heat Budget of the Arctic Ocean (SHEBA) Program, in which the Canadian icebreaker *Des Groseilliers* was frozen into the arctic ice for a year that ended in October 1998 (see *Witness* this issue). Investigators from five countries (Canada, Japan, Netherlands, Russia, and the United States) and 25 agencies/institutes now have the mammoth task of organizing and analyzing the data collected. PSC's Dick Moritz is the SHEBA Project Office director, and Andy Heiberg is the logistics chief. A science and data workshop for SHEBA investigators and cooperating partners will be held 25-29 January 1999 in Tucson, Arizona.

Study of Arctic Change

Jamie Morison, Knut Aagaard, and Mike Steele are leading the science community in proposing an international Study of Environmental Arctic Change (see *Witness* this issue). The November 1997 Arctic Change workshop report, available on the web and in hard copy, should aid further development of programs similar to other ARCSS initiatives.

International Arctic Buoy Programme (IABP)

In collaboration with the participants in the IABP, the PSC has maintained a network of drifting buoys on the sea ice of the Arctic Basin since 1979. These buoys measure pressure, temperature, position, and a host of meteorological quantities, which are transmitted and collected via the Argos satellite system. These data are used for meteorological, climatological, and oceanographic purposes, and serve both research and operational needs. PSC's Ignatius Rigor is coordinator of the IABP.

Recently, data from the IABP have played an important role in showing large changes in the arctic climate. For example, Walsh *et al.* (1996) used IABP pressure data to show an enhanced cyclonic regime in arctic circulation. Using surface air temperature data, Rigor shows a warming trend over the eastern Arctic Ocean (figure page 1) and that this is associated with the Arctic Oscillation described by Thompson and Wallace (1998). IABP data are available at the PSC web site.

Cold-Water Oceanography

Knut Aagaard's fieldwork focuses on:

- the convective forcing of shelf circulation by buoyancy fluxes in the St. Lawrence Island Polynya;
- variability of the flow through Bering Strait and its consequences for the Arctic Ocean; and
- circulation in the Alaskan Beaufort Sea.

These studies have a special emphasis on 1) spatial and temporal scales, 2) boundary current transport, and 3) convection and frontal processes in Lake Superior.

Aagaard is also involved in two analysis projects:

- the outflow of freshwater from the Arctic Ocean into convective regions of the North Atlantic, with a view toward the effects on the large-scale thermohaline circulation; and
- historical Russian data from the Arctic Ocean, to illuminate recent major changes within the Arctic Ocean.

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Satellite Remote Sensing

Ron Lindsay is exploring the evolution of the arctic pack ice using geophysical products derived from synthetic aperture radar (SAR) data acquired by the Canadian RADARSAT satellite, which images the entire Arctic Ocean every few days. Data processed at the SAR Facility in Fairbanks, Alaska are fed into the RADARSAT Geophysical Processor System (RGPS) at the Jet Propulsion Laboratory. Output from the RGPS, which includes sea-ice motion and deformation on a 10-km grid, is contributing to three PSC projects:

- A NSF-funded project uses the sea-ice deformation fields in conjunction with an ice model to estimate the rate of new ice and ridge formation. The ultimate goal is to create an accurate estimate of ice-thickness distribution for the SHEBA year (1997-98).
- A NASA-funded project is using RGPS products to improve estimates of sea-ice albedo.
- Another NASA-funded project is validating RGPS products through comparison with a wide variety of other data, including satellite AVHRR imagery, submarine (SCICEX) data, and *in situ* measurements from SHEBA.

Data Products and Models

Drew Rothrock is working with Ron Kwok of the Jet Propulsion Laboratory to provide a data-assimilation technique that produces year-round data on ice motion. They will combine:

- ice-motion data from passive-microwave sensors and drifting buoys, and
- predictions of an ice/ocean model that uses wind forcing

to drive an ice-momentum equation and compute ice velocity. This will be the first model output with accurate motion fields, which is important to predict Arctic Ocean circulation and export of both ice and ocean freshwater through Fram Strait and the Canadian Archipelago.

The NASA-funded Polar Exchange at the Sea Surface (POLES) team led by Rothrock is using the rich array of satellite data collected from the polar regions to assimilate satellite (and some buoy) observations into polar ocean-atmosphere models that not only refine the treatment of surface-exchange processes, but also quantify the roles of horizontal transport, oceanic mixing, and deep convection. With better use of data, researchers can move beyond present climatological descriptions and document inter-annual variability.

Drew Rothrock and Gary Maykut (UW), and Alan Thorndike (University of Puget Sound) are using ice-profile data taken during Submarine Arctic Science (SCICEX) cruises to measure ice draft. The data are being analyzed to estimate the ice-thickness distribution and test assumptions that are the foundation for a theory that predicts changes in the ice-thickness distribution (Thorndike *et al.* 1975). While this theory has become an integral part of many sea-ice models, it involves assumptions that have not yet been tested directly.

Jamie Morison and Mike Steele have analyzed oceanic data collected during the first two SCICEX cruises (see *Witness* Spring 1998), documenting large changes in the hydrographic structure of the Arctic Ocean. They have found intense warming of a layer that is usually quite deep (several hundred meters) but which has recently moved closer to the surface. ■

Quaternary Research Center (QRC)

The QRC was established in 1967 to promote cooperative, interdisciplinary, and interdepartmental research focusing on the processes that presently shape the natural environment and that have operated during the Quaternary, the recent period of glacial ages. Beginning with its first director, A.L. (Linc) Washburn, and his pioneering studies of physical processes in permafrost-affected soils, the QRC has had a strong emphasis on arctic research. The current director, Bernard Hallet, continues this tradition.

Quaternary Isotope Laboratory (QIL)

Minze Stuiver has developed the world standard for calibration of carbon ages. The most recent version of the radiocarbon calibration program CALIB with INTCAL98 data sets is available at http://depts.washington.edu/qil/.

Stuiver has also been a leader in stable isotope work on ice cores that have proved to be invaluable indicators of past temperatures. The measurements of GISP2 $^{18}O/^{16}O$ ratios at the QIL have been completed. A 1999 paper is scheduled for the *Journal of Quaternary Research*. GISP2 oxygen-isotope profiles as well as data from the Taylor Dome, Antarctica core are on the web site.

Beringia and Paleoclimates from Arctic Lakes & Estuaries (PALE)

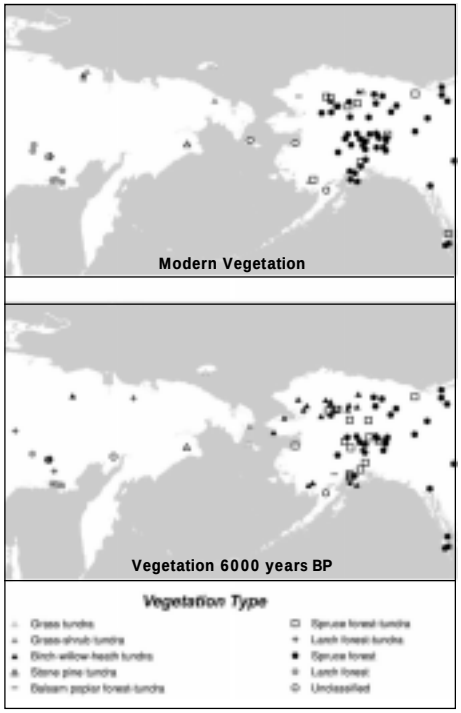
The College of Forest Resources and the QRC have a long history of research in Beringia. Projects led by Patricia M. Anderson and Linda Brubaker are describing temporal and geographical variations in vegetation and climate patterns of this subcontinent over the last 150,000 years. This work, largely supported by the NSF PALE Program, emphasizes palynological and geochemical data extracted from lake sediments. Modern pollen-vegetation-climate relationships are also being investigated. Fieldwork has been conducted throughout arctic and subarctic Alaska; current work is on the Alaskan North Slope and in northeast Siberia, the latter in cooperation with Anatoly Lozkhin (Russian Academy of Sciences).

To better understand the vegetation history and dynamics of the Arctic, Anderson and Brubaker are working with other members of the Global Paleovegetation Mapping (BIOME 6000) Project, sponsored by the International Geosphere/Biosphere Programme. This work includes application of a computer model that translates pollen data into plant functional types and biomes. Cooperative work with Pat Bartlein and Cary Mock (University of Oregon) is exploring paleoclimate patterns. Sound vegetation and climate reconstructions require reliable chronologies from the fossil records; to accomplish this, collaborative experiments with Tom Brown (Center for Accelerator Mass Spectrometry, Lawrence Livermore National Laboratory) are underway.

The PALE *Paleoenvironmental Atlas of Beringia*, which involves many U.S. and international scientists, is based at the QRC. This electronic atlas illustrates past and present environmental syntheses (*e.g.*, paleovegetation maps [figure above], animation of the Bering land bridge flooding) and provides access to the primary and value-added data used in the synthesis.

Formation and Dynamics of Patterned Ground

A collaborative effort, involving both field and modeling work, led by Bernard Hallet and Brad Werner (Scripps-UCSD) exploits recent theoretical and experimental developments to formulate and test models for the initiation and maintenance of patterned ground. Extensive instrumentation was installed at sites with exceptionally developed patterned ground—near the summit of Mauna Kea and in Spitsbergen. A numerical model for the formation of sorted circles has been developed by UCSD graduate student Mark Kessler. Thermal aspects of the active layer and surface energy balance are being investigated by postdoctoral researcher Jaakko Putkonen.



A sample from the PALE Beringian Atlas*: Beringian vegetation reconstructed from pollen data using qualitative relationships between modern pollen abundance and modern vegetation (http://www.ngdc.noaa.gov/paleo/pale/atlas/beringia/index.html).*

Rates of Glacial Erosion

Rates of glacial erosion in southern Alaska are the subject of a NSF-sponsored study led by Bernard Hallet in collaboration with Lew Hunter (CRREL), and Bruce Molnia and Austin Post (USGS). This research aims to measure and understand rates of large-scale glacial erosion and the implications for climate-tectonics-topography. Much of the fieldwork involves seismic and bathymetric surveys in fjords to determine the rate of sedimentation in front of large, rapidly moving glaciers, including Bering and Columbia glaciers, which are thought to be very erosive. The surveys are complemented by estimates of ice flux using GPS-determined ice velocities, which provide an index of how active the glaciers are. These researchers are also compiling data about glacial erosion from other areas for modeling purposes.

Studies of High-Arctic Ecosystems

Soil processes and the role of weathering in carbon cycling are being studied in high-arctic ecosystems by Ron Sletten in cooperation with Bjarne Jakobsen and Bo Elberling (University of Copenhagen) and Birgit Hagedorn (Alfred Wegener Institute for Polar and Marine Research). Their study site is on the northeast coast of Greenland at the Zackenberg Arctic Field Station, recently established by the Danish Polar Center (see *Witness* Spring 1997). To study the role of increased snow accumulation, a potential scenario in climate change models, a permanent snow fence was built and plots established for soil chemistry/physics and plant phenology.

Ionic Mobility in Frozen Soils

Ron Sletten, Bernard Hallet, and Tom Pratum (Chemistry) are funded by the Army Research Office to research unfrozen water content and ionic diffusion in frozen soils. These are important concerns for:

- contaminant transport in permafrost regions and in man-made frozen soil barriers,
- frozen soil respiration, and
- frost heave.

The researchers have optimized a technique using Stimulated Echo Pulsed Field Gradient Nuclear Magnetic Resonance to directly measure molecular diffusion. These experiments help us understand phenomena in frozen soils, such as bulk diffusion of ions and generation of electrical potentials during freezing.

Anthropology

Ben Fitzhugh (Anthropology) is conducting archaeological research in the Kodiak Archipelago, addressing questions of colonization by maritime hunting and gathering people prior to 7000 years ago. He is researching the evolutionary history of these populations, which eventually developed sophisticated social, political, and economic practices and organizations.

Fitzhugh has completed the first season of intensive excavation at Tanginak Spring on Sitkalidak Island. This large, stratified campsite dates to 7000-7500 Cal BP; it is the oldest known in the archipelago. The site includes a sizeable assemblage of artifacts and stratified occupation floors. Excavations in 1994 and 1998 uncovered core and blade tools reminiscent of earlier Paleolithic and Beringian industries and suggesting a link to later inhabitants of Alaska's Pacific coasts.

Atmospheric Sciences

The Cloud and Aerosol Research Group (CARG) in the Atmospheric Sciences Department, directed by Peter Hobbs, conducts ground-based and airborne research in the Arctic and Alaska. In 1970, CARG measured aerosol particles (including cloud and ice nuclei) near Barrow, Alaska. In 1976, 1977, and 1990, the group studied particle and gas emissions from active arctic volcanoes, including Mt. St. Augustine and Redoubt. In 1983 and 1986, CARG studied arctic haze over the Beaufort and Chukchi seas, Greenland, and the North American Arctic. And in 1995, the group showed that some of the highest dimethyl sulfide (DMS) emissions ever measured from the oceans occur when ice melts in the Arctic.

More recently, CARG has turned its attention to the radiative properties of aerosols and clouds in the Arctic. In 1995, coordinated airborne measurements, with CARG's C-131 research aircraft and NASA's ER-2 high-flying aircraft, were carried out over the Arctic Ocean. The C-131 provided measurements of the reflectivity of various surfaces in the region, radiative properties of aerosols and arctic stratiform clouds, and microphysical structures of the clouds. In 1998, CARG participated in the FIRE-ACE/SHEBA project with its new Convair-580 research aircraft. Many flights were made over the SHEBA ship and over the ARM site in Barrow for obtaining *in situ* vertical profile measurements of aerosols and clouds for comparisons with simultaneous remote sensing measurements.

Geophysics

Howard Conway, Charlie Raymond (Geophysics), and David Battisti (Atmospheric Sciences) are studying relationships between climate and glacier variations in western North America. They are studying the extractability of climatic information from glacial records by focusing on three aspects of climatic and glacier interactions:

- dynamic response of glaciers to the accumulation or loss of snowpack and ice (changes in mass balance),
- correlation between climate and glacier mass-balance fluctuations, and
- development and verification of physical models of glacier mass balance.

An important finding is that most of the information relevant to dynamics is contained in the overall gain or loss of mass (mean mass balance); the distribution of the mass (spatial pattern of balance) is far less important. This may allow researchers to extract useful climate data from the histories of glacial advance and retreat.

Oceanography

Jody Deming's research group in the School of Oceanography is currently examining the feeding and survival strategies of marine bacteria at cold temperatures. They are exploring the significance of extracellular enzymes to:

- the microorganisms that produce them,
- the ecosystem at large, and
- the cycling of carbon in arctic sea ice, waters, and sediments.

The group has shown that the sea-ice environment supports strongly cold-loving (psychrophilic) bacterial and enzyme activity, and that the most numerically important bacteria in sea ice can be cultured. Future plans include tests for bacterial and enzymatic activity at temperatures that simulate winter conditions in brine pockets of sea ice. Opportunities for studying low-temperature microbiology will begin in Fall 1999 as a result of a NSF award to establish the nation's first graduate training program in Astrobiology.

Other motivations for this research include potential applications of psychrophilic bacteria and enzymes to:

- biotechnology (the enzyme industry),
- bioremediation (potential for arctic microorganisms to degrade contaminants at low temperatures), and
- astrobiology.

The group receives support from the NSF LExEn and Arctic Natural Sciences Programs, and from the Washington State Sea Grant Program.

The contribution of degradative enzyme activity to the biogeochemical fate of sinking particulate matter, and thus to ecosystem structure and function, is being studied in collaboration with marine geologists Ian Walsh (Oregon State University) and Dave Barry (Brown University) as part of an international, interdisciplinary program led by Canadian scientists. The setting is the biologically rich polynya in northern Baffin Bay known as the North Water Polynya. Preliminary results reveal remarkably high and continuous levels of productivity on a regional scale, with microbial degradative processes appearing to track mesoscale fluctuations in productivity and particle fluxes.

Physics of Ice and Other Activities

Greg Dash of the Physics Department and John Wettlaufer of the Applied Physics Laboratory are studying fundamental aspects of ground freezing and frost heave. Basic theory is being developed at UW and tested by novel experiments measuring frost heave in solid ice and argon.

The existence of unfrozen water at subfreezing temperatures is an essential element of frost heave. This water arises, in large part, from interfacial premelting. The quasi-liquid film that forms at an ice/vapor or ice/wall interface at temperatures below the bulk melting point is generally studied semi-statically. Dash and Wettlaufer (with Larry Wilen, now at Ohio University) have conducted novel experiments on single crystal interfaces. They have also developed a dynamical theory that describes the interactions responsible for the observed melting. The results explain an essential physical mechanism underlying frost heave as it occurs in cold climates. The theory is being used to develop continuum models for ideal porous media and natural soils.

Sam Fain is studying mechanical properties of ice-solid interfaces, using atomic force microscopy (AFM) on vapor-deposited ice. Fain is investigating the role of an interfacial, quasi-liquid layer by analyzing:

- the indentation of ice by nanometer-size conical tips, and
- the friction between ice and micron-size spheres.

Growth of a hexagonal facet at -17˚C has been observed using an AFM probe tip with a hydrophobic coating.

Theories of the nucleation of solids from their liquid phases are being tested by Gerry Siedler and graduate student Lane Seeley in experiments using water as a test substance. This study seeks to determine the various physical properties of substances that are effective in lowering the nucleation barrier. The work relies on making highly sensitive automated measurements in small environmental chambers.

In the Department of Atmospheric Sciences, Marcia Baker and Brian Swanson are studying the nucleation and growth of ice from vapor. Experiments involving levitation of small crystallites in environmental chambers aim to understand the evolution of crystal shapes observed in the atmosphere. The experiments are complemented with computer simulations.