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CONTENTS

COVER PICTURE: Storglaciären, September 1995 (photograph by Peter Jansson).

Recent work

CHINA

International Trans-Antarctica Expedition

The surface features and snow-pit stratigraphic profiles were analyzed for stable isotopes, ionic concentrations, biogenic acids and Pb content along the route of the 1990 International Trans-Antarctica Expedition (5896 km from the top of the Antarctic Peninsula to Mirny via the South Pole and Vostok).

The snow stratigraphic profiles indicate that the melt-water infiltration congelation is obvious in West Antarctica, while the thin ice-glazes caused by sintering are frequently seen in East Antarctica. Deep hoar is widespread in the surface snow of the Antarctic ice sheet, especially on the East Antarctic plateau.

Stable isotope analysis gave different relationships for various regions. In the East Antarctic plateau, the isotope-temperature slope has a large difference toward east and west from Vostok station. The deuterium excess values are basically constant near the coast and increase sharply at altitudes higher than 2000 m a.s.l.

Concentration distribution of main anions and cations demonstrates that the oceanic source ions have a similar distribution tendency. The concentration is higher in West Antarctica than East Antarctica, and the non-sea-salt ions have a uniform distribution along the Trans-Antarctic route. There are also no large changes in the concentration of methanesulfonic acid (MSA) along the whole traverse route. It is of interest to note that both the concentration and the flux maximum occur at about 2–3 degrees of latitude westwards and eastwards away from the South Pole, respectively, just in the shield zone of aurora australis.

The trace heavy-metal element measurement indicates that Pb content increases from west to east along the traverse route. If the average value over the Larsen Ice Shelf and the Antarctic Peninsula is considered as the background value in modern precipitation, the average value over the section between Vostok and Mirny stations is 2–3 times higher.

Nelson Island Ice Cap

Surface feature surveys and radio-echo sounding were carried out on the Nelson Island Ice Cap, and a 1 : 50 000 map of the ice cap was published. Temperatures, surface velocity and strain-rate were measured. The current accumulation rate was observed and transformation of snow into ice was investigated. Dynamic modelling of the ice cap was made using the force budget method. Several shallow cores (within 30 m) were drilled by a PICO drill for the study of stratigraphy, crystal fabrics, tephra compositions and stable isotope analysis. Surface snow samples collected from a snow pit at the centre were analyzed for ionic concentration.

The results show that the velocity is generally below $10\,\mathrm{m\,a^{-1}}$ and that surface meltwater can percolate to the bottom of the snow/firn layer, which is at a depth of 25–26 m at the summit. Basal sliding makes a large contribution to the ice movement. The average accumulation rate was $120\,\mathrm{kg\,m^{-2}\,a^{-1}}$ at the centre during the 1970s and '80s. Analysis of the chemical component of surface snow suggests that the precipitation source is mainly the local marine air mass.

Shallow ice-core studies, Qinghai–Xizang (Tibet) Plateau

Recently, ice cores have been taken from the Dunde Ice Cap in the Qinlian Mountains, the Dongkemadi glacier in the Tanggula Mountains, the Kangwure Ice Cap on Mount Xixabangma and the Guliya Ice Cap in the West Kunlun Mountains. Climatic changes in the past 2000 years have been reconstructed from these ice cores.

The ice cores show there was an obvious warming in the past several decades on the Qinghai–Xizang (Tibet) Plateau, and that the amplitude of temperature increase on the plateau is larger than that in the surrounding areas.

It has been confirmed for the first time by shallow ice-core studies here that the coldest period in western China was 1100–1200 AD, rather than 1600–1700 AD, which is traditionally referred to as the coldest period during the Little Ice Age. Three sub-stages can be distinguished from the traditional Little Ice Age: the 15th century cold stage, the 17th century cold stage and the 19th century cold stage. Three moraine ridges extensively distributed at the terminus of existing glaciers in western China verify the occurrence of these three cold periods. Although all the evidence indicates that the Little Ice Age is synchronous, its amplitude is different in different regions.

The Holocene was intensively studied through ice-core records. In western China it started 8000 BP. The early Holocene in western China was a climatically unstable period. The middle Holocene was a stable warming period with few cold events. During the late Holocene, climate evidently began cooling. In terms of the past 500 years, 3000 BP is an important boundary. Before 3000 BP, there is a trend towards temperature increase; after 3000 BP is characterized by temperature decrease and the coldest temperatures were reached in 1000 BP. After this, the climate began warming. The present temperature is close to that of the Climatic Optimum in the Holocene.

Guliya Ice Cap, deep drilling

From 1991 to 1995, a deep ice-core drilling programme was undertaken through a cooperative programme between the Lanzhou Institute of Glaciology and Geocryology, the Chinese Academy of Sciences and the Byrd Polar Research Center, The Ohio State University. A number of shallow ice cores were drilled on the ice cap before the deep drilling year (1992), the highest altitude being 6700 m a.s.l. In 1992, two deep ice cores were drilled. One was drilled at 6100 m a.s.l. Because of a quality problem, the coring stopped at a depth of 90 m. The other was drilled around 6300 m a.s.l. and reached bedrock. The core is 308 m long and the ice temperature at the bottom of the core is about –2°C. This core was divided between the two agencies. The Chinese half was analyzed for $\delta^{18}O$, glacial accumulation, ice-crystal size, cations, anions, pH, conductivity and MSA. All items measured were converted into a corresponding time series for the past 10 000 years based on the annual resolution. The Last Glacial Maximum can be reliably reconstructed on a decadal resolution. It is calculated by using $\delta^{18}O$ and the relationship between $\delta^{18}O$ and air temperature, that the temperature decreases about 6°C in the Last Glacial Maximum compared with that at present, and temperature increases about 2°C during the Climatic Optimum in the Holocene compared with that at present. The Younger

Dryas was clearly recorded in the Guliya Ice Cap, indicating it is not a local phenomenon around the Atlantic Ocean.

Modern precipitation and aerosol chemistry in central Asia

Globally, central Asia represents one of the largest blanks with respect to our understanding of biogeochemical cycles in the atmosphere and hydrosphere. However, in the past few years a large number of snow and ice samples, including ice cores, were collected from high elevations (7660 m) of more than ten glacier basins across the mountains of the Qing–Zang (Tibet) Plateau, and tens of aerosol samples were collected from four sites.

Focusing on research in the development and interpretation of the data set, which describes the spatial and seasonal variation of snow and aerosol chemistry, and snow and eolian dust deposition in the mountains of central Asia, some primary results obtained were:

(1) The spatial distribution of concentrations of major ions and microparticles in the glaciers over the Qing–Zang (Tibet) Plateau is controlled primarily by the influx of Asian dust derived from the arid and semi-arid region of western China, with higher levels of major ions and microparticles in the northwestern plateau, and lower levels in the southern plateau.

(2) In the northwest of the Qing–Zang (Tibet) Plateau, the total aerosol burden in the atmosphere exerts a global impact, and there are significant seasonal variations in the atmospheric environment. In low dust periods, the concentrations of sulfate and nitrate in the atmosphere show similarities to the "backgrounds" of those in the atmosphere above the most remote areas in the world. Our calculations revealed that more than 76% of sulfate and 66% of nitrate in the Guliya ice core could be attributed to the influx of Asian dust.

(3) A difference in source and deposition mechanism apparently exists among different chemical species in snow and ice.

(4) The formation of glaciochemistry records in some southern plateau ice cores (e.g. Xixibangma ice core) is mainly controlled by the regional climate and atmospheric environment. Strong correlations appear among parameters such as microparticle content, major ions and oxygen isotope, etc. in the ice cores.

Glacier mass balance

Mass-balance measurements have been conducted on several remote glaciers on the Qinghai-Xizang Plateau, e.g. Hailuogou glacier, Mount Gongga (1990–present), Xiao Dongkemadi glacier, Tanggula Mountains (1989–present), Meikuang glacier, East Kunlun Mountains (1989–present), and Kangwure glacier, northern flank of Mount Xixibangma (1991–95). Glacier No. 1, at the head of the Ürümqi river, has been observed for 36 years. Analysis of the measured balance sequences in the early 1990s demonstrates that mass-balance variation is not synchronous in regions between the lower latitude (the Himalayas and Hengduan Mountains) and the higher latitude (the northeastern part of the Qinghai-Xizang Plateau). In the southern part of the Tibetan Plateau, glaciers have suffered great mass loss and shrinkage, however positive mass balance has been observed on glaciers in the north of the plateau. After the 1989/90 balance year, the average annual water loss of Glacier No. 1 was 204 mm, about 25 mm higher than its 36 year mean.

Different methods for mass-balance calculation have been attempted by many Chinese glaciologists and glacio-hydrologists. Krenke's model or its modifications are now widely accepted and applied in the calculation of mass balance and meltwater runoff of glaciers. Other models, such as degree-day, energy-balance and water-balance models, have been used either for balance calculations or for balance history reconstruction. As tested on Glacier No. 1, both the degree-day and energy-balance models (in which some elements are reasonably parameterized) give an estimate of mass-balance variation close to the observed. Based on the 5 year measurement of surface balance on Xiao Dongkemadi glacier, Tanggula Mountains and a shallow ice core, the balance history for the past 50 years has been reconstructed from ice-core stratigraphy.

Mass-balance measurements have also been made in some limited areas during Chinese field expeditions to Antarctica. Mass-balance reconstruction for Collins Ice Cap, Antarctica was tried, based on available climatic parameters of the nearby climatic observatories.

Following worldwide concern about global change, some Chinese glaciologists have paid much attention to the sensitivity test of glacier mass balance to climate change by using a glacier dynamic model or Grey System Theory. The latter is good for evaluating the equilibrium-line shifts influenced by leading climatic factors.

Ice and snow hydrology

The change of runoff of 53 rivers in the mountains of northwest China and seven large rivers from the Qinghai-Xizang (Tibet) Plateau has been analyzed and an empirical equation of glacier melt water developed with climate coefficient and air temperature as independent variables. Regional distribution of glacial melt water has been calculated. Meltwater from glaciers in China is estimated at 564×10^8 m^3 by the runoff modulus of glacier melt.

Glacier water resources of different mountain ranges and water systems were analyzed. Runoff characteristics of continental and maritime glaciers and the response of runoff to climate change have been presented. Taken as representative, the changes of glaciers, climate and hydrology have been studied in the glaciated area of the Qilian Mountains and the response of glacier runoff to climate change assessed.

Detailed studies on the hydrology of mountain permafrost were carried out at the Binggou experimental basin in the middle Qilian Mountains from 1983 to 1984. Measurements were carried out on precipitation, air temperature, ground temperature, evaporation, ground ice, freezing and thawing of the active layer and snow and ice runoff. From 1989–1994, in cooperation with Professor Ming-ko Woo, McMaster University, Hamilton, Ont., Canada, studies on water balance and runoff modelling in permafrost regions were carried out in the Empty Cirque, at the source of the Ürümqi river in the Tien Shan. Those studies indicate that runoff processes are controlled by water and heat status under certain climatic conditions. The runoff coefficient of the permafrost region is 0.7 to 0.8, larger than that of the non-permafrost region. Along with the climate warming, the runoff coefficient model is employed. A water balance and linear reservoir model has been employed successfully to simulate runoff of the permafrost region.

Based on measurement of glaciers, climate and hydrology at the source of the Ürümqi river, and data from the Tien Shan glacier inventory, the statistical characteristics of their changing conditions have been simulated and discussed for the north flank of the Mt. Tianger, in the Tien Shan. A combined climate–glacier-runoff model based on energy, water and mass balance of glaciers has been presented.

Remote sensing in northwest China

An Information System on Ice, Snow and Water Resources (ISWEIS) in the upper reaches of the Yellow River was established and has been used in the satellite snow-cover monitoring of large areas. Based on the operation of ISWRIS, the inflow discharge of Long Yangxia reservoir was simulated and forecast during the spring snowmelt season. The results showed that the precision of the forecast values was over 80%. The Technological Progress of Chinese Academy of Sciences (CAS) in 1992 has been offered for application to the hydroelectric management of reservoirs in the upper reaches of the Yellow River.

NOAA/AVHRR and Landsat MSS data were used for monitoring dynamic changes of snow in the Qilian Mountains. Models for forecasting snowmelt runoff were developed using the remote sensing data as part parameters. The forecasting accuracy was about 83%. This achievement won the second-class award for Scientific and Technological Progress of the CAS in 1988 and has been used for managing agricultural irrigation in the Heihe basin of the Hexi region.

Snow disaster monitoring and assessment using remote sensing

The system of grading criteria for snow hazards in pastoral areas of China was proposed based on the analysis of the temporal and spatial distribution characteristics of snow. The Operational System for Snow Disaster Monitoring and Assessment (SDMAOS), established in the northern plateau of Xizang (Tibet), can be updated using NOAA/AVHRR data. Some applied models for snow disaster identification, forecasting and assessment were developed, based on the integrated analysis and spatial operations of SDMAOS. The actual monitoring and assessment of snow disasters was carried out in recent years. The simulated results of 1993 and 1994 and the actual operational results of February–March 1995 showed that the SDMAOS had the higher accuracy; the assessment of losses caused by the disaster was almost identical to the statistical data from local government.

Data systems for ice, snow and permafrost

The database for glaciers, snow and permafrost was established, based on the existing information and data in northwestern China. Some NOAA/AVHRR data and Landsat MSS, TM images, collected and stored mainly for the typical areas of the Tien Shan mountains and Qinghai–Xizang Plateau, can be used for updating the database. Digital Terrain Models (DTM) and some applied models were developed for typical areas, which can then be applied to the further study of resources and environments in the cold regions of China.

Recent change of meltwater rivers in northwest China

Since many rivers in the arid northwest of China, particularly in Xinjiang, are supplied by ice–snow meltwater, it is very important that any change of river flow and the water resources should be rationally utilized for the lives and economic development of the local people. As far as global warming since the 1980s is concerned, the climate in northwest China has indicated warming and more precipitation.

Recent changes of river regime were observed in 1992–94 in the China–Japan joint project of ice core and glacier hydrology studies in three major rivers – the Karakax, Yurunkax and Keriya rivers from the West Kunlun mountains, China. Results show that the runoff of Yurunkax river declined about 9% in the 1980s compared with that of the past 30 years; its annual flow also became 27% smaller compared with the two-year period. While the flow of the Keriya and Karakax rivers did not show any change, the annual flood of the former was 27% smaller than that in the past 30 years. However, discharge of all rivers in May shows remarkable increase in the 1980s, with an increase of 17.5–29.3%. Compared with the river regime on a different scale, the hydrological response of a larger river with more glaciers is more sensitive than a smaller one. The fluctuation of discharge in May and the annual flood are two sensitive hydrological factors which respond to climatic change. In addition, in order to compare the spatial difference of the glacier hydrographs, another similar study has been done in the Manas river basin (Lui J., 1994) on the northern slopes of the Tien Shan mountains and similar results have been obtained. Both studies indicate that more precipitation will not make more runoff and floods if air temperature increases 0.5–0.6°C and precipitation increases 20%. But if temperature and precipitation decrease, the major factor that affects the river regime will be the heat conditions in the summer, instead of the annual air temperature.

Alpine hydrochemistry

Studies on the water and snow chemistry of seasonally snow-covered catchments were conducted from 1991–1994 in the headwater basins of the Ürümqi river, Tien Shan. The project was funded by the Lanzhou Institute of Glaciology and Geocryology (LIGG), the US NASA Earth Observing System and the Colorado Niwot Long-Term Ecological Research Project on the basis of a collaboration between LIGG and the University of California at Santa Barabara and between LIGG and the Institute of Arctic and Alpine Research.

Water and snow samples were collected in May 1992 in the headwater basin and along a longitudinal transect of the Ürümqi river. Dominant ions in surface water were Ca^{2+} and HCO_3^- at all sites. Maximum measured SO_4^{2-} concentration measured in surface waters is 550 μl eq l^{-1}, and is balanced by Ca^{2+} and HCO_3^-; pH was slightly alkaline at all locations. Preliminary analysis of stable sulfur isotopes in the headwater basins shows a value of +6.8 for $\delta^{34}S$ in snow and +3.3 in surface waters. Changes of the $\delta^{34}S$ value in surface water with increasing basin area is variable, suggesting change in the stable sulfur ratios of source materials. The large amounts of HCO_3^- and cations at all sites indicates that the Ürümqi river is not sensitive to acidification from atmospheric deposition.

Hydrological and hydrochemical measurements were conducted from May to September 1991 in the Empty Cirque catchment, a seasonally snow-covered Alpine basin at the headwaters of the Ürümqi river. Solute concentrations in stream water are generally highest at the beginning of snow melting and then decline through the melt season and into summer. They then increase as the contribution of baseflow to stream discharge increases. The snowpack was sampled for chemical contents during maximum snow accumulation in May 1992 to investigate the role of an ionic pulse and dissolution of aeolian particles to stream water chemistry. At the initiation of snow melting, ionic concentrations in snow are generally higher by a factor of four, close to the groundwater, compared with the top of the snowpack, consistent with the release of solutes from the snowpack in the form of an ionic pulse. Maximum concentrations of HCO_3^- and Ca^{2+} in the stratified snowpack were close to 400 $\mu l\,eq\,l^{-1}$ and associated with a visible dirty ice lens, indicating that dissolution of aeolian particles in snow is a major source of these solutes. The release of solutes from the snowpack influences the stream chemistry in snowmelt runoff, indicating aeolian deposition and an ionic pulse are important potential sources of solutes in stream flow.

Snow cover and climate

Daily snow depth records from 2300 meteorological stations, covering the period 1951–1980, are used to monitor and diagnose trends in secular variation and spatial characteristics in China. The snow mass time series reveals that there is a strong teleconnection among snow cover, ENSO, major volcanic eruptions, and the CO_2-induced warming. The country-wide snow mass variation is positively related to global mean temperature, increasing during the current warming period and decreasing during the recent cooling period prior to the mid 1960s. A synchronous relationship exists between ENSO and snow winters in China. The annual snow fluctuation seems to be generally out of phase with volcanic activity. The anomaly map shows that snow mass increases at high altitudes and in moist regions, while it decreases in arid lowland and the southern boundary zone during the warming period. The potential CO_2-induced changes in snow mass will further aggravate the regional differentiation between high mountains and lowlands, between humid and arid regions. The number of snow-cover days will decrease in the northern lowland, and snowfall will increase in the Qinghai–Xizang Plateau, high mountains and the lower reaches of the Yangtze river.

Daily snow-depth records at 60 meteorological stations over the Tibetan Plateau for 1957–92 are used as a basis for site and area time series development. A statistical model is used to test the trend in time series of snow cover. The results of three trend estimates based on the difference of fit of average and least squares imply that the annual cumulative snow depth increased by 2.9%, 1% and 1.9% in the Tibet region, Qinghai Province and over the Tibetan Plateau, respectively, for the period 1957–92. The spatial pattern of trend estimated at 60 stations convinced us that the increase trend is evident over the entire plateau. Further examination reveals a positive correlation (+0.21) between snow cover over the Tibetan Plateau and surface air temperature in winter over the Northern Hemisphere in this period.

Submitted by Yao Tandong

RUSSIA

For abbreviations, see end of this report

GLACIERS AND ICE SHEETS

Franz Josef Land

(A. Glazovskiy, Yu. Macheret, IG; I. Ignatieva, IMMSU)
The evolution of the Graham Bell Island ice caps is being modeled using radar (ice thickness, subglacial topography) and mass-balance data collected in 1994, and the mathematical models are being improved. The present state of the ice caps, and the influence of short- and long-term climate and sea-level changes on their dynamics are being measured. Various paleoglacioclimatic hypothesizes are being tested using an algorithm that takes into account relationships between ice temperature, accumulation and ablation rate, surface elevation and the size of the ice caps. If in the next 100 years the present glacioclimatic conditions do not change, the glacier area will decrease by 11%, but the glacier volume changes insignificantly, mainly at the expense of those glacier parts lying below sea level. The glacioclimatic conditions leading to the formation of the present ice caps has been evaluated: following the complete disappearance of glaciation, it takes at least 2500 years to build an ice cap of the present shape with cooling of not less than 2.5°C and an accumulation rate 30% greater compared with present conditions.

(A. Glazovskiy, Yu. Macheret, IG)
Airborne radio echo-sounding data (continuous analog records) collected on Franz Josef Land glaciers in 1994, together with SPRI, are being processed, interpreted and analyzed. Ice thickness and subglacial relief profiles and maps of glaciers on the islands investigated, including Graham Bell Island, Vilchek Land, Alexandra and George Land, are being constructed. For selected islands of the archipelago, scanned satellite images and topographic maps are available for further calculations of glacier area and equilibrium line altitude (ELA) changes during the last 40 years. The main morphological and structural characteristics of Franz Josef Land glaciers are revealed by the airborne radio echo-sounding data. Typical and maximum ice thicknesses are 250–300 m and 450 m respectively; 1.5–2 times more than previous estimates. Those parts of the glaciers (10–50% in area) with beds below sea level, at depths up to 170 m, are also detected. Moreover, it has been established that the analog and digital radar records (particularly regions with disappearance of bottom returns and registration of internal reflections, amplitude of reflected signals) can be used to identify ice-formation zones, to estimate average ice temperatures and bottom conditions, and for paleo-glaciological reconstruction.

King George Island, South Shetland Islands

(M. Moskalevskiy, A. Glazovskiy, IG)
Ground-based radio echo-sounding surveys, with mono-pulse radar and a snow survey, were carried out on the southwestern slope of King George Island ice cap in January 1995. Results indicate the bed-rock profile and show high water content in the firn/ice mass.

Snow accumulation at Vostok

(V. Lipenkov, AARI)

Monthly observations of snow accumulation and density were carried out using 79 stakes in a 1 km^2 area, 1.5 km north of Vostok station. In 1993 and 1994, accumulation was up to 2.3 and 1.4 $g\,cm^{-2}$ with an average for 25 years of 2.2 $g\,cm^{-2}$.

Snow and ice sampling in the Arctic

(L.M. Savatyugin, AARI)

Scientists of AARI, with colleagues from Geological Survey of Canada and Campbell Scientific Inc. of Canada, carried out snow and ice sampling to study anthropogenic pollution in the spring of 1993 and 1994. The samples were taken at the ice cap of the Franz Josef Land and Severnaya Zemlya archipelagos, at Dixon Island and on the sea ice at three points along the route Severnaya Zemlya–North Pole. At Academii Nauk Glacier, two boreholes with ice cores 3 and 17 m long were drilled and an automatic meteorological station was inspected. This work is a part of the ICAPP program.

Djankuat Glacier, Caucasus

(M. Kunakhovitch, A. Sokalskaya, IG)

A one-dimensional numerical model of glacier mass balance and its reaction to climatic change was developed. In the mass-balance computation, only the vertical profile of annual snow accumulation and the glaciated area distribution with altitude are used. For the ice flow part of the model, maps of the glacier surface and bottom are used. The model was applied to Djankuat Glacier, in the Caucasus, for which long-term measurements are available. Using Budyko's global climatic prognosis, a forecast of mass-balance and morphological characters of Djankuat Glacier was made for the year 2025. The mass balance will increase, owing to the increase of precipitation. The glacier will advance for about 300 m and the tongue thickness will increase by 150 m in 30 years.

Glaciers of Kamchatka

(Ya. Muraviev, IV)

Mass-balance studies of Kozelskiy Glacier and glaciers of the Klyuchi volcano group were continued for 1992–1995. Slightly negative mass balance occurred due to warm ablation seasons. An advance of Erman Glacier, which took place during the last 50 years, finished in 1994; the 1.5 km wide glacier edge advanced 3.2 km and the glacierized area was increased by 2.72 km^2 during this period. Khalaktyrskiy, Kambal'niy and Elizovskiy glaciers are advancing after the 1991 eruption of Avacha volcano, against a background of retreating glaciers.

ICE-CORE STUDIES

Drilling at Vostok station

(N. Vasil'ev, SPSMI; V. Lipenkov, AARI)

Deep ice coring at Vostok station was carried out within the framework of the joint Russian–French–USA program. From April–September 1993, the drilling of the new 5G borehole proceeded at 2483–2755 m using an electrothermal drill with a diameter of 132 mm. The operations were stopped because of a shortage of drilling fluid used to counterbalance the ice pressure. The borehole was conserved in January 1994 and re-opened in December 1994, since the Vostok station was temporary closed during this period. Borehole 5G-1 was 3100 m deep in August 1995 and ice core of good quality was taken with the help of the electromechanical drilling equipment KEMS. The diameter and inclination of the borehole was gauged and the density of liquid in it measured to control the borehole.

Vostok station ice cores

(V. Lipenkov, AARI)

The work is conducted under an agreement on cooperation in the field of Antarctic ice core and paleoclimate research between the AARI (Russia), the Laboratoire de Glaciologie et Géophysique de l'Environnement (France), and the Rosentiel School of Marine and Atmospheric Science, University of Miami (USA). The field activity was carried out during the summer of 1992/93, 1993/94 and 1994/95. Ice-core sampling and measurements were carried out by different laboratories according to their priority. The highest priority was to process the 5G-1 ice core from 2500–2755 m depth. Samples for analysing the stable isotopes (^{18}O and deuterium) and beryllium-10 were prepared and ECM (electric conductivity measurements) were done on a continuous basis.

Microscopic observations of ice structure, including the shape and size of ice crystals and air bubbles as well as of air-hydrate crystals, were carried out by Russian scientists using samples from 70–2755 m; the intervals between the measurements were 5–25 m. The volume and number of air-hydrate crystals depend on the climatic changes.

Climatic changes revealed in the Vostok core

(N. Barkov, V. Lipenkov, AARI; A. Salamatin, KSU)

The results of the Vostok ice core studies to 2546 m show the environmental record covering the last 220 kyr and include the time series of several climate-related parameters, such as atmospheric temperature, atmospheric aerosol content and concentration of the greenhouse gases (CO_2 and CH_4), as well as the isotopic composition of atmospheric oxygen. They have been reviewed on the basis of data obtained by analysing the deuterium content in ice, the concentration of microparticles, and the composition of atmospheric air occluded in the bubbles and air-hydrate inclusions. From comparison of the Vostok records with those obtained from Greenland (GRIP) and from deep-sea cores, it was revealed that major low-frequency variations of climate occurred simultaneously in different latitudes.

Ice-core drilling in Svalbard

(S. Arkhipov, IG; O. Watanabe, K. Kamiyama, NIPR)

A joint Russian–Japanese glaciological expedition obtained a 210 m ice core from Westfonna (79°58′ N, 21°02′ E), Nordaustlandet, Svalbard in May–June 1995. Increasing acidity and electrical conductivity in the upper 30–40 m part of the ice core was interpreted as a result of anthropogenic pollution during the 19th–20th centuries. Relatively high ice temperatures (-2.1 ± 0.1°C at 17–50 m and -4.5 ± 0.5°C at 90–210 m), and the presence of an isothermal layer at 150 m, are connected to changes of the ice formation regime.

Pollen data from Vavilov Ice Cap

(A. Andreev, V. Nikolaev, IG)

The Vavilov Ice Cap (79°20′ N, 95°27′ E, 665 m a.s.l.) was drilled near the present-day firn line. The ice core was represented by 458.15 m of pure glacier ice, 2.15 m of debris-containing ice and 2.28 m of underlying frozen sediments. Palynological analyses showed an unique character of pollen spectra. The high frequency of exotic pollen suggests that spectra were formed by long-distance pollen influx. This significantly restricts the use of pollen for climate–stratigraphical correlations of glacier ice. The presence of *Cerealia, Plantago lanceolata, Centaurea cyanus, Cannabis* and *Juglans* pollen (whose influx was connected with human activity in Europe) suggests the upper 65 m of the ice core was deposited during the last millennium. The high frequency of *Tilia cordifolia (platyphyllos)* pollen in the upper 40 m shows the influence of the westerlies in the summer season during the last 500 years.

Severnaya Zemlya ice cores

(V. Nikolaev, IG; D. Bol'shiyanov, O. Klementyev, AARI)
Structural-stratigraphic and isotopic (^{18}O and D) analyses of the ice core from Vavilov Ice Cap show that the pure ice is of Holocene age, the ice at 458.59–459.28 m depth, covered by blocks of frozen deposits, is Pleistocene glacier ice, and that at 459.28–461.61 m formed during the Last Interglacial. A complex investigation of ice cores from deep boreholes on these ice caps suggests these ice caps were very small during the Last Interglacial, and that permafrost formed. Glaciers probably grew till the end of the Pleistocene. They were smaller than modern ones. During the Holocene, the ice caps grew again and reached their biggest size about 2500 B.P.

Ice-core drilling, Franz Josef Land

(V. Mikhalenko, IG; L. Thompson, BPRC)
A joint Russian–American glaciological expedition obtained four shallow ice cores from Lunniy Dome, Alexandra Land (80°39′ N, 46°48′ E); Hall Island; Hydrographers Dome, Heis Island (80°37′ N, 58°02′ E); and Windy Dome, Graham Bell Island (80°47′ N, 63°32′ E), Franz Josef Land in May–June 1994. The Windy Dome ice cap is potentially an ideal site for high-latitude paleoclimatic research and reconstruction. It is about 500 m thick and has firn layers throughout the 24 m core collected there. The 24 m temperature is -6.2°C and the annual accumulation rate appears to be 500 mm.

SNOW AND AVALANCHES

Snow pack structure and properties

(V. Golubev, MSU; E. Guseva, IMMSU)
A nonlinear, thermomechanical model of stratified snowpack evolution has been developed. It incorporates Stefan's thermal problem, an equation of snow densification, and equations of structure and strength alternation. Using standard meteorological data, there is good agreement between experimental and field studies. The strong influence of snowpack discontinuities on diffusive mass transfer is established. The model permits calculation of the structural, thermal and mechanical properties of a snow layer and the time of a loose horizon formation on the bottom and inside a snow pack.

Nival-glaciological map of Russia

(N. Osokin, V, Zhidkov, IG)
One of the most convenient forms of information on the distribution of nival-glacial phenomena and their interaction for specific conditions is the nival-glaciological map. The maps depict the distribution, frequency and intensity/magnitude and potential impact of such natural hazards as snow avalanches, mud slides, ice and glacier pulses. A method for compiling such maps for Russia has been proposed.

Structure and properties snow on mountain slopes

(V. Golubev, Yu. Seliverstov, MSU)
Studies of the spatial and temporal variability of the structure, density and mechanical properties in snow-pack horizons were made on mountain slopes in the Caucasus, Tien Shan and eastern Siberia. The mean slopes were 20–30°, fluctuating at some sites from 10–40°. The variation factor of snow horizon thickness was $C_v = 0.15$, density $C_v = 0.10$, grain size $C_v = 0.15$, relative contact surface $C_v = 0.30$ and the tensile strength $C_v = 0.50$. The spatial variability can exceed by 2–5 times the temporal variability of structure and properties of snow pack horizons on any slope site.

Avalanche regime, Kamchatka

(R. Shaihutdinov, KRAS)
The submeridional disposition of the main ranges in Kamchatka results in a latitudinal orientation of river basins. As a result, 80% of all avalanches are produced from leeward slopes. The deep snow cover promotes the formation of huge volumes and runout distances. Snow avalanches of $3 \times 10^6 m^3$ and runouts of approximately 3–5 km are produced annually from the leeward slopes of Vilyuchek Volcano. All avalanches contain 5–10% of rock debris.

Ecology of a snow pack

(V. Golubev, Yu. Seliverstov, MSU)
During a significant part of the year for regions with severe and moderate climate the function of the ecosystem is affected by snow cover and the availability of dense and loose horizons in it. The distribution and genetic types of structural heterogeneities are determined by the climatic zonality and local conditions. It is possible to identify 5 main zones in Russia possessing appropriate wind, radiation, regelation or regelation-infiltration conditions inside which horizons of diffusion loosening, or crusts and densification horizons can develop. The influence of snowpack structure on plant communities, fauna and economic activity is especially important in abnormal winters (as much warmer as more cold). Such winters can change plant communities and the faunal representatives. The results of changes of snowpack structure are comparable to ecological accidents in some cases.

Geoecological aspects of Kamchatka eruptions

(Ya. Muraviev, S. Fazlullin, IV)
A method for estimating geochemical pollution from modern volcanism is being devised from the concentration of petrogenetic elements in the seasonal snow cover. The snow cover can be viewed as a reflection of the regional lower atmosphere recording volcanic and anthropogenic pollution impacts on the local atmosphere, water basins and soil.

Penetration tests of snow properties

(N. Osokin, R. Samoilov, V. Zhidkov, IG)
More than 10 penetrators, sounding and rotary shearing instruments with different indentors, have been developed. These have been used on the plain terrain and mountain slopes and plateaus of Svalbard, Siberia, Caucasus, Carpathians and Khibiny. It was shown that: (1) this field method is very efficient for evaluating spatial–temporal variations of snow properties; (2) test parameters, such as specific resistance of penetration, ram hardness and rotation shear, are invariant and have a stable correlation with several physical properties of the snow, mainly with maximum resistance to loading, rupture and deformation modules.

Snow structure changes during densification

(V. Golubev, MSU)
A regular packing of spheres or polyhedrons of a certain form, connected by rigid bonds, is useful as a model of snow structure. The basic parameters of the structure are the coordination number (i), a friability parameter ($K = L/D$) and the rigidity of structure parameter ($b = d/D$), where D is average grain size, L is average distance between grain centers and d is average linear size of contact area. The process of snow densification can be considered as a change of magnitudes i, K and b. The most probable ratios of K and b and values of i for a snow of variable density are established from possible variants of contacting the polyhedral grains and using a dependence of snow density (p) from the i, K and b parameters. The change of i from 3 ($p = 130\,\mathrm{kg\,m^{-3}}$) to 4 ($320\,\mathrm{kg\,m^{-3}}$), and then up to 6 ($550\,\mathrm{kg\,m^{3}}$) is connected to the transformation of grain packing from friable hexagonal up to tetrahedral and then to cubical. The values $i = 8, 10, 12$ ($p = 690\,\mathrm{kg\,m^{-3}}$, $810\,\mathrm{kg\,m^{-3}}$, $890\,\mathrm{kg\,m^{-3}}$) characterize octahedral and dense hexagonal grain packing. The transition from one kind of grain packing to another occurs in a relatively narrow range of density. The transformation of grain packing is reflected in the changes of the law of compaction of snow and firn and the physical properties of snow. The regular grain-packing model permits an estimate of the rate of acoustic oscillations in snow, elastic and strength characteristics, and the conductive thermodiffusivity of porous ice blocks.

Mapping snow-avalanche activity

(E. Troshkina, T. Glazovskaya, MSU)
The degree of snow-avalanche danger for each continent is reflected in snow-avalanche maps of the world. Regions with avalanche danger occupy 6% of the area and occur on every continent: 37.8% of the former USSR territory, 27.5% in Asia (excluding the FSU area), 18.1% in North America, 8% in Europe, 5.8% in South America, 1.9% in Antarctica, 0.6% in Australasia and New Guinea and 0.3% in Africa have potential danger from snow-avalanche activity.

FROZEN GROUND

Massive ice, Jamal Peninsula, Siberia

(V. Solomatin, MSU; V. Nikolaev, IG)
Structural analysis of massive ice in central Jamal has shown that the layers represent the fragments of a certain ice body, coinciding with a definite stratigraphic horizon, which dates back to the Late Pleistocene glaciation. Massive ice layers are, as a rule, bedded over subaerial sandy sediments of the pra-Ob' river and are overlapped by clayey sediments of marine origin. The degree of salinity and chemical composition of massive ice differs greatly from the overlapping sediments, while the nature of stable connections between the ions of micro elements differs from those of the underlying rocks. The chemical elements' spectra in the massive ice is similar to that of the glacier ice in the ice domes on the Severnaya Zemlya archipelago and the surface waters of Jamal. The ratio of the ordering of chemical elements in massive ice and strained ice-ground complexes, paragenetically related to them, is similar to the ratio in glacier and debris-contained ice on Severnaya Zemlya. It is concluded that the massive ice has a glacial genesis.

New paleothermometer for permafrost areas

(V. Nikolaev, IG; D. Mikhalev, MSU)
The averaged $\delta^{18}O$ values for recent ground ice (segregated ice and ice-cement) were correlated with the mean temperature of the: cold season (1); January (2); calendar winter (3); warm season (4); and mean annual temperature (5), for 17 regions extending from the mouth of the Lena to Chukotka. The correlation coefficients are 0.953 (1), 0.883 (2), 0.875 (3), –0.426 (4) and 0.406 (5). These results allow the use of structure-forming ice $\delta^{18}O$ as a paleothermometer. Paleotemperatures were calculated using $\delta^{18}O$ data on syngenetic ground ice. The results show that during cold stages in Yakutia, the ground temperature (January) was 10–14°C colder than today. The ground temperature (January) for the Last Interglacial period is estimated as 2°C warmer than present.

Isotopic studies of ice under Vavilov Dome

(V. Nikolaev, IG; J. Jouzel, M. Steivenard, LMCE; R. Souchez, ULB; D. Bol'shiyanov, O. Klementyev, AARI)
The $\delta^{18}O$ values of basal ice from the Vavilov Ice Cap core (Severnaya Zemlya) exhibit a range of about 13‰, $\delta^{18}O = -26.0$ to -13.2 ($\delta D = -187$ to -96). In the case of debris-containing ice, results are well aligned on a straight line:

$$\delta D = (7.88 \pm 0.44)\delta^{18}O + 10.8 \pm 1.4); \; r^2 = 0.970.$$

This line can be considered as a Meteoric Water Line and is typical for unmodified glacier ice. Some of the samples have $\delta^{18}O$ values of about 5–7‰ lower than normal Holocene values (present-day $\delta^{18}O$ average value for snow is –19‰) for the area. They represent the first Pleistocene ice discovered in the Eurasian sector of Arctic. In the case of ice samples from frozen sediments, they also lie on a straight line:

$$\delta D = (6.54 \pm 0.71)\delta^{18}O - (6.5 \pm 1.7); \; r^2 = 0.917.$$

This slope is typical for that arising from a freezing or melting–refreezing process in fairly closed-system conditions. Calculation of the initial isotope composition of the parent meteoric water for this ice gives: $\delta^{18}O = 12‰$ and $\delta D = -90.9‰$ (Last Interglacial).

Vapour in the frozen ground–snow–atmosphere system

(V. Golubev, Yu. Seliverstov, MSU; S. Sokratov, IG)
Experimental studies of snow evaporation, vapour diffusion in snow and mass transfer at the frozen ground–snow

interface were conducted to reveal details of vapour migration in a frozen ground–snow–atmosphere system. Studies of humidity in snow pores and snow evaporation at a temperature of 245–272 K have shown the concentration of vapour in snow exceeds the calculated concentration of saturated vapour with respect to ice; relative supersaturation grows at decreasing temperatures, whereas the absolute quantity of the redundant concentration remains constant. Studies of vapour diffusion, at a gradient of 0.05–0.5 $\mathrm{K\,cm^{-1}}$ and a snow density of 0.25–0.56 $\mathrm{g\,cm^{-3}}$, have shown that vapour transfer in snow is less than the coefficient of vapour diffusion in air and is proportional to snow porosity. Research on mass transfer at the snow–frozen ground interface, at small temperature gradient, has shown that vapour migration in the frozen ground, and the formation of loose horizons on the bed of a snow pack, are due to increased vapour concentration in the snow pore space.

GLACIAL GEOLOGY

Volcanic activity, glaciers and climate of Kamchatka

(O. Solomina, IG; Ya. Muraviev, IV)

Lichenometrical and dendroclimatological studies of volcanic and glacial deposits were done at the Avacha and Klyuchi volcano groups. Moraines of the Little Ice Age were dated and their features correlated with young lava stream lahar deposits. The volcanic signal can be identified in the dendroclimatological data.

Glaciation of Tibet

(A. Orlov, IG; R. Gobedzhishvili, IGG)

The ancient glaciation of southern and southeastern Tibet was reconstructed from field studies. Valley glaciers occurred basically during the Pleistocene in these regions. Local ice caps existed only on ancient flat surfaces with altitudes greater than 4500–500 m a.s.l. The latest period of glacier activity began about 4000 yrs ago.

ICE AS A MATERIAL

Artificial pore ice for demineralizing salt water

(A. Sosnovskiy, IG)

It is possible to generate artificial pore ice by freezing water drops in a spray-cone formed by modern long-stream sprinklers at an air temperature below −5 to −10°C. The productivity of this method is an order higher than traditional methods. The purification and demineralization from organic admixtures, ions and micro-elements has great potential as a process of spray-cone freezing, which makes it possible to get a mass of artificial ice more than 10 m high. This ice has an order of magnitude less mineralization. Parts of the melt discharge has mineralizations hundreds of times less than the original water.

Structure development of congealing ice

(V. Golubev, MSU)

The basic factors of ice structure development are: (1) the structure, chemical and mineralogical composition and physical properties of substrates or the surrounding medium; (2) water supply to the crystallization surface or water distribution in the medium; (3) thermal conditions of crystallization; and (4) water mineralization. The first factor determines ice nucleation conditions and the structure of the contact layer for ice. Three other factors operate throughout the ice crystallization process. Congealing ice generation in the cryosphere can be classified into three basic groups, depending on the conditions of thermal interaction of water and the substrates: (1) the progressive cooling of water and substrates (floating ice formation, ground freezing and ice crystal nucleation in the atmosphere); (2) freezing on cold substrates (naleds, injection ice in frozen ground, ship/shore engineering construction icing from water pouring, artificial freezing of ice bodies in layers); (3) the freezing of supercooled water on substrates (plain icing, ship/shore engineering construction icing from water splashing, glaze icing, artificial icing effects on cloud systems). Periodic changes in the thermal interaction conditions are inherent to icing processes and infiltration events in snow/firn packs and frozen ground. The differences of thermal interaction conditions predetermine the structural features of ice bodies and their mechanical properties. Theoretical and experimental research permits prediction of the conditions of generation, structure and properties of ice covers on natural and artificial surfaces.

Abbreviations

AARI:	Arctic and Antarctic Research Institute, St. Petersburg
BPRC:	Byrd Polar Research Center, The Ohio State University, USA
IG:	Institute of Geography, Russian Academy of Sciences, Moscow
IGG:	Institute of Geography, Georgian Academy of Sciences, Tbilisi
IV:	Institute of Volcanology, Russian Academy of Sciences, Petropavlovsk–Kamchatskiy
IMMSU:	Institute of Mechanics, Moscow State University
KRAS:	Kamchatka Regional Avalanche Service
KSU:	Kazan State University
LMCE:	Laboratoire de Modélisation du Climat et de l'Environnement, CEA/DSM CE Saclay, France
MSU:	Moscow State University
NIPR:	National Institute of Polar Research, Japan
SPRI:	Scott Polar Research Institute, UK
SPSMI:	St. Petersburg State Mining Institute
ULB:	Université Libre de Bruxelles, Belgium

Submitted by Vladimir Mikhalenko

USA - EASTERN

For abbreviations, see end of this report

GLACIERS

Flow of Columbia Glacier, Alaska

(K. van der Veen, E. Venteris, I. Whillans, BPRC)
Columbia Glacier, a (large) tidewater glacier in southeast Alaska, has been monitored by the United States Geologicl Survey, Tacoma, since 1977, when the possibility of rapid retreat was raised by A. Post. Rapid retreat started in late 1983 and has continued since at an accelerated rate. The main data source used in our study consists of surface velocities and elevations derived from repeat aerial photogrammetry of the lower 14 km of the glacier conducted about four times per year. These data are used to evaluate patterns in surface strain rates and driving stress, and how these changed during the retreat. This is done to identify mechanisms responsible for the rapid retreat and the rapid increase in glacier speed that occurred at the same time. In addition, derived calving rates and geometry of the glacier terminus are used to study the process of tidewater calving, and what factors control the production of icebergs.

Glaciohydrology and glaciohydraulics

(D. E. Lawson, CRREL; J. C. Strasser, E. B. Evenson, LEHIGH/EES; G. J. Larson, MSU/GS; R. B. Alley, PSU/ESSC)
Subglacial water and suspended sediment discharge were monitored at the terminus of the Matanuska Glacier, Alaska, during 1993, 1994, and 1995. Water samples for sediment concentration were obtained regularly in summer from subglacially fed discharge vents at the glacier margin and from the Matanuska River, at a gauging station approximately 300 m downstream from the terminus. A meteorological station at the terminus records information for correlation of subglacial hydrological events with precipitation events. Conductivity/temperature/depth sensors suspended in subglacial vents accurately record water-quality parameters that reflect changes in water sources, discharge and the drainage system. Subglacial water and sediment discharge in the river vary with glaciohydraulics within and below the ice. Dye tracer experiments revealed that subglacial water flow during the peak melt season occurs through a complexly distributed system. The stable isotopic compositions of water sources ($\delta^{18}O$, δD) within the drainage basin are being compared to those of subglacial discharge, and the Matanuska River, to further assess basin hydrology and its role in temporal changes in glaciohydrology. These multiple sources of data are currently being analyzed to assess the glaciological controls on sediment and water runoff in this basin. Investigations will continue in 1996, with expanded analyses of ice motion correlated with subglacial measurements using boreholes and glaciohydrologic analyses at the ice margin.

Basal ice formation and sediment entrainment

(D. E. Lawson, S. A. Arcone, CRREL; J. C. Strasser, E. B. Evenson, LEHIGH/EES; G. J. Larson, MSU/GS; R. B. Alley, PSU/ESSC)
Investigations of the basal zone of the Matanuska Glacier, Alaska, indicate that debris-rich stratified facies ice has formed recently from freeze-on of subglacial waters enriched in bomb-produced tritium, ^{18}O, and D relative to englacial zone ice. Field analyses and theoretical calculations demonstrate that ice accretes to the glacier sole from water that supercools as it flows uphill out of an overdeepening within a distributed subglacial drainage system. Significant amounts of sediment (mean ~30% by volume) are entrained by filtering through the open structure of frazil ice and other platy ice forms, and by ice growth into subglacial materials. Preliminary petrographic analyses suggest a continuum of ice fabrics and textures exists between frazil and anchor ice masses and the stratified facies. Such a continuum would reflect deformation of newly accreted ice during flow. Ground-penetrating radar (GPR) analyses provide data on bed configuration and the subglacial drainage system. Additional ice facies analyses that include tritium, $\delta^{18}O$ and δD are planned at the Matanuska and other valley glaciers in south-central and southeast Alaska to evaluate rates of subglacial freeze-on and the factors controlling it. Boreholes drilled using hot water will provide information on subglacial hydrologic conditions. Additional GPR analyses will evaluate the distribution of the basal zone relative to the bed and ice surface configuration. Glaciohydrologic investigations will provide water-quality data on conditions determining subglacial freeze-on.

North Cascade glacier–climate project

(M. S. Pelto, Nichols College, Dudley, MA)
The North Cascade Glacier Climate Project (NCGCP) is completing its 12th year of annual balance monitoring on eight North Cascade glaciers. After strongly negative mean annual balances (b_n), 1995 will be close to equilibrium or slightly positive (1992 $b_n = -1.81$, 1993 $b_n = -0.75$, 1994 $b_n = -0.69$). Terminus position was monitored on 47 glaciers in 1994 and 1995. All 47 have retreated from their 1993 positions. Glacier runoff is being monitored below four glaciers on a daily basis. In one basin, the glacier has lost 26% of its total area since monitoring began in 1986; the result has been a 20% reduction in glacier runoff during August and September. A survey of glaciers around Glacier Peak in 1994 and 1995 revealed that average retreat since 1984 has been 84 m. This retreat has led to the uncovering of seven new Alpine lakes. One glacier, the Milk Lake Glacier, has disappeared and is now just Milk Lake.

Holocene paleoclimate and ice margin fluctuations, Glacier Bay, Alaska

(D. Lawson, L. Hunter, S. Bigl, CRREL)
Slope instability and recent deglaciation of upper Muir Inlet have led to exhumation of interstadial stumps and wood fragments overridden during the Holocene, including the Little Ice Age advance in Glacier Bay. Field efforts during 1994 and 1995 focused on the collection of organic samples (cross-sections of tree stumps, wood fragments, and buried soil horizons) for AMS ^{14}C dating. A total of 118 samples (some duplicates and subsamples) have been collected and 46 AMS ^{14}C dates have been acquired. Dates cluster in two primary groups: (1) 6900–8200 BP and (2) 2010–2820 BP. In addition, analyses are being conducted on samples from central Glacier Bay on Whidbey Island, Queen Inlet and Reid Inlet. Many samples are from areas where dates were previously unavailable. Continuing

analyses will provide additional data in the Muir and Tarr Inlets region for defining the paleoclimate and glacial history of Glacier Bay.

Process monitoring and dynamics of glaciers with tidewater and terrestrial termini

(D. Lawson, L. Hunter, S. Bigl, CRREL; E. Cowan, ASU; G.J. Larson, MSU/GS; E.B. Evenson, LEHIGH/EES; P. Carlson, USGS/MP; R. Powell, NIU)
Ongoing research on tidewater glaciers in southeast Alaska focuses on documenting glacial and proximal marine processes and glacier response. Studies are in two general categories: (1) monitoring of terminus dynamics and sedimentary processes in morainal bank growth and decay; and (2) analyses of subglacial processes and glaciohydraulics. Category 1 studies have documented that termini dynamics are controlled by sedimentary processes that determine morainal bank growth and grounding-line water depth. Isotopic studies (^{18}O, D, and tritium) are being carried out to evaluate basal ice formation processes and to test a model of ice accretion developed at the Matanuska Glacier, AK. These studies are part of investigations of rates of debris entrainment, transport and flux in large tidewater glaciers. Future research will focus on water and sediment flux in relation to tidewater ice margin dynamics. Basal zone ice and subglacial conditions will be examined using nonintrusive geophysical methods linked to borehole observations.

Irian Jaya glaciers, vegetation, and climate variability since 30 ka

(M. L. Prentice, UNH/CCRC; G. S. Hope, ANU; J. A. Peterson, MONASH; W. S. Hantoro, IIS)
Glacial geomorphology and geology in the highlands of western Pegunungan Maoke, Irian Jaya, Indonesia (4° S, 137° E) were mapped . This area includes Puncak Jaya (4884 m a.s.l.), which features the only remaining glaciers in New Guinea and, to the north, the Kemabu, Zengillorong and Ekabu Plateaus. The mapping is at 1 : 50 000 scale and based primarily on SPOT panchromatic (10 m resolution), Landsat Thematic Mapper (30 m resolution), and Synthetic Aperture Radar (15 m resolution) data. Moraines and outwash morphology and stratigraphy. as well as cored bogs in Hogayaku Valley on the Kemabu Plateau, were studied. Glaciation of the region, probably during the Last Glacial Maximum, was far more extensive than previously considered. Not only was the crest of the cordillera glaciated, but outlying lower massifs also held highly active icefields. Glaciation of these low summits indicates more equilibrium line altitude depression than previously thought, and also that most of the depression resulted from LGM cooling. The oldest deglaciation date found so far for the island of New Guinea is 14.8 ^{14}C kyr BP. There are diverse, well-preserved, glacial-sediment landscapes that predate the LGM.

Central Asian glaciochemical program

(C. Wake, P. Mayewski, M. Twickler, S. Whitlow, J. Dibb, Y. Qinzhao, UNH/CCRC; L. Zhongqin, X. Zichu, Q. Dahe, W. Ping, H. Jiankang, LIG)
Over the past several years, high resolution, short-term (<20 years) glaciochemical records have been collected from glacier basins in central Asia, including the western Himalaya, Karakoram and eastern Tien Shan. These records, combined with new records from the eastern and central Himalaya, Karakoram, eastern Tibet Plateau, western Kun Lun and Pamirs, provide a broad sampling of the dominant atmospheric circulation patterns and landscape in central Asia. The resulting glaciochemical data base clearly illustrates the systematic geographic distribution of major ions in snow and ice throughout the mountains of central Asia. The spatial variability of snow chemistry is closely linked to the relative input of desert dust derived from large deserts in central Asia (e.g., Taklamakan, Gobi, Qaidam and Thar). Only glaciers at high elevation on the southern slopes in the eastern Himalaya are relatively free from the chemical influence of desert dust, and therefore likely hold the best records detailing the annual variation in the strength of the Indian monsoon.

The soluble, major-ion content in aerosol samples collected at four high-elevation sites in central Asia was also analyzed. The aerosol data indicate that high elevation sites in the Himalaya and southeastern Tibetan Plateau regions provide isolated platforms, above the planetary boundary layer, from which to investigate the composition of the remote continental troposphere.

Ice-core records from monsoon Asia

(C. Wake, P. Mayewski, D. Meeker, J. Dibb, M. Twickler, S. Whitlow, Y. Qinzhao, A. Shrestha, UNH/CCRC; S. Adhikary, Himalayan Climate Center, Katmandu; K. Shankar, NEPAL/MWR)
The highlands of central Asia possess a diversity of natural archives from which detailed paleoclimatic records can be developed (e.g., lake sediments, loess, tree rings, ice cores, glacier fluctuations, geomorphologic features). Despite this potential, relatively little is known concerning climatic changes in the region over time-scales ranging from centuries to hundreds of thousands of years. The primary objective of this project is to develop multi-variate, well-dated, high resolution (i.e. annual) paleoclimatic records for monsoon Asia for the last 500 to > 1000 years through the chemical and physical analysis of deep (approximately 200 m) firn/ice cores recovered from two high elevation (>6000 m) glaciers in the eastern Himalaya. Time-series developed from the physical and chemical analysis of the ice core will form the basis of a detailed paleoclimatic record for monsoon Asia. The Himalayan ice-core records will also be compared with similar detailed ice-core data records recovered from Tibet, Peru, Greenland and Antarctica, in order to develop a broader, more globally comprehensive, ice-core data base from which to investigate global change.

Aerosol and precipitation chemistry, Nepalese Himalaya

(C. Wake, J. Dibb, A. Shrestha, UNH/CCRC; K. Shankar, NEPAL/MWR)
Over the past two years, both short-term (daily) and longer-term (monthly) aerosol samples have been collected at high-elevation sites in the Nepalese Himalaya. The short-term data confirm the original conclusions, drawn from limited samples, that high-elevation sites in this region are excellent locations from which to investigate the chemistry of the remote atmosphere at a mid-continental location. During the past year, an autonomous aerosol sampler was designed and set up at 5700 m in the Hidden Valley region of Nepal. The 16 samples collected over the

course of the past year provide the first year-long record of aerosol chemistry in the high Himalaya.

In the coming years, examination of the relationships between the composition of snow accumulating above 6000 m in the Himalaya and the composition of the atmosphere in Nepal over a range of altitudes (physiographic regions) will be continued through two related sampling campaigns. The first will consist of a series of manned sampling sites where aerosol and precipitation samples will be collected in collaboration with the Nepalese Department of Hydrology and Meteorology. These stations will establish relationships between atmospheric composition in the 4–5 km altitude range down to the lowland region (Terai) where most Nepalese live. A parallel stream will involve collection of aerosol and snow samples in the area of each core collection site (in conjunction with the "Ice-core records from monsoon Asia" program described above). Year-round aerosol collection with autonomous samplers will be supplemented by intensive sampling for several weeks each year, when the sites are visited for servicing, and the collection of snow samples. The entire network is intended to allow the extrapolation of insights concerning past atmospheric composition in the high peaks (derived from the ice-core records) across a broad range of elevation and physiographic gradients.

Fjord oceanography

(D. Lawson, L. Hunter, S. Bigl, CRREL; E. Cowan, ASU; P. Carlson, USGS/MP; R. Powell, NIU)

Thirty stations in upper Muir Inlet have been reoccupied for three years, beginning in 1993, at different seasons to analyze changes in fjord hydrography. During the early 1990s, Muir Glacier underwent a transition from tidewater to terrestrial. Studies, include repeating CTD profiles at each station during the spring, summer, and fall seasons and fjord sediment trapping, document what changes occur in the fjord as glacier dynamics are altered. Previous data from the 1980s will be correlated with these periodic measurements. Results will be integrated with more proximal process studies and a revised paleoclimate model based upon tidewater glacier dynamics, controls on terminus stability and ice-margin fluctuations. Future work will include analyses in McBride, Reid and Tarr Inlets.

ICE SHEETS

Ice and climate

(R. Alley, T. Sowers, M. Mahaffy, S. Anandakrishnan, P. Fawcett, A. Agústsdóttir, M. Spencer, G. Spinelli, T. Creyts, PSU/ESSC; K. Cuffey, UW/GEOL; C. Shuman, GSFC/MD; M. Fischer, NIU)

The Earth System Science Center and Department of Geosciences, Pennsylvania State University maintain an active research effort on the large ice sheets of the present and past. Projects focus on ice-core gases, ice-flow modeling, seismic investigations of ice and substrate, modeling of atmospheric circulation tied to ice-core data, and various studies of ice-core physical properties and climate-change questions.

The best way of documenting changes in the composition of the atmosphere throughout the last 200 000 years is through the analyses of gases trapped in ice cores. A number of projects are designed to understand the nature of the gas-trapping process better, as well as to reconstruct the nitrous oxide concentration of the atmosphere over the last 200 000 years. Recently initiated firn-densification studies will contribute to this effort. Ice-flow modeling centers on a new, three-dimensional, thermomechanical model. Formulation for internal ice deformation is nearly complete, and work will begin to incorporate basal hydrology and subglacial-till physics to allow study of a wider range of ice sheets.

Seismic investigations include active-seismic work to delineate and characterize sub-glacial sedimentary basins in West Antarctica that may contribute to ice-stream channelization, as well as to characterize ice fabrics. Passive-seismic studies are building on the previously published data suggesting that the shutdown of Ice Stream C is related to water piracy caused by the thinning Ice Stream B, consistent with ongoing ice-sheet drawdown rather than with a negative feedback stabilizing the ice sheet.

Work on the GISP2 deep ice core from central Greenland, involves contributing (with other GISP2 investigators) to documentation of the origin and persistence of annual visible strata and their accuracy as dating tools, and using them to help date the ice core well into the last ice age, and to estimate past accumulation rates, their sudden changes and their relation to temperature and circulation changes. The accumulation rates also allow improved estimates of changes in atmospheric loading of impurities. Global and mesoscale atmospheric modeling of rapid climate shifts, focused on the Younger Dryas event, will help interpret the changes observed and the roles of oceanic circulation, storm tracks, seasonality in accumulation, and other factors in the ice-core signal. Participation in ongoing GISP2 investigations of physical properties of the core includes documentation of folding and stratigraphic disruption in lower reaches, and identification of c-axis indicators of folding for use where stratigraphic layers are not visible.

Work begun at Penn State, and continued elsewhere, includes calibration of the isotopic paleothermometer using borehole-temperature profiles and instrumental and remote- sensing data, and ice- and firn-fracture studies.

GISP2 ice-core analysis

(A. J. Gow, D. A. Meese, CRREL)

Substantial data sets have been collected on the relaxation characteristics, density, grain size, *c*-axis fabrics, and ultrasonic velocities of the GISP2 core to its contact with bedrock at 3053.5 m. Changes in all these properties paralleled closely those found in cores from Byrd Station, Antarctica and Dye 3, Greenland. Density increased progressively with depth to a maximum of 0.921 $Mg\,m^3$ at about 1400 m, at which depth the ice became bubble-free. Below about 2000 m, in-situ densities began to decrease in response to increasing ice-sheet temperatures. Densities, remeasured at intervals since drilling, revealed significant volume expansion (relaxation) due to microcracking and the exsolving of enclathratized gases, especially in the brittle ice zone from between 600 and 1400 m. Grain-size increased linearly to about 1000 m, thereafter remaining fairly constant until the Younger Dryas event at 1678 m, where a two- to threefold decrease in grain size occurred. These grain size changes were accompanied by a progressive clustering of crystal *c*-axes towards the vertical, including a small increase in *c*-axis concentration across the Younger Dryas/Holocene boundary. Increased dust levels in the Wisconsin ice have contributed to the maintenance of a fine-grained texture that, with its strong vertical c-axes fabric, persisted to nearly 3000 m. However, beginning at about 2800 m, layers of coarse-grained ice are observed. Below 3000 m the ice became very coarse-grained. This change, attributed to annealing recrystallization at elevated temperatures in the ice sheet, was accompanied by a dispersed or ring-like redistribution of the c-axes about the vertical. Ultrasonic measurements of vertical and horizontal p-wave velocities, made at 10 m intervals along the entire length of the GISP2 core, fully confirmed the results of the crystallo-optical observations. A return to fine-grained ice coincided with the first appearance of brown, silty ice 13 m above bedrock. Bedrock material consisted of 48 cm of till, including boulders and cobbles, overlying gray biotite granite comprising the true bedrock.

GISP2 depth-age scale

(D. A. Meese, A. J. Gow, CRREL)
The GISP2 depth-age scale is based on a new multi-parameter, continuous-count method. This is the first ice core or geological material to be continuously dated, with minor breaks beyond 110 000 BP. Parameters used to date the core include visual stratigraphy, oxygen isotopes, electrical-conductivity measurements, laser-light scattering from dust, volcanic signals and major ion chemistry. Comparisons with deep-sea cores, tree rings and varves using radiochemical methods calibrated to corals show agreement within the expected error for each method. Additional comparisons are also made to the GRIP ice core and a model based on the $\delta^{18}O$ of O_2 combined with SPECMAP.

Passive microwave remote sensing, central Greenland

(C. A. Shuman, GSFC/MD; M. A. Fahnestock, UMD/JCESS; R. B. Alley, PSU/ESSC; R. A. Bindschadler, GSFC/MD)
Passive microwave brightness temperature data from the SSM/I F8 and F11 sensors are being examined for spatial patterns related to hoar development in the vicinity of the GISP2 site. Hoar-complex development, due to larger crystal sizes, lower density, and stratification changes, produces characteristic features that can be used as an annual marker in ice core studies. The effects of hoar formation on SSM/I data can be used to map their spatial and temporal occurrence and thereby assist interpretation of ice-core records. In addition, 37 GHz brightness temperature trends from the SSM/I can be used as a proxy temperature record in this area. They have been used, with empirical techniques, to extend, connect, and complete automatic-weather-station, air-temperature records which has resulted in a nearly continuous air-temperature record for the Summit region from 1987 to 1994. The ability of SSM/I brightness temperature data to document daily temperature information has also assisted the study of oxygen and hydrogen stable-isotope trends from this area. Comparison of the two temperature proxy records allows dating of snow strata with high confidence. These comparisons support the utility of isotope thermometry and assist in determining the timing of accumulation in this region.

GISP2 Science Management Office

(P. A. Mayewski, M. S. Twickler, UNH/CCRC)
The summer of 1993 saw the completion of drilling activities for the Greenland Ice Sheet Project Two (GISP2) and the recovery of the deepest ice core in the world (3053.44 m). This ice core will provide the longest, most detailed, most broadly and extensively analyzed, continuous record of climate history available from the Northern Hemisphere. The GISP2 Science Management Office (SMO) has played a critical role in the success of GISP2 to date by: operating the on-site core processing line; contributing to the success of essential activities including drilling; collecting, verifying, and distributing data sets and information on the core and core sampling; and organizing meetings and workshops within GISP2, with the Greenland Ice Core Project (GRIP), and with other outside collaborators. During the interpretative phase of GISP2, the SMO continues to: function as an organizational tool for new and original GISP2 Principal Investigators (PI's); handle data; coordinate core sampling activities in Denver; coordinate workshops and meetings; organize final products; and communicate with PIs, other scientists, NSF, GRIP, and the public.

GISP2 major ions — climate change

(P. A. Mayewski, M. Twickler, S. Whitlow, Y. Qinzhao, UNH/CCRC; L. D. Meeker, UNH/CCRC/MATH)
This project will provide a high-resolution paleoenvironmental record through the acquisition, analysis and interpretation of glaciochemical (chloride, nitrate, sulfate, sodium, calcium, magnesium, potassium and ammonium) series developed from the complete (3053.44 m deep, >250 000 year long) GISP2 ice core from central Greenland. By combining high-quality, continuous, high-resolution, multivariate chemical series with mathematical and statistical techniques, the following will be addressed and characterized: (1) fundamental connections among the glaciochemical signals deposited in the ice and other variates measured within the GISP2 program; (2) fundamental connections between the GISP2 record and other ice-core records, instrumental records and proxy records; (3) changes in the sources and production rates of the chemical species recorded in the GISP2 record (yielding detailed records of volcanism, biomass burning and other unique climate events (eg., dust bowls, marine storms)); (4) high-resolution records of Holocene and pre-Holocene climate (focusing on, e.g., stadial and interstadial events, the Eemian, unique "patterns" in climate); (5) causes of sub-decadal to century-plus-scale climate variability (discriminating between climate forcing due to changes in insolation, volcanic aerosols, dust loading, inherent or forced variability in the ocean–atmosphere–ice-sheet system, atmospheric trace gas variability, solar variability, inherent ("random") decadal scale variability in the atmosphere); (6) influence of climate forcing agents over different time periods and the degree and type of environmental response to these agents; (7) extent of environmental record represented in the lower ~200 m of the GISP2 record; and (8) basal silty ice as a tool for understanding the basal ice environment.

Ross Ice Drainage System (RIDS), Late Holocene climate variability

(P. A. Mayewski, M. Twickler, S. Whitlow, K. Kreutz, UNH/CCRC; L. D. Meeker, UNH/CCRC/MATH)
This project will provide a high-resolution record (equivalent to the GISP2 record) of the Antarctic climate through the acquisition, analysis, and interpretation of records of atmospheric chemical deposition taken from three ice cores at sites within or immediately adjacent to

the Ross Ice Drainage System (RIDS). These sites provide a well-spaced sampling of one of the most dynamic and climatologically significant regions in Antarctica. One core, to bedrock, was retrieved from McMurdo Dome (P. Grootes, University of Washington, 1993) and covers the period ~70–90 kyr. The other two, at West Antarctic locations (Siple Dome and near 79° S, 115° W), have been specified as potential deep drilling sites by the US ice core community. Collection of the latter two cores was completed in 1994 and 1995, respectively, and should provide records of ~2 kyr. These records are intended to solve a variety of scientific objectives while also providing spatial sampling and reconnaissance for future US efforts in West Antarctica. Several collaborative efforts are planned at each core site (e.g. stable isotopes, particles, trace elements, ECM). Glaciochemical analyses will focus on the major cations (sodium, potassium, ammonium, calcium and magnesium) and major anions (nitrate, chloride and sulfate) found in the Antarctic atmosphere, plus methanesulfonic acid and selected measurements of the hydrogen ion, aluminum, iron, and silica.

The major RIDS-scale goals include:

(1) Documentation of sub-decadal to century-plus-scale climate variability over the RIDS region.

(2) Characterization of major atmospheric (e.g. ENSO, cyclogenesis) and oceanic (e.g. changes in sea-ice distribution and marine productivity) phenomena affecting climate over RIDS (e.g. mass balance, temperature, circulation strength or pathway).

(3) Assessment of how much the environment over RIDS has changed during the Late Holocene and differences between sites.

(4) Comparison of the ice-core-derived RIDS climate record with the GISP2 climate record.

(5) Assessment of the effects of anthropogenic activity (e.g., ozone depletion, pollutant levels, biomass burning, global warming) on Antarctic climate and/or atmospheric chemistry.

(6) Production of a detailed Holocene volcanic history of the RIDS region.

GISP2 glaciochemical records, GCM-modeling of Northern-Hemisphere climate

(M. L. Prentice, P. A. Mayewski, UNH/CCRC; L. D. Meeker, UNH/CCRC/MATH; D. Rind, GSFC/NY)

This project will develop, test, and interpret atmospheric GCM simulations of Northern-Hemisphere climate variability represented by the GISP2 glaciochemical time series. Equilibrium simulations of the Last Glacial Maximum (LGM) were tested to reveal atmospheric circulation changes that can explain the observed large LGM increases in chemical species reflecting both marine seasalt and continental dust. The GCM shows an LGM atmosphere with more meridional flow both at surface and aloft than occurs without ice sheets. Correspondingly, LGM jet winds were in many regions located north of their present locations, contrary to common wisdom. The GISP2 glaciochemical record supports this important GCM result.

Holocene environmental variability and West Antarctic ice-sheet retreat, Victoria Land coast

(M. L. Prentice, UNH/CCRC; P. A. Berkman, BPRC)

Near-shore, surface-water conditions, principally temperature, salinity, and glacier-meltwater input during the retreat of the West Antarctic ice sheet from the western Ross Sea, and subsequent Holocene local glacier fluctuations, will be reconstructed. The principal data set is the $\delta^{18}O$, $\delta^{13}C$ of fossil Antarctic scallop shells, *Adamussium colbecki*, which occur in emerged marine deposits at selected South Victoria Land coastal localities. Shells were collected in Holocene glacial-marine sediments and deglacial moraines at the: Explorer's Cove area, at the mouth of Taylor Valley, north to Marble Point; Terra Nova Bay region along the Northern Foothills Peninsula (74° S); and, across McMurdo Sound from the Dry Valleys at Capes Barne and Byrd. The glacial sediment sequences, the fossils were associated with, were observed and sampled.

Snow gamma-ray detector

(J. E. Dibb, UNH/CCRC; P. Dunphy, E. Chupp, UNH/SSC)

A down-hole instrument has been developed that can measure gamma radiation from ^{137}Cs in situ. The device has successfully located horizons corresponding to fallout from atmospheric testing of thermonuclear bombs in three bore holes around South Pole; a prototype had earlier proven successful at Summit, Greenland. This instrument provides the same dating horizons as the well-established beta radioactivity techniques, but the results are available in nearly real time.

Preservation of atmospheric signals in snowpack, Summit, Greenland

(J. E. Dibb, V. Hart, UNH/CCRC; E. Linder, UNH/MATH)

Preliminary investigations over the past four summer seasons at Summit, Greenland, indicated the composition of surface and near-surface snow appears to change significantly within days to months of deposition. These changes during aging must be verified and understood if rigorous reconstructions of past atmospheric composition based on chemical records recovered from glacial ice are to be possible. A major unknown at present is the extent to which the apparent temporal trends in snow chemistry are reflecting poorly understood spatial heterogeneity.

The impact of aging on snow chemistry at Summit continues to be investigated (specifically the concentrations and inventories of soluble ionic species in stratigraphically discrete layers of snow), extending the temporal range to the first few years after deposition of the snow. In addition, an ambitious sampling program expressly designed to characterize spatial variability over meter to kilometer scales was conducted during the 1994 and 1995 seasons.

All sampling is at the site of ongoing multi-institution, multi-parameter investigations of air-to-snow transfer processes, so that observed changes in snow chemistry can be assessed in relation to contemporaneous variations in physical and chemical characteristics of the overlying atmosphere. The spatial survey will thus also be relevant to a variety of the other investigations at this site, insofar as the variability of ionic species concentrations in snow can be assumed representative of other species of interest. In addition, characterizing spatial variability in surface snow composition will allow estimating confidence in interpretations of short "event" signals discovered in the two evolving deep ice-core records from the Summit region.

Near-surface firn processes, Summit, Greenland

(M. R. Albert, E. M. Arons, R. E. Davis, CRREL)

The processes by which chemical species in the atmosphere become incorporated into the firn depend both upon the nature of the forcing from the atmosphere and upon the properties of the firn itself. This program investigates processes of conduction, ventilation, and radiation penetration that affect the manner in which heat, vapor, and chemical species in air are incorporated into snow and polar firn. The research involves both mathematical modeling of the advective and diffusive transport processes with reaction, and field experiments to measure key parameters and to quantify existence and extent of the processes involved. Permeability measurements in the top meters of the firn reveal values ranging from 10 to 80 × 10^{-10} m^2, depending on firn microstructure, and generally increasing with depth over the top several meters. Directionality in permeability was found to be important. Preliminary calculations with measured permeabilities and surface pressure forcing indicate that ventilation can be induced in the near-surface firn under moderate wind speeds, in spite of the fact that there are no large surface dunes. Preliminary analysis of spectral radiation penetration measurements suggests that greater depths of penetration occur than previously estimated, especially in the red wavelengths. The spatial variability of snow properties was measured in a snow trench. The measurements show large variance in the thickness and physical properties of winter and summer layers, which could adversely affect the vertical resolution in the interpretation of firn and ice cores. Collaborative work is underway to determine the effects of these physical processes on chemical species concentration in the firn gas and air, in order to facilitate polar ice-core interpretation.

Atmospheric concentrations and air–snow exchange of soluble gaseous acids, Summit, Greenland

(J. E. Dibb, UNH/CCRC; R. Talbot, UNH/CSRC)

Chemistry records recovered from polar ice cores contain a wealth of information about past atmospheric composition. However, quantitative interpretation of these proxy records requires understanding of the complex set of atmosphere–snow and snow–firn–glacial ice transfer functions. The main thrust of UNH efforts is to characterize airborne concentrations and air–snow exchange of several soluble gaseous acids.

Concentrations of HNO_3 measured at Summit, are consistently at the low end of the range for atmospheric sampling, even in some of the most remote regions of the free troposphere. On the other hand, concentrations of the organic acids, acetic and formic, are higher than those reported for many other remote, and even some rural, areas. Total reactive N (NO_y) concentrations measured by a group from Harvard were also consistently near the upper end of the range reported for rural and remote locations. We now have enough data to suggest that much of the NO_3^- in snow at Summit may be derived from N species besides HNO_3 and aerosol-associated NO_3^-. Peroxy acetyl nitrate and one or more alkyl nitrate species appear to be the most likely candidates, and they may also be contributing to the elevated concentrations of organic acids observed just above the snow surface.

We were able to make gradient measurements of soluble acidic gases with two mist chamber samplers at different heights in the 1995 season at Summit. Our gradient measurements (particularly for HNO_3) are now being compared to the NO_y concentrations and fluxes determined by Harvard and to temporal variations in the concentrations and inventories of soluble species in the surface layer of the snow pack. The primary goal of this study will be to enable improved interpretation of the NO_3^- records in polar ice, but additional insights into reactive N chemistry over snow-covered surfaces are also anticipated.

Late-Quaternary climate variability, Penny Ice Cap ice core, Baffin Island, Canada

(G. A. Zielinski, C. P. Wake, UNH/CCRC; R. M. Koerner, D. A. Fisher, J. Bourgeois, GSC; E. Blake, Icefield Instruments, Inc., Whitehorse, YT, Canada; K. Goto-Azuma, Nagaoka Institute of Snow and Ice Studies, Nagaoka, Japan; J. D. Jacobs, Dept. of Geography, Memorial Univ., St. Johns, Nfld, Canada)

In 1995, an international team of scientists drilled a 334 m ice core into the silty ice immediately above bedrock on the Penny Ice Cap, southern Baffin Island. Reconstruction of paleoatmospheric and climatic conditions in this part of the Arctic will be undertaken through a multiparameter analysis of the core that includes continuous glaciochemical, microparticle and MSA studies, melt layer counts/physical stratigraphy, $\delta^{18}O$, electrical conductivity and pollen studies. Initial findings indicate that the age of the core extends through the Holocene to the Last Glacial Maximum and beyond. Probable age of the base has yet to be determined. Peaks in SO_4^{2-} and electrical conductivity can be matched to known volcanic eruptions, thereby providing time lines for assisting in developing the core chronology. Several snow pits (2–5 m in depth) were dug both in 1994 and 1995 to determine the variability in modern snow chemistry and recent accumulation rates. An automatic weather station, previously established on the Penny, will be extremely useful in calibrating results from the snow pits and ultimately in calibrating the downcore trends in chemical species and $\delta^{18}O$.

GISP2 ice core — tephrochronology

(G.A. Zielinski, UNH/CCRC)

A continuous scan for tephra in the Holocene and deglacial portions of the GISP2 ice core is being undertaken to better establish the paleovolcanic record in the core that will ultimately lead to a more complete understanding of the climatic impact of past eruptions. A SEM and electron microprobe has been used successfully in recent years to locate volcanic glass in the core and identify the source eruption through comparisons of major oxide compositions. This work is continuing, but preliminary investigations using an ion microprobe are also being done to better fingerprint glass found in the core through trace-element compositions. In addition, visible tephra layers in the deeper sections of the core have been analyzed. Composition of the glass in two of the layers in the GISP2 core matches that of the Saksunarvatn ash, a Late Pleistocene (~10 300 years ago) marker in terrestrial and deep-sea records of the North Atlantic region and the ash that comprises the Z2 ash zone (~52 200 years ago) found in many marine cores in the North Atlantic. These ashes have also been found in the GRIP ice core, providing an absolute time line for correlation among these many climate proxy data sets.

Mass balance of Greenland and Antarctic ice sheets

(I. Whillans, G. Hamilton, BPRC)
A program has been started to measure the mass balance of the ice sheets using the so-called coffee-can method. Markers are placed 20 m or more into the firn, and the vertical component of velocity is measured by occupations with GPS (Global Positioning System) tracking receivers that are repeated after a year or more. The local accumulation rate is obtained from a core. After a small correction for down-slope motion, the difference between the measured vertical component of velocity and the long-term accumulation rate is the rate of thickening or thinning of the glacier.

Originally the markers were coffee cans at the bottom of very long poles. However, newer markers are at the lower end of steel cables frozen into hot-point drilled holes. Each site has four or five markers at various depths to assess local repeatability.

In Greenland, five sites were installed along the western flank of the ice sheet in May and June 1995. Further installations in the south and east and perhaps north are planned for April 1996. In Antarctica there are now four sites: near South Pole with three sub-sites, under the dome, in 120 m holes 3 km from the dome, and in shallower holes 6 km distant; near Byrd Station, two sub-sites, 2 and 5 km from the existing camp; two further sites on Ice Stream B and just outside the southern boundary to the ice stream. Further installations are planned for the 1996–97 field season.

The method is different from other methods for mass-balance determination. It is considerably more precise than comparison of ice discharge with snow accumulation over a catchment because there is no need to conduct problematic integration of accumulation over the catchment. Unlike repeat snow-surface elevation measurements (from satellite or aircraft) it is unaffected by very recent snowfalls or densification and provides a long-term value for mass balance. Its limitation is that the result is very locally specific.

The program is relatively inexpensive. After obtaining drilling and GPS equipment and accounting for logistics, operational costs are about US$100 per site. Other groups are encouraged to conduct such studies.

McMurdo Ice Shelf

(I. Whillans, G. Hamilton, C. Merry, BPRC)
The major US and New Zealand bases in Antarctica are on Ross Island facing McMurdo Sound. The airstrip used after about 10 December each summer is on the nearby McMurdo Ice Shelf (Williams Field). There is a short portion of the junction between the ice shelf and Ross Island where vehicles may be driven between ice shelf and land.

A satellite image acquired in December 1994 (SPOT HRV) shows a dark line across the ice shelf. It is suggestive of a sagging crevasse bridge parallel to the ice front. If so, one can expect a major calving event and major disruption of logistic capability. A less dramatic interpretation is that it is not due to a crevasse, but is the boundary between firn that has and has not collapsed due to percolating brine. Brine can access the firn because the firn-to-ice transition is below sea level. The brine can soak horizontally, weaken firn structure and collapse part of the firn.

To test these hypotheses, strain grids were installed across the mysterious line and surveyed with precision GPS receivers. The idea is to search for special stretching at the putative crevasse, to obtain detailed topographic information and to assess whether the feature has migrated since the time of imagery.

Snow accumulation, Ice Streams B, C, D and E, West Antarctica

(E. Venteris, I. Whillans, BPRC)
An accumulation-rate study is being conducted on the Ross Ice Shelf side of the West Antarctic ice sheet. Approximately 80 15 m cores have been collected since 1983 over an area 1000 km by 1000km. These cores have been sectioned, measured for density, melted and filtered through cation exchange paper to collect ^{137}Cs and ^{90}Sr. The beta activity of each core section is measured. The 1955 and 1964 accumulation horizons are identified by distinct increases in activity. Accumulation rate is calculated by the integration of the density measurements above the bomb horizon and dividing by time.

Possible causes of variability are assessed. Measurement error and error due to loss of core is minimal (<0.01 m a^{-1} ice equivalent (910 kg m^3)). Wind causes variation on two scales: large scale (5 km) slope changes that drive katabatic wind velocity and transport, and smaller scale (10 m) sastrugi surface roughness. Values for these have been determined previously for the study area. The maximum slope effect is about 0.016 m ice equivalent. The standard deviation of sastrugi roughness is 0.02 m ice equivalent for two independent locations. The effect of year-to-year precipitation changes has also been determined previously. The standard deviation of interannual variation is 0.02 m a^{-1}. These values of variability are compared with previous studies done in Antarctica. Values of accumulation rate and variation are similar to other inland sites on the continent. In general, coastal sites show larger accumulation rates and proportionally greater temporal and spatial variation than inland sites.

Accumulation rates range from 0.06 m a^{-1} to 0.26 m a^{-1}, with an average of 0.12 m a^{-1}. Accumulation tends to increase with elevation up to 1900 m, after which the accumulation rate decreases. Causes for this pattern are presently being investigated by comparison of the accumulation distribution with model windflow patterns. Results of this study will be used in mass-balance calculations. Data density is higher than anything previously available and will allow a more detailed analysis of snow accumulation and transport.

GENERAL SNOW AND ICE PROPERTIES AND PROCESSES

Physical properties and processes of snow

(S. Colbeck, CRREL)
Several studies of the physical properties of snow are being undertaken. The effect of layers on windpumping in snow has been studied with a model of air flow resulting from surface roughness. The effects of buried hoar layers are especially interesting because of piping of air through them. The frictional properties of snow are being pursued through investigations of the energy budget of the base of a snow ski. The effects of slider color are studied to try to understand the effect of solar radiation absorption on the ski base. A device has been constructed and is being tested to investigate the dielectric properties of wet snow as the liquid-water content is changed by controlling the water

tension. The relationship between grain-scale geometry, liquid-water content, and liquid tension will be modeled.

Energy transfer modeling in snow and soil for boreal ecosystems

(R. E. Davis, J. P. Hardy, R. Jordan, CRREL; C. Woodcock, W. Ni, X. Li, BU/CRS; W. Rosenthal, UC/ICESS)
This project develops models of the snow cover and the underlying soil which will predict spatial distribution of snow properties important to the hydrology and other snow- ecosystem interactions of the boreal forest. Radiation is the dominant mechanism of energy exchange between the atmosphere and snow during winter and thaw. Shortwave radiation at the snow surface is calculated with a hybrid Geometric Optic Radiative Transfer (GORT) model. Longwave radiation is calculated with variables also used in GORT and measurements of canopy radiant temperature. Both show good agreement with integrated measurements from spatially distributed radiometers at the forest floor. Coupled runs of GORT and the CRREL snow process model SNTHERM show close agreement with time series of snow properties measured at the stand scale. Investi- gations on optical remote sensing of snow cover in and around boreal forest stands will develop methods to separate snow cover on the ground and snow intercepted by forest canopies to estimate snow extent. Comparison of optimized spectral unmixing of Landsat TM shows good comparison with ground-based, canopy-closure measure- ments, except where snow was present in the canopy. Examination of gas transmissivity measurements through snow has identified the effects of canopy closure on snow, and the formation of spring ice lenses, as the primary controls of forest cover on gas release from the soil to the atmosphere, both of which can be measured remotely or modeled. Spatial modeling will span scales from tens of meters to thousands. Preparation of the spatial data sets for model initiation and validation are underway. The validation of these models will be accomplished with data from both the intensive field activity during winter and thaw, and images collected from the Advanced Visible and Infrared Imaging Spectrometer (AVIRIS) and Landsat TM.

Snowdrift modeling

(J. H. Lever, R. Haehnel, CRREL)
Wind-tunnel modeling of snowdrifting can be a useful tool to improve building performance in cold regions. Modeling should correctly predict drift shapes and their rates of development. Unfortunately, field data suitable for model validation are scarce, especially data on drift-development rates. Two field sites were established to acquire drift-development data for simple objects (a solid fence, a cylinder and a cube). Measurements include developing drift profiles (measured with snow stakes), incident snow flux (measured with a Wyoming snow fence), and standard meteorological data. These full-scale results will be compared with corresponding wind-tunnel results to assess the merits of the modeling methods.

Chemical movement in snow

(J. Cragin, R. McGilvary, D. Leggett, CRREL)
Snow cover is often viewed as a stable storage medium for atmospheric chemicals deposited either by direct gravitational sedimentation or by snowflake scavenging. These chemicals originate from natural (terrestrial dust, vegetation, oceans, volcanoes) and anthropogenic (e.g., pollutant acids and heavy metals from industry and vehicles) sources. Unfortunately, these chemicals are not static in the snowpack but can be redistributed by any one of several physiochemical processes, such as melt–freeze cycles, water-vapor movement, grain (crystal growth), volatilization and air movement ("wind pumping"). Earlier work has shown that dry snow metamorphism (no melting) excludes chemical impurities to the surfaces of snow grains, which are released first during spring snowmelt, resulting in a highly concentrated ionic slug colloquially called "acid flush". On a larger scale, losses of sulfate, but not nitrate or chloride, have been observed during snow sublimation under isothermal conditions at –5°C. The mechanism is believed to be diffusiophoretic (i.e. associated with water vapor movement) and experiments are currently underway to verify this hypothesis. Additional work is also being done to determine the diffusivities of several inorganic and organic chemical species in snow.

Wedging during vertical penetration of floating ice sheets

(D. S. Sodhi, CRREL)
Existing failure criteria for the bearing capacity of floating ice sheets can only predict the load for the occurrence of the first crack, when the maximum stress in the ice equals the tensile strength. Formation of radial cracks does not result in catastrophic failure of floating ice sheet under an applied load because of wedging action during deformation. From the results of full-scale and small-scale tests, the ultimate load to cause complete penetration of a floating ice sheet is much higher than that to cause the first crack.

Using a plastic limit analysis of the deforming region close to the load, an estimate of the breakthrough load was obtained by assuming a velocity field and equating the rate of energy dissipation due to wedging (or compression), in the circumferential direction, to the rate of work done by the load. A comparison between the theoretical estimates and the experimental breakthrough loads was found to be good for ice sheets having thicknesses in the range of 0.2–2.0 m.

Small-scale experiments were conducted with beams and plates of freshwater ice in the basin at the laboratory to understand the wedging action during the vertical loading of floating ice sheets. The results of the beams tests were used to predict the breakthrough loads of floating ice sheets, which are in agreement with loads measured during experiments.

A deflection analysis of radially cracked, floating ice sheets was conducted by the finite-element method. The results of this analysis were used to obtain the elastic-energy release rate (or the crack-extension force) for propagation of radial cracks, that form when the maximum stress in an intact ice sheet exceeds the flexural strength of ice. The elastic-energy release rate goes to zero when the radial cracks are about twice the characteristic length of a floating ice sheet. This is in agreement with the length of radial cracks observed during full-scale and small-scale experiments. Future work will incorporate an analysis of floating ice sheets with radial and circumferential cracks for the determination of the breakthrough loads.

Ice forces on a cluster of conical structures

(D. S. Sodhi, CRREL)

Drilling platforms in water depths of 30–100 m are likely to have multiple legs. If the vertical surfaces of a multi-leg platform interact with moving ice, the ice will most likely fail in crushing mode and cause large forces on the structure. To reduce the magnitude of the interaction forces, the shape of legs near the water surface can be made conical to fail the ice in bending, by pushing it either up or down. Because partially consolidated rubble ice occurs extensively in the Arctic, the focus of the work in progress is to determine the ice forces from partially consolidated rubble ice moving past a multi-legged platform and to observe jamming of broken ice pieces between the conical structures. Small-scale experiments are being conducted to determine the interaction forces that are generated between partially consolidated rubble ice and a cluster of conical structures, to compare the forces obtained from the experiments with those estimated from theoretical formulations in existing literature, and to observe the jamming of broken ice pieces between the conical structures.

Size of brittle crushing zone

(D. S. Sodhi, CRREL)

The results of small-scale tests indicate a strong influence of indentation speed on the effective pressure generated during ice crushing against an indentor. At low indentation velocity, the ice deformation is predominantly by creep and results in high effective pressure in the range of 5–13 MPa at the interface because of full contact between the ice and the indentor. In contrast, ice failure during high-speed indentation is by brittle crushing or flaking. There is some indication that the size of individual brittle flaking regions becomes small with increasing indentation speed. The small size of the brittle flaking region (or many zones of non- simultaneous failure) with respect to the size of the contact area implies that the variation in the interaction force will decrease. A decrease in the standard deviation of the interaction force was found during small-scale tests conducted in the test basin at the laboratory. The objective of this work is to understand the brittle-crushing process by determining the size of brittle-damage region. The ultimate objective is to predict the forces generated during high- speed, ice-structure interaction.

Monitoring snow cover with FMCW radars

(G. Koh, N.E. Yankielun, CRREL)

FMCW radars have potential as a valuable tool for snow scientists. Radar methods are nondestructive and can monitor large areas of snow-covered terrain. These characteristics make them ideal for investigating the temporal and spatial changes in snow-cover properties. Recently, FMCW radars have been used to observe wind-induced drying of wet snow cover, to monitor subsurface melting in a seasonal cover and to obtain stratigraphic profiles of tundra snow cover. Investigations to explore the benefits of multifrequency FMCW radars (C, X, Ka, and W bands) for future snow research are in progress.

Glaze-ice mass and thickness detection

(C. Ryerson, CRREL; A. Ramsay, Hughes STX, Sterling, VA; N. Lott, National Climate Data Center, Asheville, NC; M. Laster, National Weather Service ASOS Program Office, Silver Spring, MD; G. Carter, National Weather Service Eastern Region, Bohemia, NY)

Severe glaze-ice storms threaten the integrity of the nation's utility and communications networks by causing damage to, or the collapse of, high voltage transmission lines and communications towers. Individual storms in Iowa and Mississippi in recent years have caused the collapse of almost 100 miles of transmission lines in each state. Structural engineers need to know the probability of potential glaze-ice loads for line and tower design. The National Weather Service (NWS) does not systematically report glaze-ice accretion amount. The only extensive monitoring program, conducted by the Association of American Railroads in the 1920s and 1930s, collected nine years of data with mixed results. This multi-agency cooperative project's goal is to create algorithms for NWS Automated Surface Observation System (ASOS) ice detectors enabling ice mass and thickness to be recorded automatically throughout the nation for decades. Glaze-ice mass and thickness are being measured on CRREL-designed ice racks collocated with ASOS ice detectors located at CRREL, Dulles airport, Johnstown, PA, and at Binghamton, NY, and Cleveland, OH, NWS offices. Results from the 1995–96 pilot study will be used to develop a more formal, long-term measurement program.

Quantitative microscopy of snow

(E. M. Arons, R. E. Davis, CRREL; M. J. Kwiecien, Islington, Ont., Canada)

Methods for quantifying snow microstructure are required to relate physical properties of snow such as thermal, hydraulic, and electrical conductivities to snow type. Present methods for numerical reconstruction of serial photomicrographs are inadequate for use as input to quantitative models that estimate such properties. One of the drawbacks of the serial photomicrograph approach is the difficulty in obtaining high-quality data even under the best laboratory conditions. A new stochastic method developed for analysis of sedimentary rocks has been used to generate a 3-D data cube based on a small number of statistically independent 2-D sections. Such a data set is easy to generate and can be used as a basis for numerical investigation of mechanical, electromagnetic and thermal properties.

Avalanche tender spots

(E. M. Arons, S. C. Colbeck, CRREL; J. M. N. T. Gray, Institut für Mechanik, Technische Hochschule Darmstadt, Darmstadt, Germany)

Observations of slab-avalanche releases in Alpine terrain have led to the hypothesis that terrain features can influence the spatial distributions of temperature and heat flow in dry Alpine snow covers and thus enhance the growth of mechanically weak depth hoar. A numerical model demonstrates that snow overlying a rocky outcrop is predisposed to higher temperatures and temperature gradients than snow far from the outcrop. The influence of season, snow properties, soil properties, terrain geometry, and snow depth on this phenomenon are being examined, in all cases, terrain-enhanced growth occurs. These results imply that methods of remote sensing, quantitative geomorphology, and climatology may be combined to estimate avalanche hazards and improve forecasting methods.

RIVER ICE

River-ice transport and ice-jam dynamics

(H.T. Shen, CU)

The formation and release of surface ice jams are closely related to the dynamics of river-ice transport. Existing ice-jam theories are obtained based on the static equilibrium of a floating accumulation of ice fragments. These theories can predict ice-jam profiles, but cannot describe the process of ice-jam initiation and release. In this study, a dynamic river-ice transport theory and a two-dimensional numerical simulation model with coupled hydrodynamics and ice dynamics are developed. The two-dimensional numerical model has been validated with the field and physical model data of the upper Niagara River. The model can be used to simulate river-ice transport and jamming processes. It can also be used to calculate dynamic forces associated with ice runs on control structures. Further study on the dynamics of ice-jam release and its effect on river-ice breakup is being carried out.

Undercover frazil ice transport and hanging dam formation

(H. T. Shen, CU; Z. Sun, Hefei University of Technology, Anhui, China)

Frazil ice jams or hanging dams often form under river-ice covers downstream from open water reaches. The critical velocity concept, which has commonly been used as a means of determining the limiting thickness of the undercover frazil accumulation, was inadequate to explain the frazil-jam evolution process. In this study, a transport capacity concept is introduced. The ice-transport capacity is defined as the equilibrium rate of ice discharge for a given flow condition and ice-particle characteristic. Deposition occurs when the ice supply exceeds the transport capacity. When the ice supply is less than the transport capacity, the undercover deposits will erode. When the ice supply equals the transport capacity, the ice transport maintains a dynamic equilibrium condition such that rates of deposition and erosion are balanced. The transport capacity concept is validated with field data from the upper Yellow River and laboratory flume experiments. An ice-transport capacity formula is developed based on the field and laboratory data.

Anchor-ice evolution

(H. T. Shen, CU; L. Hammar, Luleå University, Luleå, Sweden)

Formations of anchor ice have been observed in rivers ranging from shallow streams with steep slopes to deep rivers with mild slopes. The existence of anchor ice has both physical and biological implications. Anchor ice can cause significant discharge and water level changes, since it raises the effective bed elevation and alters the bed roughness. It can also have serious effects on invertebrates and fishes, since it can block the oxygen-bearing water flow into the gravel beds. An analytical formulation is being developed for anchor-ice evolution in stream channels considering both the contributions from frazil attachment to the bed roughness and thermal growth due to the heat exchange with the supercooled river water. Field and laboratory studies are being planned to provide needed data for validating the analytical formulation.

Drift and collision of ice floes in a wave field

(H. H. Shen, S. Frankenstein, CU)

Ice floes in the marginal ice zone are subject to wave actions. The resulting floe drift and collisions influence the extent and morphology of the ice cover. Due to the unlimited fetch and openness, the Southern Ocean is more strongly subject to the wave effect than the Arctic. A thorough laboratory study of the floe drift and collision in a one-dimensional wave field was conducted to investigate the wave effect on ice floes. A warm wave tank at Clarkson University and a refrigerated wave tank at CRREL were employed in 1994 for this study. Plastic and real ice floes were tested in these two wave tanks. Both wave tanks were equipped with a paddle the width of the respective tanks. Clarkson's wave tank was 18 m long, 1.7 m wide and 0.8 m deep and CRREL's tank was 37 m long, 1.2 m wide and 0.6 m deep. A wide range of wave frequency and amplitude was tested for single and multiple floe drift. In the multiple floe case, the collision frequency was extracted from video recordings. The drag coefficients of the floes were obtained for the plastic and the ice floes. The added mass coefficient was only obtained for the plastic floes, since it was extremely difficult to measure it for the ice floes. The test data are being compared with a theoretical model.

Doppler radar for continuous remote measurement of river-ice velocity

(M. G. Ferrick, N. E. Yankielun, CRREL)

River-ice velocity measurements are fundamental to analyses of river-ice dynamics. Ice-velocity measurement with a continuous-wave Doppler radar system having real-time data acquisition and digital signal-processing capability was evaluated during a river breakup and a frazil run on the Connecticut River. This system can be rapidly deployed, requires minimal operator interaction, will continuously acquire, process, store and display ice velocity data, and does not depend on visibility conditions. In parallel, video records of ice motion were obtained at the same location for later manual processing and comparison with the radar results. Doppler radar can measure and resolve the velocity of ice moving in a river with precision comparable to or better than analysis-intensive video techniques, over the complete range of ice and velocity conditions. The principal error in Doppler ice-velocity measurement is due to the beam width of the radar antenna, and an analytical method was developed to minimize this error. A high-gain, narrow-beam antenna improved signal-to-noise performance of our Doppler radar system and minimized data processing requirements. An increase in the source frequency of the system provided a proportional increase in the velocity resolution. Measured ice velocities ranged from 1 to 2.5 m s^{-1} during the river breakup, and from 0.5 to 0.65 m s^{-1} in the frazil run. Quantitative comparisons between the radar and video results show fundamental agreement between these measurement methods, and demonstrate that Doppler radar is an effective, efficient and precise tool for obtaining river-ice velocities over the full range of possible ice and velocity conditions.

3-D simulation of river-ice jams

(S. F. Daly, M. A. Hopkins, J. H. Lever, CRREL)

A three-dimensional, discrete-particle model coupled with a one-dimensional, depth-averaged, unsteady hydraulic model is being developed to simulate river ice-jam formation. The particle simulation consists of several thousand floes. Each floe is a flat circular disk with arbitrary diameter and thickness. Feedback between ice floes and water is through water drag on floes and the effect of changes in the flow area caused by the ice floes. Three regimes of flow can be modeled: open water, flow under the ice and porous flow through the ice floes. Simulations begin by releasing a large concentration of floes upstream of an ice-control structure consisting of cylinders spaced across a channel. As the ice floes move downstream, collisions between neighboring floes and collisions between floes and the channel bottom and ice-control structure are explicitly modeled. An ice jam is initiated by arching of floes between the cylinders. The momentum of colliding floes and water drag cause the jam to thicken. The arrival of additional ice causes the jam to progress upstream. The simulations will lead to better understanding of the dynamics of ice-jam formation.

Ice action on riprap

(D. S. Sodhi, S. L. Borland, J. M. Stanley, CRREL)
Small-scale experiments were conducted to assess the damage on riprap-covered banks by ice shoving. A review of literature on this subject revealed that there is very little experience or guidance available for the design of riprap in cold regions, where presence of moving ice can cause substantial damage to a riprapped bank. The following test conditions were changed during the experimental program: the slope of the model riprap bank, the size and the mix of rocks, and the thickness of model ice sheets. Results of these tests are presented in terms of measured horizontal and vertical forces, outcome of interaction as pile-up or ride-up events, and damage to the model riprap bank. From the observations made during the tests, it appears that the damage to the riprap takes place during pile-up events, because the incoming ice sheet is forced to go between the riprap and the piled-up ice, bringing with it rocks from the bottom to the surface of an ice pile. To sustain no damage to the riprapped protective layer, the data from this study indicate that the maximum rock size (D_{100}) should be twice the ice thickness for shallow slopes (1V:3H) and about three times the ice thickness for steeper slopes (1V:1.5H).

SEA ICE

Arctic Ocean sea ice properties, 1994

(W. B. Tucker, III, A. J. Gow, D. A. Meese, H. W. Bosworth, CRREL; E. Reimnitz, USGS/MP; F. M. Williams, NRC Institute of Marine Dynamics, St. John's, Nfld, Canada)
The US/Canada Arctic Ocean Section was a multi-disciplinary scientific expedition that crossed the Arctic Ocean from the Chukchi Sea to Fram Strait during July and August 1994 with the USCGC *Polar Sea* and CCGS *Louis S. St. Laurent*. Physical and mechanical properties of sea ice were documented from collected samples while in-situ measurements characterized snow depths, surface albedos, and melt pond size distribution. Typical summer ice properties were evident, with salinities ranging from 0 at the surface to 3–4 ppt at depth, while temperatures cooled linearly from zero at the surface to −1.8°C at the bottom. Melt ponds within 200 km of the western ice edge were numerous, progressing to frozen and snow covered ponds within 100 km of the Pole. Aerial photography indicated a decrease in the unfrozen melt pond fraction from 27% at 75° N to 2% at 87°N between 29 July and 16 August. Albedos ranged from 0.80 for snow-covered ice surfaces to 0.09 in deep melt ponds. Pervasive sediment was found on the ice from the Chukchi Sea to the North Pole sometimes covering as much as 10–15% of the ice surface but more often covering 1–2%. Mineralogy and contaminant levels are now being determined for the collected sediment samples, with a major goal being to determine the source area of sediment incorporation. Chemical properties of the ice are now being assessed in the laboratory.

Pancake ice formation

(S. F. Ackley, CRREL; H. H. Shen, CU)
Pancake ice floes cover a vast portion of the marginal ice zone in the Southern Ocean. Their formation is believed to be associated with ocean waves. A laboratory study of this process has begun at the US Army CRREL, utilizing an outdoor pond that is 18.3 m long, 7.6 m wide and 2.4 m deep. The pond is equipped with a paddle one fifth the width of the pond. One test was done in January 1995 and two in January 1996. The experiment was recorded with video and pressure transducers in 1995. An infrared camera and an accelerometer were added in 1996 to enhance the monitoring. Air and water temperatures were recorded with a thermistor string. Sediment distribution in the ice floes and in the water column were measured for the 1996 tests. The resulting pancake ice covers from these three tests were very different. The first one not only formed the typical pancakes with raised rims, but the pancakes further consolidated into composite floes. The second test stopped at a uniform distribution of pancake floes of a similar size as the first test. No further consolidation took place before sunrise and the termination of the test. The third test at first formed small circular pancakes. These pancakes disintegrated shortly after their formation. Irregular floes were formed but without much structural integrity towards morning. It is observed that the formation of pancake ice is strongly related to the interaction of waves and the air and water temperatures. Further study is planned to determine these relationships.

Four stages of pressure ridging

(M. A. Hopkins, CRREL)
The pressure ridging process is simulated using a two-dimensional, discrete-element model. In the model, blocks are broken from an intact sheet of relatively thin lead ice driven against a thick, multi-year floe at a constant speed. The blocks of ice rubble accumulate to form the ridge sail and keel. During the simulations, the energy consumed in ridge growth, including dissipation, is explicitly calculated. Based on the results of simulations performed with the model, the ridging process can be divided into four distinct stages. Each stage has its own characteristic energetics. The first stage begins with an intact sheet of lead ice impacting a floe and ends when the sail reaches its maximum height. In the second stage the ridge keel maintains a triangular shape, deepening and growing in the leadward direction. The second stage ends when the maximum keel draft is reached. In the third stage the direction of growth is leadward creating a rubble field of more or less uniform thickness. The third stage ends when the supply of thin ice is exhausted. The fourth stage is the compression of the rubble field between floes. The results of simulations establish the dependence of ridging energetics on the thickness of the ice sheet and the volume of the ridge. In the simulations, up to 1 km of lead ice is

pushed into the ridges to determine maximum sail heights, keel drafts, and ridging forces.

Optical properties of sea ice

(D. Perovich, CRREL)

A combined observational and theoretical study is investigating relationships between the optical properties of sea ice and its physical state and structure. The focus of the observational program has been on monitoring and understanding the evolution of sea-ice optical properties from initial growth through the onset of summer melt. Observations of spectral albedo, bidirectional reflectance, reflected light polarization and transmittance, from the ultraviolet to the near infrared (280–1000 nm), have been made for a variety of ice types. The large spatial and temporal variability of sea-ice optical properties during the melt season has been documented. Optical measurements have been supplemented by a characterization of the physical state and structure of the ice. This characterization includes the vertical distribution of the volume of brine and air in the ice and also the size distribution of the brine pockets and air bubbles. The present effort is directed towards incorporating the results into radiative transfer models and extending the small-scale measurements of the optical properties of individual ice types to estimate the large-scale optical properties of the ice cover.

Arctic pack-ice stress

(J. Richter-Menge, CRREL)

In-situ stress sensors were used to monitor the spatial and temporal variability of pack-ice stresses in the southern Beaufort Sea over a six-month period, beginning in the fall and ending in the early spring. Sensors were deployed at the center of seven multiyear floes, in an array that covered a 10 km region. At the center of the stress array, a floe was further instrumented to investigate the process of stress transmission at the boundary of the floe, the attenuation of stress from the edge towards the center, and the variability of stress as a function of position on the floe. Analysis of these data has focused on identifying the various components of stress and their specific characteristics and driving mechanisms. In collaboration with the Pacific Marine Environmental Laboratory of the National Oceanographic and Atmospheric Administration, deformation measurements were concurrently taken over the same region. By coupling the stress and deformation and applying computer model techniques, specific information will be gained on the process of ice deformation at the regional scale.

POLAR ENGINEERING

Radar crevasse detection for SPIT

(S. Arcone, A. Delaney, G. Blaisdell, CRREL)

Crevasse detection using airborne and ground-based short-pulse radar has been performed across the shear zone between the McMurdo/Ross Ice Shelves, and along the Skelton and Leverett Glaciers in support of the proposed South Pole Inland Traverse for reconstruction of South Pole Station. The radar operates at a bandwidth centered near 500 MHz, considerably higher than used previously. Several crevasses have been opened and explored to determine the origin of the many reflections and diffractions that emanate from a crevasse. The airborne mode gives characteristic responses that have been discussed by other researchers, but the higher bandwidth gives more detail about the snow-bridge width, thickness and slope, and the disposition of the crevasse walls. In particular the apices of half hyperbolic diffractions appear to define the crevasse walls. Control lines have been surveyed across the shear zone and future work will concentrate on the evolution of crevasses there and detection of their total depth, which exceeds 50 m.

Snow for roads and runways

(R. M. Lang, PLU, Tacoma, WA; G. L. Blaisdell, CRREL; C. D'urso, G. Reinemer, The Evergreen State College, Olympia, WA; and M. Lesher, Logan Manufacturing Corporation, Logan, UT)

Using a variety of conventional equipment in deep snow fields in west Yellowstone, MT, snow-processing techniques having the potential for producing high-strength snow roads and runways were studied. The test location and timing were selected to obtain snow properties and winter ambient temperatures as cold and dry as possible to simulate conditions in polar regions. Four separate test sites, each with a different treatment, were established using the snow-processing equipment. Observations were made for 12 weeks after construction to monitor snow hardness (strength) and temperature distribution. Plane sections were taken at each site weekly to allow comparison of bond density and strength. Image analysis was used to find which critical microstructural properties correlate best with compressive strength changes. Temperature data were also correlated with strength changes. Test results indicate that a powered tiller, with a relatively dense tooth population, provided the highest strength snow. This snow was strong enough to support easily contact loads greater than 700 kPa, which could allow the use of conventional aircraft and wheeled vehicles in areas of deep snow.

Pegasus model glacial ice runway, McMurdo Station, Antarctica

(G. L. Blaisdell, CRREL; R. M. Lang, PLU; G. Crist, Antarctic Support Associates, Englewood, CO; K. Kurtti, CRREL; and J. Harbin and D. Flora, Antarctic Support Associates, Englewood, CO)

On 7 February 1994, a C-141 departed Christchurch, New Zealand, and landed on the 3050 m Pegasus glacial ice runway on the Ross Ice Shelf 13 km south of McMurdo. 54 passengers boarded along with 13 000 kg of priority science cargo. The C-141, at a gross mass of 127 000 kg, began its take-off roll at the north threshold and cleared the runway at its midpoint. The pilot and his crew indicated great satisfaction with the runway. This event marked the final test for a five-year development program to demonstrate the feasibility of a semipermanent glacial ice runway capable of supporting heavy wheeled aircraft at a site easily accessible to McMurdo.

In the later phases of developing the glacial ice runway, numerous working flights of LC-130s, on wheels rather than skis, moved cargo more efficiently to the South Pole, and the LC-130 and a C-130 carried larger passenger loads to Christchurch. The primary benefit of the Pegasus runway is its ability to support heavy wheeled aircraft for most of the period from mid-January through November, previously limited to ski-equipped aircraft. It allows increased payloads for the LC-130 (an additional 3600 kg takeoff weight with wheels), and provides access for virtually any conventional aircraft.

The technology for siting, constructing, maintaining and operating such a runway is now well understood and is described in a comprehensive manual.

Weaknesses on a glacial ice runway

(R. M. Lang, PLU; G. L. Blaisdell, CRREL)

Following construction of a glacial ice runway on the Ross Ice Shelf, and prior to flight operations, the runway was proof rolled. This was to simulate typical heavy aircraft. Initial testing produced numerous brittle surface failures in the runway ice. Thin sections of ice cores taken from the failed areas showed large crystals (*c*-axis vertical) of clear, blue ice with long, vertical bubbles, indicative of ice formed directly from meltwater. Uniaxial unconfined compression tests on core samples were used to compare runway ice strength with published data for polycrystalline laboratory ice. Since the frequent failure of surface ice had not been expected, it was critical to understand the formation and mechanical properties of the weak ice to prevent its occurrence in the future and to strengthen the existing problem areas. Likely scenarios have been established for development of the weak ice on the airstrip. A procedure for successfully repairing the runway surface was developed and applied, culminating in test flights, followed by full flight operations.

Tractor route to South Pole

(I. Whillans, C. Merry, G. Hamilton, BPRC)

It may be economic to supply South Pole Station with material and fuel by tractor train; currently supplied entirely by air. However, a suitable tractor route has yet to be identified. Glaciological advice is being provided in the selection of a route over ice shelves, up outlet glaciers and across the inland ice in collaboration with other groups, who are collecting aerial photography (US Geological Survey), doing radar sounding (CRREL), and probing and inspecting crevasses (Antarctic Support Associates).

An important tool is satellite imagery. Glaciological features are identified and interpretations made about where crevasses may or may not be. The recommendations are used by ground teams for further investigation.

The first major hurdle is the shear zone between Ross Ice Shelf and the much more slowly moving McMurdo Ice Shelf. Comparison of features on Landsat-TM and SPOT images taken 5 years apart has led to velocity determinations and the detection of the zone of most intense shearing and hence crevasse hazard.

The second hurdle is the route through the Transantarctic Mountains. Three routes are being considered: Skelton Glacier, Leverett Glacier and Ice Stream C.

Abbreviations used

ANU Dept. of Biogeography and Geomorphology, Australian National University
ASU Dept. of Geology, Appalachian State University, USA
BPRC Byrd Polar Research Center, The Ohio State University, USA
BU/CRS Center for Remote Sensing, Boston University, USA
CRREL US Army Cold Regions Research and Engineering Laboratory, USA
CU Clarkson University, USA
GSC Terrain Sciences Division, Geological Survey of Canada
GSFC/NY Goddard Space Flight Center, Institute for Space Studies, USA
GSFC/MD Oceans and Ice Branch, NASA/Goddard Space Flight Center, USA
IIS Research and Development Centre for Geotechnology, Indonesian Institute of Sciences, Bandung, Indonesia
LEHIGH/EES Dept. of Earth and Environmental Sciences, Lehigh University, USA
LIG Lanzhou Institute of Glaciology and Geocryology, Academia Sinica, China
MONASH Dept. of Geography and Environmental Science, Monash University, Australia
MSU/GS Dept. of Geological Sciences, Michigan State University, USA
NEPAL/MWR Dept. of Hydrology and Meteorology, Ministry of Water Resources, Nepal
NIU Dept. of Geology, Northern Illinois University, USA
PLU Pacific Lutheran University, USA
PSU/ESSC Earth System Science Center, Dept. of Geosciences, The Pennsylvania State University, USA
UC/ICESS Institute for Computational Earth System Science, University of California, USA
UMD/JCESS Joint Center for Earth System Science, Dept. of Meteorology, University of Maryland, USA
UNH/CCRC Climate Change Research Center, Univ. of New Hampshire, USA
UNH/MATH Dept. of Mathematics, University of New Hampshire, USA
UNH/CSRC Complex Systems Research Center, University of New Hampshire, USA
UNH/SSC Space Science Center, University. of New Hampshire, USA
USGS/MP U.S. Geological Survey, Menlo Park, USA
UW/GEOL Dept. of Geological Sciences, University of Washington, USA

Submitted by Edward M. Arons

Glaciological Diary

1996

12-15 August
** International Symposium on Representation of the Cryosphere in Climate and Hydrological Models, Victoria, B.C. (Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, UK)

12-17 August
ASCE 8th International Specialty Conference on Cold Regions Engineering, Fairbanks, Alaska (L. Bennett, School of Engineering, University of Alaska Fairbanks, P.O. Box 755900, AK 99775-5900, USA Fax: +1 907 474 6087; fyasce@aurora.alaska.edu)

13-15 August
19th Nordic Hydrological Conference (NHK-96), Akureyri, Iceland (NHK-96, Orkustofnun, Grensásvegi 9, IS-108 Reykjavík, Iceland Tel: +354 569 6040/6042; Fax: +354 568 8896; ke@os.is or asn@os.is)

18-22 August
5th Chinese Conference on Glaciology and Geocryology, Lanzhou, China (Zhu Yuanlin, Lanzhou Inst. Glaciology and Geocryology, Lanzhou 730000, China Fax: +86 931 888 5241; ggcheng@bepe2.ihep.ca.cn)

27-31 August
* IXth International Symposium on the Physics and Chemistry of Ice, Dartmouth College, Hanover, USA (V. Petrenko, 8000 Cummings Hall, Dartmouth College, Hanover, NH 03755-8000, USA)

1-7 September
4th International Symposium on Glacier Caves and Cryokarst in Polar and High Mountain Regions (H. Slupetzky, Institut für Geographie, Universität Salzburg, Hellbrunnerstrasse 34/III, A-5020 Salzburg, Austria Fax: +43 662 8044 525; slupetzky@edvz.sbg.ac.at)

2-6 September
Avalanches and Related Subjects: the Contribution of Theory and Practice to Avalanche Safety, Kirovsk, Murmansk region, Russia (Centre of Avalanche Safety, 33a, 50 years of October st., 184230 Kirovsk, Murmansk region, Russia Fax: +7 477 891 4124: master@apatit.murmansk.su)

12-13 September
** IGS British Branch Meeting, Manchester, UK (Andrew Lowe, Department of Geography, University of Manchester, Manchester M13 9PL, UK Fax: +44 161 273 4407; mfvstal@afs.mcc.ac.uk)

24-26 September
POLARTECH '96, International Conference on Development and Commercial Utilization of Technologies in Polar Regions, St. Petersburg, Russia (POLARTECH '96 Secretariat, Boris P. Polonsky, Krylov Shipbuilding Research Institute, 44 Moskovskoye Shosse, 196158 St. Petersburg, Russia Tel: +9 812 127 9647; Fax: +9 812 127 9595; krylspb@sovam.com)

25-27 September
Third Annual West Antarctic Ice Sheet (WAIS) Workshop, Algonkian Meeting Center, Sterling, Virginia, USA (R. A. Bindschadler, Code 971, NASA/Goddard Space Flight Center, Greenbelt, MD 20771, USA http://igloo.gsfc.nasa.gov/wais; Tel: +1 301 286 7611; Fax: +1 301 286 0240; bob@laural.gsfc.nasa.gov)

6-10 October
ISSW96, International Snow Science Workshop, Banff, Alberta (Banff Centre for Conferences, P.O. Box 1020, Stn.15, Banff, Alta, T0L 0C0, Canada Tel: +1 403 762 6308; Fax: +1 403762 7502)

24-25 October
** IGS Nordic Branch Meeting, Denmark (C. Hammer, Geophysical Department, Niels Bohr Institute, Juliane Maries Vej 30, DK-2100 Copenhagen, Denmark Tel: +45 35 320559; Fax: +45 35 365357; Email: cuh@gfy.ku.dk)

October/November
Northwest Glaciological Meeting, University of British Columbia, Vancouver, Canada (Garry Clarke, clarke@geop.ubc.ca)

20-22/23 November
Snow as a Physical, Ecological and Economical Factor: International Symposium to Celebrate 60 years of Snow and Avalanche Research at Davos, Congress Center, Switzerland (Swiss Federal Institute for Snow and Avalanche Research, Flüelstrasse 11, CH-7260 Davos, Switzerland Fax: +41 81 417 0110; frey@slf.ch)

9-13 December
AGU Fall Meeting, San Francisco, CA, USA

1997

2-7 March
Sea Ice Ecology, Gordon Research Conference, Ventura, Ca, USA (Stephen F. Ackley, CRREL, 72 Lyme Road, Hanover, NH 03755-1290, USA Tel: +1 603 646 4436; Fax: +1 603 646 4644; sackley@hanover-crrel.army.mil)

13-18 April
OMAE '97, 16th International Conference on Offshore Mechanics and Arctic Engineering, Yokohama, Japan (OMAE'97 Conference Secretariat, Hisaaki Maeda, Inst. Of Industrial Science, Univ. Tokyo, 7-22-1 Roppongi, Minato-ku, Tokyo 106, Japan Tel: +81 3 3402 6231 ext.2255; Fax: +81 3 3402 5349; maedah@iota.iis.u-tokyo.ac.jp; http://www.ketch.iis.u-tokyo.ac.jp/omae97.html)

15-17 April
International Symposium on Ground Freezing and Frost Action in Soils, Luleå, Sweden (L. A. Karbin, CENTEK, Luleå University of Technology, S-971 87 Luleå, Sweden Tel: +46 920 971 75; Fax: +46 920 990 20; Lena.Karbin@centek.se; http://www.luth.se/depts/anl/frost97/)

4-10 May
ISCORD '97, 5th International Symposium on Cold Region Development, Anchorage, Alaska, USA (Chairman, Organizing Committee, The Northern Forum, 4101 University Drive, APU Carr-Gottstein Center, Suite 221, Anchorage, AK 99508, USA Fax: +1 907 561 6645; iscord97@ccmail.orst.edu; http://www.orst.edu/~vinsont/iscord.html)

25-30 May
7th International Offshore and Polar Engineering Conference, Honolulu, Hawaii (ISOPE-97, P.O. Box 1107, Golden, CO 80402-1107, USA Fax: +1 303 420 3760)

26-30 May
** International Symposium on Symposium on Snow and Avalanches. Chamonix, France (Secretary General, International Glaciological Society, Lensfield Road, Cambridge, CB2 1ER, UK)

10-12 June
International Symposium on Physics, Chemistry, and Ecology of Seasonally Frozen Soils, Fairbanks, Alaska, USA (P. Groenvelt, Department of Land Resource Science, University of Guelph, Guelph, Ont., N1G 2W1, Canada Fax: +1 519 824 5730)

1-9 July
Glaciers of the Southern Hemisphere, Melbourne, Australia (A. G. Fountain, U.S. Geological Survey, P.O. Box 25046 MS-412, Denver, CO 80225, USA Tel: +1 303 236 5025; Fax: +1 303 236 5034; andrew@usgs.gov)

13-18 July
** International Symposium on Antarctica and Global Change, University of Tasmania, Hobart, Australia (Secretary General, International Glaciological Society, Lensfield Rd, Cambridge, CB2 1ER, UK)

5-8 August
2nd International Conference on Cryopedology, Syktyvkar, Russia Prof. I.V. Zaboeva, Intitute of Biology, Komi Center, Russian Academy of Sciences, 167610 Syltuvkar, Komi Republic, Russia (Tel: +7 821 22 25213; Fax: +7 821 22 25231; gilichin@issp.serpukhov.su)

28 August - 3 September
IV International Geomorphology Conference, Bologna, Italy (M. Panizza, University degli Studi di Moden, 59-41100 Modena, Italy Tel: +39 59 23 0394; Fax: +39 59 21 8326)

1998

8 May
International Offshore and Polar Engineering Conference, Montréal, Que, Canada (ISOPE-98, P.O. Box 1107, Golden, CO 80402-1107, USA Fax: +1 303 420 3760)

23-27 June
7th International Conference on Permafrost, Yellowknife, N.W.T., Canada (J. A. Heginbottom, Terrain Sciences Division, Geological Survey of Canada, 601 Booth Street, Ottawa, Ont., K1A 0E8, Canada Fax: +1 613 992 2468; http://www.emr.ca/gsc/permaf_e.html; heginbottom@gsc.emr.ca)

August
** International Symposium on the Interaction between Ice Sheets and Landscapes, Kiruna, Sweden (Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, UK)

** IGS Symposia
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International Glaciological Society

BRANCH NEWS

BRITISH BRANCH

This year, the 1995 Annual Meeting was hosted by Leeds University on 28–29 September 1995. The conference consisted of two days of presentations, a meal on Friday evening, and a field trip to see Quaternary deposits on Sunday. The topics covered included deforming beds in the lab and field (Robert Watts, Jane Hart), solute variations (Eric Wolff, Helen Lamb, Dave Collins, Jacque Killawee), lakes and jökulhaups in modern and paleoenvironments (Martin Siegert, Felix Ng, Andrew Russell), mass-balance modelling and remote sensing of ice sheets (Andrew Bingham, Owen Turpin, Isabelle Marsiat), glacial hydrology (Richard Hodgkins, Neil Arnold, Pete Nienow, Mike Kennett), glacial structure (Mike Hambrey) and glaciomarine sedimentation (Julian Dowdeswell), finishing with a talk by Richard Hindmarsh on clast ploughing. Two entertaining videos were also shown by John Wright.

On the Sunday, those who weren't hungover or nursing injuries witnessed a demonstration of a ground penetrating radar, given at Marfield Pit near Masham (Email tavi@geog.leeds.ac.uk for details). This was followed by food at the nearby White Bear pub. A local ice-cream factory proved too much of a temptation for such a large number interested in ice! After stuffing themselves for three hours solid, the group finally proceeded to the last quarry of the day. Asenby Pit (Asenby) surprised the organisers with some beautiful glaciotectonic structures and the rest of the group by sandblasting their skin. The party finally split up and went home, with the consensus that everyone sees each other far too infrequently and looks forward to the next meeting, which will be held in Manchester.

Abstracts of the meeting, and details of future meetings, are available on the web in the British Branch home pages at http://www.geog.leeds.ac.uk/staff/t.murray/igswww/igsgate.htm

Details of the 1997 Keele meeting from Andrew Russell, Earth Sciences Dept., Keele University, Newcastle under Lyme, U.K. (Tel: 01782 584303; gea21@keele.ac.uk)

Andrew Evans

Announcement of 1996 meeting

The 1996 Annual Meeting of the British Branch will be hosted by the Alpine Glacier Project, Department of Geography, University of Manchester, on 12–13 September 1996.

The meeting starts at 1100 h on Thursday, 12 September, with coffee from 1030 h, permitting arrival from most parts of the U.K. that morning. The Annual Dinner will be held that evening. Further presentations will be given on Friday, before the AGM of the Branch, which should end in time to allow those who wish to leave to catch trains by 1700 h. Following the success of the Fav in Leeds in 1995, there will be an opportunity to take in a top club night in Manchester on Friday evening!

It is hoped presentations of completed work and work in progress on all aspects of snow and ice will be made. There will also be display space for posters. Postgraduates are particularly welcome. Oral presentations will be allowed 15–20 minutes. Please indicate the nature of your contribution when registering and provide a title and abstract.

The registration fee of £12 (waged) and £6 (unwaged) includes coffee and tea and distribution of abstracts. Details of the Annual Dinner, which all participants are encouraged to attend, will be included in the second circular, at a cost of £16.00 including wine. Lunches will be available on a cafeteria basis. Evening meals in the Hall on nights other than that of the Annual Dinner should be reserved when registering. Parking spaces are available at Dalton Ellis Hall.

Accommodation will be available at Dalton Ellis Hall, at an inclusive cost per night of £35 for en-suite accommodation (bed and breakfast) and for registered postgraduate students only, standard accommodation at £15 per night.

Participants are asked to register by 1 July. For further details consult the Web page at http://www.man.ac.uk/Arts/geography/igsconf.html or contact Andrew Lowe (Tel:0161 275-3664; mfvstal@afs.mcc.ac.uk) or David Collins (Tel: 0161 275 3646; David.Collins@man.ac.uk). The second circular will be distributed in August.

Andrew Lowe

NORDIC BRANCH

The 1995 Annual Meeting of the IGS Nordic Branch was held in Finland in the Lammi Biological Station, 130 km north from Helsinki, on 7–9 December 1995. It was organized by the Department of Geophysics of the University of Helsinki.

The objective was to present Nordic snow and ice research activities and enhance cooperation in research and education in this field. There were altogether 38 participants; 6 from Denmark, 14 from Finland, 4 from Norway, and 3 from Sweden. The other 11 were students and scientists from Canada, China, Germany, Japan, Russia and United Kingdom.

The site was appropriate for an IGS meeting as the seasonal snow cover had grown to 10–20 cm and the lake at the station was frozen. The air temperature was –5 to –15°C providing us beautiful days in a winter landscape.

The talks dealt mainly with glaciers in northern Europe and sea ice. The former included results on climatic records in the GRIP ice core and mass balance studies in Scandinavia and Svalbard; the latter, sea-ice physics, regional ice climatology and short-term ice dynamics. Baltic Sea ice was treated by local scientists while the visitors from the Far East discussed equivalent work in the Bohai Sea (China) and Sea of Okhotsk (Japan). One talk was given on the energy balance of a variable thickness snow cover. Finally, the ice technology section included papers on ice forces and ice accretion.

Education in snow and ice science was described for the Nordic countries. This includes introductory courses for 2nd/3rd year students and advanced courses both in the field and classroom. Specific Arctic educational centres have been established quite recently. The Arctic Centre in Rovaniemi, Finland offers an international, multidisciplinary, Arctic studies programme as well as short-term intensive courses. Norway has established an educational centre UNIS in Longyearbyen (Universitetsstudiene i Svalbard) where students come for one or two terms at a time. Courses are given in Arctic geophysics, geology and biology. At Lammi there were students and teachers from both these new centres.

Due to the size of the Nordic snow and ice group it was thought useful to set up joint, advanced-level educational activities which could be open to others. Funding could be sought from NorFA (Nordic cooperative research funds) or the EU. The existing Nordic field stations would be excellent sites, providing real snow and ice if the courses were scheduled properly. A snow school is planned for Finland in the winter of 1997 and a physics-of-glaciers field course in 1996 or 1997.

The recreational portion included a visit to the Ski Museum in Lahti, the main ski centre of Finland. The history of skiing was presented and there were a few do-it-yourself simulators starting with ski jumping. The oldest remnants of skis found from Finnish bogs date back to 5200 years ago. There were several also several interesting snow and ice videos shown. Then the test for a real glaciologist was to try rolling naked in the snow after sauna: a must in Finnish winter traditions!

The 1996 annual meeting of the IGS Nordic Branch will be held in Copenhagen, Denmark, 24–25 October, with an excursion on the 26th. Further information from Claus Hammer (see Diary information).

Matti Leppäranta

JOURNAL OF GLACIOLOGY

The following papers have been accepted for publication in the *Journal of Glaciology:*

J-G WINTHER, H ELVEHØY, C E BØGGILD, K SAND AND G LISTON
Melting, runoff and the formation of frozen lakes in a mixed snow and blue ice field in Dronning Maud Land, Antarctica

M STIEVENARD, V NIKOLAËV, D Yu BOLSHIYANOV, C FLÉHOC, J JOUZEL, O L KLEMENTYEV AND R SOUCHEZ
Pleistocene ice at the bottom of Vavilov ice cap (Severnaya Zemlya archipelago)

Z ZUO AND J OERLEMANS
Modelling albedo and specific balance of the Greenland ice sheet: calculations for the Søndre Strømfjord transect

D CRANE AND P WADHAMS
Sea-ice motion in the Weddell Sea from drifting buoy and AVHRR data

N V DAVIDOVICH AND M D ANANICHEVA
Prediction of possible changes in glacio-hydrological characteristics under global warming: southeastern Alaska

R B ALLEY AND G A WOODS
Impurity influence on normal grain-growth in the GISP2 ice core

W H KNAP AND J OERLEMANS
The surface albedo of the Greenland ice sheet: satellite-derived and in situ measurements in the Søndre Strømfjord area during the 1991 melt season

P M CUTLER AND D S MUNRO
Visible and near-infrared reflectivity during the ablation period on Peyto Glacier, Alberta, Canada

J SCHWEIZER AND P M B FÖHN
Avalanche forecasting — an expert system approach

W LAWSON
Structural evolution of Variegated Glacier, Alaska, since 1948

ØA HØYDAL
A force-balance study of ice flow and basal conditions of Jutulstraumen, Antarctica
R M LANG AND G L BLAISDELL
Localized surface ice weakness on a glacial ice runway
T B KELLOGG, T HUGHES AND D E KELLOGG
Late Pleistocene interactions of East and West Antarctic ice flow regimes: evidence from the McMurdo Ice Shelf
S C B RAPER, K R BRIFFA AND T M L WIGLEY
Glacier change in northern Sweden from AD 500: a simple geometric model of Storglaciären
W T PFEFFER AND N F HUMPHREY
Determination of timing and location of water movement and ice-layer formation by temperature measurements in subfreezing snow
C J VAN DER VEEN
Tidewater calving
E RIGNOT, R FORSTER AND B ISACKS
Interferometric radar observations of Glaciar San Rafael, Chile
R BINDSCHADLER, P VORNBERGER, D BLANKENSHIP, T SCAMBOS AND R JACOBEL
Surface velocity and mass balance of Ice Streams D and E, West Antarctica
B J P LEPRETTRE, J-P NAVARRE AND A TAILLEFER
First results of a pre-operational system for automatic detection and recognition of seismic signals associated with avalanches
K A ECHELMEYER, W D HARRISON, C F LARSEN, J SAPIANO, J E MITCHELL, J DEMALLIE, B RABUS, G ADALGEIRSDOTTIR AND L SOMBARDIER
Airborne surface profiling of glaciers
G WENDLER, K AHLNÄS AND C S LINGLE
On the Mertz and Ninnis glaciers, East Antarctica
R H GWIAZDA, S R HEMMING, W S BROECKER, T ONSTOTT AND C MUELLER
Evidence from $^{40}Ar/^{39}Ar$ ages for a Churchill Province source of ice-rafted amphiboles in Heinrich Layer 2
M J SIEGERT AND J A DOWDESWELL
Spatial variations in heat at the base of the Antarctic ice sheet from anaylsis of the thermal regime above sub-glacial lakes
S-E HAMRAN, E AARHOLT, J O HAGEN AND P MO
Estimation of relative water content in a sub-polar glacier using surface penetration radar
G D CLOW, R W SALTUS AND E D WADDINGTON
A new high-precision borehole temperature logging system used at GISP2, Greenland and Taylor Dome, Antarctica

ANNALS OF GLACIOLOGY

The following papers have been accepted for publication in *Annals of Glaciology* Vol. 22, the Proceedings of the International Symposium on Glacial Erosion and Sedimentation held in Reykjavik, Iceland, 20–25 August 1995 and edited by D. N. Collins

H BJÖRNSSON
Scales and rates of glacial sediment removal: a 20 km long and 300 m deep trench created beneath Breidamerkurjökull during the Little Ice Age
J BOGEN
Erosion rates and sediment yields of glaciers
G S BOULTON
The origin of till sequences by subglacial sediment deformation beneath mid-latitude ice sheets
T A BRENNAND, J SHAW AND D R SHARPE
Regional-scale meltwater erosion and deposition patterns, northern Quebec, Canada
G H BROWN, M SHARP AND M TRANTER
Subglacial chemical erosion: seasonal variations in solute provenance, Haut Glacier d'Arolla, Valais, Switzerland
K A BRUGGER
Implications of till-provenance studies for glaciological reconstructions of the paleoglaciers of Wildhorse Canyon, Idaho, U.S.A
G K C CLARKE
Lumped-element model for subglacial transport of solute and suspended sediment
D N COLLINS
A conceptually based model of the interaction between flowing meltwater and subglacial sediment
E A COWAN, P R CARLSON AND R D POWELL
The marine record of the Russell Fiord outburst flood, Alaska, U.S.A
K CRAWFORD, G KUHN AND M J HAMBREY
Changes in the character of glaciomarine sedimentation in the SW Weddell Sea, Antarctica: evidence from the core PS1423-2
K CUFFEY AND R ALLEY
Is erosion by deforming subglacial sediments significant? (Toward till continuity)
B ETZELMÜLLER, J O HAGEN, G VATNE, R S ØDEGÅRD AND J L SOLLID
Glacial debris accumulation and sediment deformation influenced by permafrost: examples from Svalbard
I S EVANS
Abraded rock landforms (whalebacks) developed under ice streams in mountain areas
S J FITZSIMONS
Formation of thrust-block moraines at the margins of dry-based glaciers, south Victoria Land, Antarctica
A C FOWLER AND F S L NG
The role of sediment transport in the mechanics of jökulhlaups
A J GOW AND D A MEESE
Nature of basal debris in the GISP2 and Byrd ice cores and its relevance to bed processes
B HALLET
Glacial quarrying: a simple theoretical model
M J HAMBREY, J A DOWDESWELL, T MURRAY AND P R PORTER
Thrusting and debris entrainment in a surging glacier: Bakaninbreen, Svalbard
R C A HINDMARSH
Cavities and the effective pressure between abrading clasts and the bedrock
R C A HINDMARSH
Sliding of till over bedrock: scratching, polishing, comminution and kinematic-wave theory
R HODGKINS
Seasonal trend in suspended-sediment transport from an Arctic glacier, and implications for drainage-system structure
P HOLMLUND, H BURMAN AND T ROST
Sediment-mass exchange between turbid meltwater streams and proglacial deposits of Storglaciären, northern Sweden
B HUBBARD, M SHARP AND W J LAWSON
On the sedimentological character of Alpine basal ice facies
L E HUNTER, R D POWELL AND D E LAWSON
Morainal-bank sediment budgets and their influence on the stability of tidewater termini of valley glaciers entering Glacier Bay, Alaska, U.S.A
N R IVERSON, T HOOYER AND R LeB HOOKE
A laboratory study of sediment deformation: stress heterogeneity and grain-size evolution

P JANSSON, J KOHLER AND V A POHJOLA
Characteristics of basal ice at Engabreen, northern Norway

M KIRKBRIDE AND N SPEDDING
The influence of englacial drainage on sediment-transport pathways and till texture of temperate valley glaciers

Y MERRAND AND B HALLET
Water and sediment discharge from a large surging glacier: Bering Glacier, Alaska, U.S.A., summer 1994

B F MOLNIA, A POST AND P R CARLSON
20th-century glacial-marine sedimentation in Vitus Lake, Bering Glacier, Alaska, U.S.A

R D POWELL, M DAWBER, J N McINNES AND A R PYNE
Observations of the grounding-line area at a floating glacier terminus

A PUGIN, S E PULLAN AND D R SHARPE
Observations of tunnel channels in glacial sediments with shallow land-based seismic reflection

B R REA AND W B WHALLEY
The role of bedrock topography, structure, ice dynamics and preglacial weathering in controlling subglacial erosion beneath a high-latitude, maritime ice field

C RICHARDSON AND P HOLMLUND
Glacial cirque formation in northern Scandinavia

J C STRASSER, D E LAWSON, G J LARSON, E B EVENSON AND R B ALLEY
Preliminary results of tritium analyses in basal ice, Matanuska Glacier, Alaska, U.S.A.: evidence for subglacial ice accretion

H TÓMASSON
The jökulhlaup from Katla in 1918

W B WHALLEY, C F PALMER, S J HAMILTON AND D KITCHEN
Supraglacial debris-transport variability over time: examples from Switzerland and Iceland

C M ZDANOWICZ, F A MICHEL AND W W SHILTS
Basal debris entrainment and transport in glaciers of southwestern Bylot Island, Canadian Arctic

News

TARFALA 50 YEARS ON

The 50th anniversary of the initiation of field work at Storglaciären was celebrated at Tarfala Research Station during August 1995. The festivities occurred 50 years to the day after the first visit to the valley by the late Professor Valter Schytt, who started the mass balance record of Storglaciären in the spring of 1946. His advisor, Professor Hans W:son Ahlmann, was aware of the need for a reliable long-term study of the mass balance of a glacier, as his research had proved it to be a good indicator of climate change.

During the first year Valter Schytt and his co-investigators stayed in a tourist hut in the valley. In 1947, the first small building was constructed where the present station is now situated. The station was significantly expanded in 1961 and became an official field station of Stockholm University. Since then, the research programme has been expanded to cover not only the mass balance of Storglaciären, but also observations of the terminal position of about 20 glaciers and, currently, mass balance on five other glaciers. In the 1960s, a hydrological programme was carried out in order to study high-alpine hydrology as part of the International Hydrological Decade. In the latter part of the 1970s, a glacio-meteorological project dominated the research efforts at the station. In the 1980s, a project concerning the effect of subglacial water pressure on glacier dynamics was run, a project which later developed into a study of basal processes.

During the last ten years or so, there has been significant technological development in glaciological field methods at Tarfala. Digital data recording techniques, such as data loggers, are used instead of chart recorders, and remote-sensing techniques, such as radar combined with GPS, have revolutionized the work. The radar programme covers studies from low-frequency measurements for depth penetration in temperate ice, to high-frequency, micro-wave measurements of snow stratification in glaciers.

Tarfala Research Station also acts as an important educational centre for glaciology and related topics in Sweden. Every summer, student courses and field excursions, as well as graduate courses and training camps for polar expeditions, are based at the station. The station has about 40 beds, which allows for courses with up to 25 persons, as well as staff, to be accommodated. In addition, there are laboratories, a lecture hall, a sauna and, most importantly, good food.

Current activity is expanding with new academic positions in an effort to promote cooperative projects between the academic centres in the Kiruna area. From the point-of-view of Tarfala, this will broaden the research towards environmental problems and remote sensing. This is a promising development, which will hopefully act as a guarantee for the continuation of the long records of climate and mass balance into the future.

During the weekend of 12–13 August, we celebrated both the length of our records and the encouraging developments we see today. Fifty invited guests and the station staff enjoyed two fantastic days in excellent weather and a high-spirited atmosphere. The programme included research information, round-trip flights, excursions, and a lot of fun among friends. The people invited included some of those who have done the job at the station during all these years, scientists actively working there today, representatives of importance for the programme at Tarfala and, of course, the family of the late Valter Schytt.

During the celebration, a Swedish Meteorological and Hydrological Institute (SMHI) synoptic weather station was officially opened. This station is now automatically reporting weather conditions hourly via telephone. During a storm in the winter of 1992/93, peak wind speed reached 81 m s^{-1}, which is a Swedish record. For this reason, media interest is always focused on the Tarfala record while storms are passing.

Wibjörn Karlén, Per Holmlund and Peter Jansson

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INTERNATIONAL GLACIOLOGICAL SOCIETY

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