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CONTENTS

COVER PICTURE: Upper part of ablation zone of Gilkey Glacier, Coast Mountains, southeast Alaska — a main trunk made up of contributions from over a dozen tributaries and with many medial moraines. Ogives, arch-shaped dirt bands also known as "Forbes bands", can be seen on several of the ice streams, pointing down-glacier (photograph by Juneau Icefield Research Project, W. O. Field, American Geographical Society).

JAPAN – HOKKAIDO

For abbreviations, see end of this report

SNOW AND ICE PHYSICS

Heat and vapor transport in snow

(S. A. Sokratov and N. Maeno, ILTS)

Heat transport in snow is one of the most essential processes characterizing a variety of snow properties, which play many important roles in snow technology and science. A systematic experiment of heat transport in snow was carried out to find a more comprehensive insight into the process. Fine thermocouples were installed with 2–10 cm intervals on a snow sample, and time variations of temperatures, densities, and other microscopic structures in the sample were studied as functions of temperature, temperature gradient (actually sample length) and snow properties. It was found that a quasi-steady temperature distribution was achieved in each snow sample when one of the surfaces was kept at a higher temperature. The quasi-steady temperature distribution was not linear but could be roughly approximated by a quadratic function, convex towards the warmer side. This result suggests that the heat transport cannot be explained as a pure conduction mechanism in snow having uniform thermal conductivity. It leads to a conclusion that the effective thermal conductivity is larger in the colder part, which may be attributed to the water vapor transfer and change of the structure due to the temperature difference in snow.

Bubble formation in snow densification

(S. Ishii, H. Narita and N. Maeno, ILTS)

Bubble formation experiments were conducted for snow composed of ice spheres of 303 μm in diameter at various temperatures and applied pressures. By measuring volumes of closed-off bubbles at various densities the bubble formation density (ρ_f) and the bubble close-off density (ρ_c) were obtained. ρ_f, that is the density at which the bubble formation begins, decreased with the lowering of temperature or pressure. On the other hand, ρ_c, that is the density at which the bubble formation finishes, increased with the lowering of temperature or pressure.

Dielectric properties of ice and snow from HF to mm-wave frequencies

(S. Fujita, T. Matsuoka and S. Mae, DAP; T. Hondoh, ILTS)

Recent developments in remote-sensing technique in glaciology have clarified that accurate knowledge on ice/snow dielectric properties is essential as the basis of that technique. However, due to experimental difficulties, there are still many uncertainties in ice/snow dielectric properties over wide frequency ranges from HF to mm-wave. To clarify this, we investigated dielectric properties with several techniques that are appropriate for each frequency range. Our particular interests are dielectric properties dependent on frequency, temperature, crystal orientation, impurity content, grain-size and shape. The phenomena include interaction between electromagnetic waves and structures of ice and snow that have various scale ranges, such as crystal lattice, molecules, lattice defects and dielectric mixture systems composed of ice and air. Knowledge of the dielectric properties is very useful for extracting information from the remote-sensing data, such as radio-echo sounding of ice sheets and glaciers, and microwave/mm-wave satellite remote sensing of snow and ice.

Observations of growing cracks in ice

(M. Arakawa, N. Maeno and M. Higa, ILTS)

The crack growth process in the high-velocity impact of water ice was directly observed with an image-converter camera which stored 24 successive images at speeds of 2×10^5 and 5×10^5 frames s^{-1}. At high-velocity impact experiments, 140–650 m s^{-1}, a shear fracture region was observed to grow hemispherically from the impact point with a velocity between 2.0 and 3.5 km s^{-1}, depending on the impact velocity, which is larger than the shear wave velocity of water ice, 2.05 km s^{-1}. Then the fracture velocity gradually decreases, and the radial cracks continue to grow outside the region. The subsequent radial growth of cracks was similar to that found at low-velocity impacts.

Ejection velocities in collisional disruption of ice spheres

(M. Arakawa and M. Higa, ILTS)

Impact experiments were performed on ice spheres to measure the velocity field of ejected ice fragments and considered the conditions under which the fragments would reaccumulate during accretion in the outer Solar system. The ejection velocity of fine fragments formed by the jetting process near the impact point was determined to be 1.3–3.1 times as large as the impact velocity, irrespective of the target size and the impact velocity. The ejection velocity of fragments at the rear side of the target (Ve) varied with distance from the impact point according to a power-law relation, $Ve = Va\,(l/D)^{-n}$, where Va is the antipodal velocity, l and D are the distance and the target diameter, and n is 2.2 ± 0.6.

Restitution coefficients of ice at low temperatures

(M. Higa, M. Arakawa and N. Maeno, ILTS)

Measurements of the restitution coefficient (ϵ) of a water-ice sphere (radius 1.5 cm) were made in a wide range of impact velocities (Vi, 1–1000 cm s^{-1}) and temperatures (269–113 K). The impact velocity dependence of ϵ was different in the quasi-elastic and inelastic regimes divided by a critical velocity (Vc). It was observed that Vc corresponded to a velocity at which fracture deformation occurs at the impact point of ice samples. In the quasi-elastic regime ($Vi < Vc$) the values of ϵ were almost constant (0.9) and ice samples showed no fracture deformations. In the inelastic regime ($Vi > Vc$) ϵ decreased with increasing Vi and ice samples have fracture patterns. Velocity dependence of ϵ was fit as $\epsilon = (Vi/Vc)^{-\log(Vi/Vc)}$. Vc was shown to increase with decreasing temperature from 25 (269 K) to 180 cm s^{-1} (113–213 K).

Viscosity of partially melted ice in the ammonia-water system

(M. Arakawa and N. Maeno, ILTS)

The steady-state deformation of partially melted ice in the ammonia-water system was studied by means of a concentric cylinder viscometer in shear stresses, 10–100 kPa, temperatures, 180–210 K and NH_3 contents, 4.0–8.4%. The flow law found was a non-Newtonian power-law type; the stress exponent was 4.0 ± 0.1. The activation energy at constant melt fractions was $33.7 \pm 0.8\,\mathrm{kJ\,mol^{-1}}$, which was close to that of viscosity of aqueous ammonia solutions. However, the effective viscosity of partially melted ice estimated at 100 kPa was 10^7–10^8 Pa s, which is about ten orders of magnitude larger and smaller than that of the ammonia-water mixture in the liquid and solid phases (below a peritectic point, 176 K), respectively.

SNOW DRIFTING

Grain-size dependence of eolian saltation lengths during snow drifting

(N. Maeno, K. Nishimura and K. Sugiura, ILTS; K. Kosugi, SBSIS)

Eolian saltation, a primary process in the transport of fine granular material by wind, produces a variety of geophysical effects on Earth and other planetary surfaces. Wind-tunnel experiments were carried out to investigate the dependence of saltation on grain-size. The saltation length of snow particles was estimated at size intervals of 0.05 mm in diameter by measuring local vertical mass fluxes in 17 snow collectors arrayed at the lee end of the snow surface. The measured mean saltation length of snow particles of 0.01–1 mm in diameter ranged from 0.1 to 1.0 m at wind velocities of 5–10 $\mathrm{m\,s^{-1}}$. Mean saltation length decreased with increasing diameter and decreasing wind speed. The probability of the saltation length of a particle at each diameter was described by a monotonically decreasing distribution function, that is, the shorter the saltation length, the higher the frequency of its occurrence. One ramification of this distribution is that the mean saltation length does not imply the dominance of saltating particles of this length.

Snow-particle saltation

(K. Nishimura, ILTS)

Wind tunnel experiments were carried out to measure the trajectories of saltating snow particles in a turbulent wind with varying velocity. Trajectories of saltating particles were recorded by a video system with a laser sheet, and trajectory statistics such as ejection and impact velocities and angles were obtained for each particle. The significant findings were that some discrepancies between our results and those of other researchers can be explained by the experimental limitation of previous studies; parabolic trajectories were considerably elongated with increase in the friction velocity; impact angle was approximately the same but ejection angle descreased with increasing friction velocity. Further it should be noted that the gradient of flux decay with height decreased with the friction velocity.

Trajectories of saltating grains were computed, using the measurements of the initial ejection velocities and the mean velocity profile of air flow. The results showed exponential profile and agreed fairly well with our measurements. Using the measured probability distribution of ejection velocities, an ensemble of trajectories was computed and thence the vertical profiles of stream-wise fluxes and saltation-length distribution. The exponential decay of the flux on height was obtained in all cases and it supports the basic validity of the model. Although agreement is less than expected in some cases, the relation between the gradient of flux decay and the friction velocity was proved in the numerical simulation as well.

SNOW COVER

Surface hoar formation

(A. Hachikubo and E. Akitaya, ILTS)

Field observations of surface hoar formation were carried out with the measurements of water-vapor condensation rate, snow surface temperature, air temperature, humidity, wind velocity and net radiation. Surface hoar crystals are formed by the deposition of water-vapor on to the snow surface during the clear night. In general, large surface hoar crystals grew up when the snow surface temperature was 5°C (or more) lower than the air temperature, the humidity was higher than 90%, and the wind velocity was 1–2 $\mathrm{m\,s^{-1}}$ at 10 cm high. The condensation rate increased linearly with the product of the vapor pressure gradient and the wind velocity. This relation made it possible to estimate the condensation rate of surface hoar from the meteorological data. The bulk transfer coefficient of water-vapor was roughly constant when the surface hoar crystals were small, whereas it showed some increase as the hoar crystals grew to several millimeters in height. A possible cause of this increase in the bulk transfer coefficient is that the developed surface hoar crystals modify the aerodynamic roughness and consequently increase the turbulent transfer of water vapor. The surface hoar formation may involve a feedback mechanism.

Sun-crust formation

(T. Ozeki and E. Akitaya, ILTS)

The mechanism of sun-crust formation was investigated through field observations for five winters as well as laboratory experiments. Sun crust is a thin, glittering ice layer which sometimes forms on the surface of a snowpack on sunny days. During the observation periods in northern Hokkaido, Japan, sun crusts formed 15 times in such conditions as fine weather, air temperature around 0°C, wind speed of about 1–5 $\mathrm{m\,s^{-1}}$ and relative humidity of about 30–60% at a height of 1 m. Sun crusts observed in this study were thin ice layers, 1–2 mm in thickness. Energy balance calculations showed that longwave radiative flux and latent heat flux cooled the snow surface, while shortwave radiation was absorbed and internal melting occurred beneath the surface, leading to the formation of cavities just below the crust.

An experiment on sun-crust formation was conducted in a wind tunnel located in a cold room as well. Photo-reflector lamps were used as shortwave radiation, while sensible and latent heat transfers chilled the snow surface. The structure of sun crust which was reproduced in the cold room was consistent with those observed in the field.

Hydro-meteorological activities in Hokkaido

(N. Ishikawa, Y. Kodama, Y. Ishii and D. Kobayashi, ILTS)

In a small experimental watershed, Moshiri, Hokkaido, ILTS has carried out long-term meteorological and hydrological observations since 1992. Longwave radiation properties from different types of forest, soil moisture conditions along the hillslope and seasonal variations of evapo-transpiration were obtained in order to reveal the characteristics of water cycles in the watershed. In the snowmelt season, increases of net radiation and sensible heat flux with elevation were found becasue of the temperature inversion, the descrease of forest density and the increase of wind speed, which resulted in the snowmelt increase with elevation.

GLACIERS

Thinning and retreating Patagonian glaciers

(R. Naruse, ILTS; M. Aniya, IGUT; P. Skvarca, IAA; G. Casassa, CAA)

Large thinning rates were obtained by measuring surface profiles of three outlet glaciers in the northern and southern Patagonian ice fields (NPI and SPI); namely, 5.2 m a^{-1} from 1983 to 1985 at Glaciar Soler (eastern NPI), 4.0 m a^{-1} from 1985 to 1990 and 3.1 m a^{-1} from 1990 to 1993 at Glaciar Tyndall (southern SPI), and 11 m a^{-1} at Glaciar Upsala (eastern SPI). Compared with the thickness changes at 42 glaciers in the world (IAH/UNEP/UNESCO, 1993), the thinning rate of Glaciar Upsala is among the largest. On the other hand, at Glaciar Moreno (eastern SPI) the thickness has remained unchanged from 1990 to 1993. By analysing satellite-images and air photographs, the frontal variations were revealed at 22 major outlet glaciers from the NPI and SPI. During the last 45 years, five glaciers retreated more than 3 km, seven retreated ranging from 1 to 3 km, eight retreated less than 1 km, one (Moreno) has been almost in an equilibrium state, and one (Glaciar Brüggen or Pio XI: western SPI) has advanced up to 8.5 km.

Seasonal and short-term flow variations at Glaciar Moreno, Patagonia

(R. Naruse, ILTS; P. Skvarca, IAA; K. Satow, NCT)

Measurements of ice flow were made at the ablation area of Glaciar Moreno (SPI) in November and December 1993, and March 1994. It was found that velocities were larger in late spring or early summer (November) than mid-summer (January–February). Measurements at an interval of three hours in November showed that velocities in the afternoon were two or three times larger than those in the morning. The velocity correlated well with the ablation rate. These seasonal and short-term fluctuations in ice flow can be attributed to variations in the basal sliding velocity which is strongly controlled by the subglacial water network.

Heat balance and annual ablation at Patagonian glaciers

(Y. Takeuchi and R. Naruse, ILTS; K. Satow, NCT; P. Skvarca, IAA)

Heat-balance studies were made at Glaciar Moreno in November and at Glaciar Tyndall in December 1993. Contributions of net radiation, sensible heat flux and latent heat flux to ice melting were 54, 49 and –3%, respectively at Glaciar Moreno, and 51, 42 and 7%, respectively at Glaciar Tyndall. During 110 days in summer, the amount of surface ablation was measured by stakes as 7.0 m in thickness at the ablation area (350 m a.s.l.) of Glaciar Moreno. Based on the degree-day method with the ablation amount and the cumulative daily mean air temperature, the annual ablation was estimated at 13.4 ± 1 m in water equivalent.

ANTARCTIC SEA ICE AND ICE SHEET

Sea-ice growth processes in a heavily snow-covered region, Lützow-Holm Bay, Antarctica

(T. Kawamura and K. I. Ohshima, ILTS; T. Takizawa, JAMSTEC; S. Ushio, NIPR)

As part of the Antarctic Climate Research program, a two-year study of atmosphere/sea-ice/ocean interaction was conducted off Dronning Maud Land and Enderby Land, Antarctica from 1990 to 1991 by the Japanese Antarctic Research Expedition. Observations of sea ice were made at 11 stations on two latitudinal lines in Lützow-Holm Bay in April–May, August and October in both years to clarify characteristics and growth processes. The snow depth increased consistently with distance from the margin of the ice sheet, reaching a nearly constant maximum value of 1.0–1.5 m during the winter. The spatial increase in ice thickness corresponded with that of the snow depth, the maximum thickness at the offshore stations being 2.0–3.0 m. In the region with thick snow cover, sea ice was observed to be governed by characteristic growth processes. The result of the measured ice thickness in both 1990 and 1991 showed that this sea ice considerably thickens up to 0.8 m during summer and autumn rather than in winter. Specific layered structure was found in the sea-ice cores collected in that region. The layer contained transparent ice with coarse grains and the underlying opaque ice with fine grains, both ice types always existing in pairs. Correspondence of a specific ice layer in the 1990 core to that in the 1991 core revealed that this ice grows upward, not downward as in ordinary growth. Our stake measurements also showed that part of the snow cover near the sea-ice surface is transformed into an ice layer, which strongly supports upward growth. The properties (i.e. structure, salinity and isotopic composition) of the ice layer suggest that the upward increment in sea-ice thickness is produced by the combination of snow ice and superimposed ice. Evidence for melting of snow cover, which is a prerequisite for superimposed ice formation, was found. Several studies pointed out that snow cover contributes positively to sea-ice growth by the formation of snow ice, which is a common process of upward growth in the Antarctic winter sea ice. The summer growth as superimposed ice should also be added to this positive contribution of snow cover.

Surface mass balance in east Dronning Maud Land, Antarctica

(S. Takahashi, KIT; Y. Ageta, NU; Y. Fujii and O. Watanabe, NIPR)

Surface mass balances have been observed mainly by the stake method at more than 2300 points along the 16 traverse routes in east Dronning Maud Land. The surface mass balance was larger than 250 mm a^{-1} in the coastal region and smaller than 50 mm a^{-1} in the inland region higher than 3500 m in altitude. The whole mass input in five drainage basins with a total area of 620×10^3 km^2 is 61.2 Gt a^{-1} and the mean surface mass balance is 99 mm a^{-1}.

Weather and climate of Dome Fuji, Antarctica

(H. Enomoto and S. Takahashi, KIT)
Automatic weather stations using data-loggers were installed along the traverse route from the coastal region to Dome Fuji (3800 m a.s.l.). It was evident from the observations during traverses from Syowa Station to Dome Fuji that the wind direction was steady in the slope area, but became variable near the top of Dome Fuji. The year-round data at Dome Fuji were first obtained in 1995. These data showed that the wind direction rotated through the year with a period of a few weeks. Air temperature fluctuated greatly in winter and often increased more than 30 K within only a few days. Such recurring abrupt warmings were significant at Dome Fuji and in the inland region.

Refractive index of air hydrates and ice-hydrate interfacial energy in Vostok ice cores

(T. Uchida, HNIRI; T. Hondoh, ILTS; S. Mae, DAP)
The composition of ancient air can be restored by gas analysis of polar ice cores. However, air constituent gases are fractionated during the transformation process from air bubbles to air-hydrate crystals in deep ice sheets. The air-hydrate crystal is a molecular complex which includes air molecules in cage-like cavities. The cage occupancy of air molecules in an air-hydrate crystal is important for understanding the fractionation process. Because the cage occupancy is associated with the refractive index, the refractive index of air-hydrate crystals included in the 2542 m ice core of Vostok, Antarctica, was measured by an interfergometer. The refractive index was found to be about 0.4% larger than that of the surrounding ice matrix. Using the value of the index, the cage occupancy was calculated to be about 0.92 by the dielectric material model. The depth profile of the cage occupancy is obtained by this method.

Ice-hydrate interfacial energy was measured in order to clarify the effect of hydrate crystals on grain growth of ice crystals in deep ice sheets. The microscope observations were carried out on triple junctions of ice-grain boundary and ice-hydrate interfaces to obtain a relative value of the interfacial energy to the grain-boundary energy. We concluded that the ice-hydrate interfacial energy was approximately equal to the grain-boundary energy of ice. This result suggests that grain-boundary migration of ice must be impeded considerably by the existence of hydrate crystals. Since the number concentration of air-hydrate crystals is much higher than that of dust particles, grain-size distribution of ice achieved in deep ice sheets must be limited by distribution of air-hydrate crystals.

These studies on air-hydrate crystals from Vostok cores have been continued in collaboration with P. Duval (LGGE), V. Ya. Lipenkov and N. I. Barkov (AARI). The studies on air hydrate have been applied to the CO_2 storage in the deep sea and the development of new natural gas resources.

Abbreviations

AARI: The Arctic and Antarctic Research Institute, Russia
CAA: Centro Austral Antártico, Universidad de Magallanes, Chile
DAP: Department of Applied Physics, Faculty of Engineering, Hokkaido University
HNIRI: Hokkaido National Industrial Research Institute
IAA: Institoto Antártico Argentino, Argentina
IGUT: Institute of Geoscience, University of Tsukuba
ILTS: Institute of Low Temperature Science, Hokkaido University
JAMSTEC: Japan Marine Science and Technology Center
KIT: Kitami Institute of Technology
LGGE: Laboratoire de Glaciologie et Géophysique de l'Environnement, France
NU: Nagoya University
NCT: Nagakoa College of Technology
NIPR: National Institute of Polar Research
SBSIS: Shinjo Branch of Snow and Ice Studies, National Research Institute for Earth Science Disaster Prevention

Submitted by R. Naruse

NEW ZEALAND

Glacier monitoring programme

(T. J. Chinn, Institute of Geological and Nuclear Sciences Ltd., Dunedin)
A programme to estimate annual mass-balance changes of 47 selected glaciers of the New Zealand Southern Alps has been continued using the end of summer position of the snow line (ELA) as a surrogate for annual mass balance. The method has been employed since 1977 as an expedient form of glacier monitoring in lieu of ground-based mass-balance and glacier-front monitoring programmes. The positions of the ELAs were obtained by oblique aerial photographs taken from a hand-held camera in a small fixed-wing aircraft. The annual flights, timed for the elusive last day of perfect weather before the first snowfall of winter, have many gaps in the record up to 1993. However, both the 1994 and 1995 flights managed to cover the entire set of glaciers. On the 1995 survey, the frontal positions of an additional 67 larger cirque and valley glaciers were also photographed from the air. The programme is continuing with a view to relating ELA fluctuations to atmospheric circulation.

Proglacial lake formation

(M. P. Kirkbride, Department of Geography, University of Dundee, U.K.; C. Warren, Department of Geography, University of Edinburgh, U.K.)
Two expeditions to the Godley Valley, in March–April 1994 and 1995 were made to study the dynamics of proglacial lake development at the fronts of the Godley and Maud-Grey Glaciers. Lake bathymetry, ice-front morphology and position, ice velocities and ablation were measured. Ground-radar measurements of ice thickness were unsuccessful due to equipment failure.

Tasman Glacier snout

(J. Purdie, Department of Geography, University of Otago)
Over the 1994–95 summer, a research project was carried out to measure ablation on the lower Tasman Glacier, where the debris-covered surface is decaying to thermokarst features and a large proglacial lake is forming. Measurements were made on arrays of ablation stakes to be related to meteorological variables taken on the glacier surface.

Submitted by T. J. Chinn

POLAND

For abbreviations, see end of this report

The last report on Polish glaciological research was published in *ICE* in 1987. Because of the time that has elapsed since then, this report will include some retrospect on the intervening years. Permafrost, glacial geomorphology and glacial geology of the glacierized areas will be presented in a second report.

GLACIOLOGICAL STUDIES IN SPITSBERGEN, SVALBARD

Glacier mapping and survey of geometric changes

(J. Jania and L. Kolondra, KG/US)
The mapping of glaciers in south Spitsbergen is connected to research into changes in their geometry, which in turn is connected to climatic change. This work is a contribution to the Norwegian-Polish-Russian Cooperation in Glaciology on Svalbard project. Furthermore, maps of the most studied glaciers are used for field work and for compiling results. The maps are based on Norwegian aerial photographs (1961/62 and 1990) and our own terrestrial photogrammetric surveys. From those done in 1983, a detailed map of Werenskioldbreen (1 : 10 000) was produced (C. Lipert). Since 1982, the recession of this glacier has been monitored every two years by terrestrial photogrammetry, from permanent fixed-camera stations. Using these photographs, maps of the frontal part of the glacier at a scale of 1 : 5000 are prepared. The ice cliffs of the grounded tide-water glaciers (Austre Torellbreen, Korberbreen and Paierlbreen) are surveyed every 2–4 years at the end of the ablation season. For all but Korberbreen, a systematic recession of the front has been noted.

The most detailed measurements are those of changes in the ice-cliff location of Hansbreen, a grounded tide-water glacier. Terrestrial photogrammetric photos have been taken from permanent camera stations every 3–6 weeks since 1962, except during the polar night, and seasonal fluctuations detected. The winter advance reaches about 50 m and the summer retreat is 90–100 m, averaged across the cliff, giving a mean annual retreat of 40–50 m. An acceleration of this retreat has been observed in recent years as the front has terminated in deeper sea water.

Based on vertical aerial photographs from 1960/61, a set of topographic maps at a scale of 1 : 25 000, covering the Hornsund Fiord area, was published by the Institute of Geophysics, Polish Academy of Sciences, in 1987 (S. Barna and Z. Warchoł). New 1 : 25 000 maps of Hansbreen and Amundsenisen were published in 1994 by the University of Silesia (in cooperation with UQAM and NPI), based on 1990 photos. The first topographic map of Amundsenisen (the central accumulation field for large glaciers in Wedel Jarlsberg Land) was prepared and published at 1 : 50 000 in 1938 by the first Polish Spitsbergen Expedition of 1934, from terrestrial photogrammetry. The remapping showed a reduction in glacier elevation from 1934–90 of about 10–12 m. The thickness of Hansbreen decreased by about 24 m, averaged over the whole glacier surface, from 1936–90. Digital elevation models of these maps are now being prepared. The monitoring of Hansbreen and Werenskioldbreen continues and studies will be extended to other south Spitsbergen glaciers using Landsat TM and SPOT images.

Glacier mass balance

(J. Jania and co-workers, KG/US)
Mass-balance measurement of Hansbreen started in 1988/89. Mass loss, due to calving, was calculated and included in the total net balance. The superficial and [total] net balances, in water equivalent, were as follows: –0.18 m [–0.53 m] in 1988/89; –0.57 m [–0.90 m] in 1989/90; +0.07 m [–0.28 m] in 1990/91; –0.28 m [–0.63 m] in 1991/92; –0.63 m [–0.98 m] in 1992/93 and about –0.10 m [–0.45 m] in 1993/94. The volume of ice loss by calving was calculated from the glacier cross-section at the terminus, from the glacier velocity and from the mean annual front position change, the last two determined by terrestrial photogrammetry.

The winter balance and net balance of Amundsenisen has been measured at 720 m a.s.l. since the 1989/90 balance year. The mean winter accumulation is +1.5 m w.e. and the net balance about +0.5 m w.e. Therefore, about 70% of the winter accumulation melts and percolates into the firn. It seems that the relatively high mineralization of the percolating water inhibits the formation of significant internal nourishment in the form of ice lenses and glands. Most meltwater flows away, feeding the englacial and subglacial drainage systems.

The mass-balance measurements on Werenskioldbreen were started in 1993/94 when the net balance was –0.36 m w.e. Studies of all three areas will be continued until the end of the century.

Dynamics of tide-water glaciers

(J. Jania, KG/US)
Research on the calving process and glacier-flow velocity at and near the front of tide-water glaciers was initiated in 1982. Hansbreen has been the main objective of systematic research in the context of other tide-water glaciers emptying into Hornsund. The mass loss due to calving appears to be a very important factor in the glacier mass balance, constituting 25% of the general ablation.

Factors which determine the general calving rules are the principal objective. Relationships between the calving speed and glacier velocity near the ice cliff have been observed and surveyed by terrestrial photogrammetry. Time-lapse photographs have been taken from metal tripods fixed into bedrock every 3–4 weeks. The pseudo-parallax method was used for determining glacier velocity. A significant acceleration of surface velocity was observed in the lowest reaches of the glacier. Extending flow increases the velocity 3.5 times over a distance of less than 1 km. Seasonal fluctuations of velocity have been noted. Some positive feedbacks between glacier velocity and calving speed can be defined. Comparative studies using aerial photographs have been made between Korberbreen, Samarinbreeen, Muhlbackerbreen and Paierlbreen. Satellite remote-sensing data will be used for this in the future.

Seismic activity of a tidewater glacier

(M. Górski and M. Zalewski, IGF/PAN)
The Polish Polar Station is located on the northern shore of Hornsund, close to Hansbreen (about 1.5 km). Four seismometers are mounted in the area and connected to the central seismograph in the station. One of the seismometers is located on bare rock near the glacier (about 200 m from the western lateral margin of the

tongue). Seismic activity of the glacier with the typical low frequency (2–3 Hz) has been recorded since 1978, with some breaks. Ice tremors of different energy and origin have been distinguished. The most frequent seismic signals are related to propagation of crevasses in the frontal zone of extending flow. Since 1993, portable seismographs have been located directly on the glacier surface for 2–6 week periods during spring. Results permit the location of the focuses of the ice quakes and interpretation of glacier seismicity with respect to the velocity and calving activity of the glacier. The "on-glacier" experiments should provide data for better interpretation of the main seismometer readings at the station.

Hydrology of glaciers and glacier-drainage systems

(M. Pulina, J. Leszkiewicz, W. E. Krawczyk, J. Jania, KG/US; J. Rehak, Sr and Jr, CSA; J. Schroeder, UQAM)
Hydrological studies have traditionally been carried out in the Werenskioldbreen basin and the permafrost basin of the Fuglebekken. The new cycle of investigations started in 1988. Apart from hydrological and hydrochemical studies, a specific task has been the direct exploration and mapping of englacial and subglacial channels (moulins and R-channels). Drainage systems of Werenskioldbreen and Hansbreen have been investigated in detail. The supraglacial channel and moulin entrances on Hansbreen were mapped on the 1990 air photographs. More than 20 moulins have been explored by speleologists, several twice or more times during the last five years. A significant increase of water level in the moulins was noted during the winters.

The annual runoff of meltwater from Hansbreen was calculated using the summer-balance data. The glacier released into the fiord between $60 \times 10^6\,m^3$ and $95 \times 10^6\,m^3$ of water in certain years. An estimate of the meltwater contribution of tide-water glaciers emptying into Hornsund, and runoff from the land-based glaciers, suggests that the total volume of meltwater is of the order of $1127 \times 10^6\,m^3\,a^{-1}$ (rainfall and discharge from unglacierized basins not included). The volume contributed by calving added a further $530 \times 10^6\,m^3$ w.e. The annual total contribution of freshwater to the fiord therefore appears to be the equivalent of a layer about 7.1 m thick, averaged over the whole fiord surface.

Thermal structure of glaciers

(D. Mochnacki, J. Jania, KG/US; H. Blatter, GI/ETHZ)
Ice temperatures of Hansbreen have been measured since 1988. One profile of thermistors was placed near the Werenskioldbreen terminus in 1989. More accurate measurements were begun in 1991. A cooperative project with the Institute of Geography, ETH Zürich, Switzerland (GI/ETHZ) started in 1994. Three deep bore holes to bedrock on Hansbreen were prepared using a hot-water drill. Strings of thermistors were implanted in the holes in the accumulation zone, near the ELA and near the terminus. Results obtained since 1988 show a polythermal structure to the glacier, however, in the western lateral part of the lower reach of the tongue, an absence of cold ice is noted. Firn and ice in the accumulation zone is temperate. The cold ice layer is about 95 m thick near the ELA and about 45 m thick in the frontal zone. The cold ice continues but gets thinner and warmer towards the terminus. Using data from an automatic weather station operating at the ELA for the last two years (1994–95) the energy balance of the glacier surface can be modelled and its relationship with the glacier ice temperatures. Studies on the origin of the glacier's polythermal structure and its possible evolution with time and changing climate will continue in 1995 and 1996. Additional bore holes for thermistors will be drilled in the spring of 1995 in Hansbreen and Werenskioldbreen.

Snow depth measurements and chemistry of the snow cover

(P. Głowacki, M. Pulina and J. Burzyk, KG/US:ICh/US)
Research on the distribution, thickness and chemistry of the winter snow cover was started in 1989 on south Spitsbergen. In cooperation with NPI (J. O. Hagen and B. Lefauconnier) and IG/RAS (A. F. Glazovskiy and M. Yu. Moskalevsky) the studies were widened to include Lomonosovfonna, the Kongsvegen-Sveabreen system and some other areas. Around the Polish Polar Station at Hornsund, samples of new snowfalls were taken during the winter. The specific conductivity (total mineralization), pH, selected ions and heavy-metal content (Pb, Zn, Cu, Cd) were determined. The same elements were determined in the snow cover on the glaciers. Detailed research was carried out on Hansbreen and Amundsenisen from 1989–94 and continued in 1995. Relatively high content of salt, which comes from sea spray (chlorides), was determined in the winter snow cover, and anthropogenic pollution, low pH, also noted. The demineralization of snow and firn caused by percolation of meltwater was especially interesting. The mineralization ratio of winter snow in the accumulation area was in the range of $0.09–0.22\,g\,m^{-2}$ for a 10 mm thick layer (in w.e.). However, the one-year-old firn produced from this winter snow cover contained only $0.02–0.03\,g\,m^{-2}$ for 10 mm w.e. It suggests more than an order of magnitude demineralization of snow during summer percolation. This process is definitely very important for the drainage development of the flat accumulation fields of glaciers and also for modelling the ice hydrothermal conditions of these zones.

SOUTH SHETLAND ISLANDS, ANTARCTICA

Physical properties of glacier ice and meltwaters flowing to Admiralty Bay

(H. Gurgul, W. Stochnal, W. Szymczak, KF/USz)
Studies in the South Shetlands concerned the influence of the concentration and dispersion of mineral admixtures on the optical properties and radiation transmission into Ecology Glacier. The inflow of solar radiation was measured. The seasonal changes in the concentration and dispersion distributions of suspended matter flowing in meltwater from tidewater glaciers into Admiralty Bay waters were studied. These studies took place during the 13th Antarctic Expedition of the Polish Academy of Sciences (1989–90) to Arctowski Station, King George Island.

POLAND AND SLOVAKIA

Inventory and fluctuations of permanent snow and ice masses, Polish Tatras

(A. Wiśliński and Z. Wiślińska, INoZ/UMCS/FL)
Following instruction from the World Glacier Monitoring

Service (WGMS/ICSI), an inventory of permanent snow patches in the Polish part of the Tatra Mountains was completed. Long-term studies (since 1978) permitted trends to be determined. The patches occur within the 1550–2400 m a.s.l. altitude zone. At the end of the ablation season from 52 to 119 snow patches were found and 65 of them had existed at least during two consecutive years. Their total area was about 33 000 m^2. In each year of observation 48 patches were noted. One of the larger firn masses, in the Wielki Mięguszowiecki Cirque, shows the features of a glacieret (Mięguszowiecki Glacieret). The number and total area of snow patches have noticeably decreased since the 1920s and underwent some fluctuations in the 1980s. There has been a trend towards a decrease in the size of the largest firn masses during the last few years (after several warm summer seasons). The Mieguszowiecki Glacieret has been systematically monitored by terrestrial photogrammetry since 1989 (J. Jania and L. Kolondra, KG/US).

Inventory and fluctuations of permanent snow and ice masses (Slovak Tatras)

(J. Jania, L. Kolondra, T. Kołodziej and L. Litwin, KG/US)

Monitoring of geometric changes of the largest glacieret in the Tatras, the Medeny Glacieret (Medena Kotlina), has been carried out since 1992 using terrestrial photogrammetry. At the end of the 1993 and 1994 ablation seasons, observations for an inventory of permanent snow patches in the Slovak High Tatra Mountains were done. The extremely warm summer of 1994 made it possible to establish the minimal state of snow and ice masses. It is the first complete and uniform field inventory undertaken according to the WGMS/ICSI standard. The presence of 19 large snow patches was determined, several showing features of glacierets. Detailed mapping and measurements of ablation were carried out in Medena Kotlina and the Velka Zmrzla Dolina (W. Ziob and D. Zagól, KG/US). Studies on the fluctuations of selected glacierets will continue.

Seasonal snow cover, Sudety Mountains, Poland

(J. Piasecki, IG/UWr; P. Głowacki, KG/US)

Studies of the snow cover in the Śnieżnik Massif were carried out in 1990–93 with special reference to the Kleśnica Valley. They included snow-cover distribution and thickness at different altitudes. The load of hydrogen ions, potentially migrated from the snow cover to the soil during thawing, was measured. This load varied in different years from 3 to 102 mg m^{-2}. The buffer ability of the gneiss bedrock was about 20–50 mg m^{-2}. The highest value was noted above timberline (1310 m a.s.l.) in 1991, whereas at the summit of the Śnieznik (1425 m a.s.l.) it was only 5.2 mg m^{-2}.

In 1992–94, the chemistry of snowfalls on the northern (Polish) and southern (Czech) parts of the Śnieżnik Massif was measured (P. Głowacki, M. Pulina and B. Zacharska, KG/US). The pH values, specific conductivity, selected ions (Cl^-, SO_4^{2-}, NH_4, NO_3^-, NO_2^-) and content of heavy metals (Pb, Zn, Cu, Cd) from fresh snow and from older snow layers were determined. About 45% of the salt mass present in the snowfalls represents air pollution compounds (for instance nitrates: 3–6 t km^{-2} $year^{-1}$). A more acidic character of snowfalls and snowcover was determined on the northern slopes of the massif (average pH = 4.4). On the northern slopes, the average pH is 5.0 and on the summit 5.2. These studies are continuing as an element of monitoring mountain environments.

Abbreviations

CSA = Czech Speleological Association
FL = Free-lance
GI/ETHZ = Geographisches Institut, ETH-Zürich, Switzerland
ICh = Instytut Chemii
IG/RAS = Institute of Geography, Russian Academy of Sciences, 109017 Moscow, Russia
IG/UWr = Instytut Geograficzny, Uniwersytet Wrocławski, PL-50-076 Wroclaw, Poland
IGF/PAN = Institute of Geophysics, Polish Academy of Sciences
INoZ/UMCS = Instytut Nauk o Ziemi, Uniwersytet Maria Curie-Skłodowskiej, PL-20-950 Lublin, Poland
KG = Katedra Geomorfologii
KF/USz = Katedra Fizyki, Uniwersytet Szczeciński, Poland
NPI = Norsk Polarinstitutt, Maj., N-0301 Oslo, Norway
UQAM = Université du Québec à Montréal, CP 8889, Suc. A, Montréal, Québec H3C 3P3 Canada
US = Uniwersytet Śląski Wydzial Nauk o Ziemi, PL-41-200 Sosnowiec, Poland

Submitted by J. Jania

UK

For abbreviations, see end of this report

GLACIOLOGICAL MODELLING

Modelling marine ice sheets

(R. C. A. Hindmarsh, BAS)

A re-examination of the stability of marine ice sheets has been carried out. Marine ice sheets without ice streams seem to be in neutral equilibrium. Numerical models do not automatically respect this condition, and can produce spurious dynamical features, in particular instability. A uniformly valid perturbation scheme has been produced for the ice-sheet/stream/shelf transition which yields the usual sheet and shelf approximations as limiting cases of a range of values achievable by a dimensionless basal traction number. This analysis questions the significance of longitudinal deviatoric stress transmission from ice shelves into ice sheets. Investigations into the linearised theory of ice sheet evolution have been continued. Certain ice-sheet configurations and in particular the short-term response may well be describable by linear theories, and by constructing influence functions either analytically or numerically the effect of data uncertainty upon model predictions is much more readily understood. Linearised models describing the change of ice-sheet geometry and divide position have been constructed in conjunction with investigations into the triple junction forms often found at domes.

Modelling the stability of the East Antarctic ice sheet

(A. R. Kerr, D. E. Sugden, M. A. Summerfield, UEG)
Recent empirical evidence for the stability of the East Antarctic ice sheet is equivocal. It has been interpreted as indicating either stability over millions of years, or a more dynamic ice sheet which only attained its current form in the Quaternary. A suite of modelling experiments will examine ice-sheet stability over a range of scales. At the largest scale, the tectonic uplift of the Transantarctic Mountains appears to play a crucial role, and is modelled with flexural isostatic-response models of the passive margin. At medium scales, the form of bed topography is crucial, while at the smallest scales, detailed modelling of the outlet glaciers in the Transantarctic Mountains is used to examine high-resolution field data.

Numerical modelling of ice sheets in the Eurasian High Arctic

(M. J. Siegert, UWA)
A time-dependent ice-sheet model is being used to help reconstruct the dimensions of the Svalbard–Barents Sea ice sheet during the last glaciation. The results are compared against the existing paleoceanographic and geological record in order to find the most likely glacial scenario in terms of the date of glacial onset, the maximum ice-sheet extent and dynamics, and the timing of deglaciation. The behaviour of the ice sheet in the presence of a deforming bed, and the creation of ice streams within the ice sheet, is also being examined. An early Cenozoic glacial run tests the possibility of massive ice-sheet-induced bedrock erosion, and investigates why the present Barents Sea bedrock elevation is below sea-level.

Numerical modelling of the Late Weichselian ice caps on Franz Josef Land, Russian High Arctic

(M. J. Siegert and J. A. Dowdeswell, UWA)
Numerical ice-sheet modelling is being used to reconstruct the Late Weichselian ice mass over Franz Josef Land. Results are compared to the limited geological datasets from the region. Deglaciation is modelled by coupling model results to the measured uplift history of the archipelago. Results indicate that the relatively deep inter-island channels may have been instrumental in initiating high rates of iceberg calving and, hence, rapid ice-sheet decay at the end of the last glacial.

SATELLITE REMOTE SENSING

SAR interferometry on the Rutford Ice Stream

(R. M. Frolich and C. S. M. Doake, BAS)
The new technique of satellite radar interferometry has been applied to Rutford Ice Stream by with collaborators at JPL and CalTech, USA. Synthetic Aperture Radar (SAR) images from the ERS-1 satellite were processed and compared to give the displacement of the ice stream surface over a six day period. The technique depends on phase coherence between two observations to give interferograms, and can be destroyed by inappropriate satellite positioning or changes to the glacier surface. However, when suitable imagery exists, displacements of a few centimetres can easily be measured. The Rutford Ice Stream example showed the importance of having good ground data to calibrate the interferograms. A field campaign has been undertaken to obtain contemporary ground control for SAR interferometry of the Rutford Ice Stream area. Fifteen radar reflectors were established at five sites, distributed along 200 km of Rutford Ice Stream. Velocities have been measured to 1 m over a year at two sites and with centimetre precision relative to a fixed station over roughly 40 d at the other three. The reflector sites were chosen and the reflectors within each site aligned to maximise the number of SAR scenes that can be calibrated.

Ice divides and drainage basins on the ice caps of Franz Josef Land defined from Landsat, Russian KFA-1000 and ERS-1 SAR imagery

(J. A. Dowdeswell, UWA; A. F. Glazovsky and Y. Y. Macheret, Russian Academy of Sciences, Moscow)
Satellite imagery from the Landsat TM and MSS, Russian KFA-1000 and ERS-1 SAR instruments has been analysed to define ice divides and basins on the ice caps of the 16 130 km^2 Franz Josef Land archipelago, Russian High Arctic. Photographic products from the Russian KFA-1000 camera system provide the highest resolution satellite imagery (5 m) presently available of the archipelago. Over 900 km of ice divides have been identified on the crests of these ice caps. The largest ice-cap drainage basin in Franz Josef Land is that of Znamenity Glacier in Vilchek Land, at about 470 km^2. The ice masses on this island, Graham Bell, La Ronsier, Hall and Eva-Liv islands, are relatively simple in surface topography and are underlain by relatively thick ice. On smaller ice caps, where thinner ice is present, drainage basins are also inferred from the position of nunataks marking their boundaries. Mapping of major drainage basins on the ice caps of Franz Josef Land is a prerequisite for detailed glaciological investigations in the archipelago, and is complimentary to existing Russian inventories of the main ice-cap outlet glaciers.

Satellite investigations of fast-ice breakup in East Greenland fjords

(E. K. Dowdeswell and J. A. Dowdeswell, UWA)
Landsat satellite imagery is used to provide a record of the breakup of fast ice in several major fjord systems in East Greenland (68°–74° N). The areas considered are Kangerdlugssuaq Fjord, Scoresby Sund, Kong Oscars Fjord and Kejser Franz Josephs Fjord. Thematic Mapper and Multispectral Scanner QuickLook images from 1979 to 1993 indicate that for the most part, the breakup of fast ice occurs by a regular pattern of thinning and polynya development prior to final disappearance. Interannual variability in timing of breakup is being compared with climate records for these years. The spatial and temporal pattern of fast-ice breakup also provides constraints on iceberg calving and the potential sediment flux into these fjord systems.

Ice drainage basins and balance velocities in East Greenland from Landsat imagery

(A.-M. Nuttall and J. A. Dowdeswell, UWA)

A collection of 20 Landsat MSS images of East Greenland is being used to map drainage basin divides for tidewater glaciers in the study area, from about 68° N to 75° N. For those glaciers which are entirely covered by the imagery, the drainage basin area can be determined. If the accumulation rate and terminus thickness are estimated, then it is possible to calculate a balance velocity for those glaciers by considering the mass flux across the equilibrium line. Very few field measurements of velocity are available for this area, so these estimates can provide useful information in a poorly known region. In the few cases where velocities have been measured, they can be compared with the balance velocities to determine whether the glacier is gaining or losing mass.

Double ridges on satellite imagery of ice rises

(A. H. Goodwin, University of Aberdeen; D. G. Vaughan, BAS)

The appearance of apparent double ridges in Landsat imagery of some Antarctic ice rises has for some time been a puzzle. Using GPS levelling data from Fletcher Promontory it has been shown that here the origin of the double ridge is topographic (a subtle concavity parallel to the real ridge). Such distortions at the ice divide might possibly indicate a divide migration.

ICE CORES

Analysis of Antarctic Peninsula ice cores

(R. Mulvaney, E. C. Pasteur and N. Holman, BAS; C. Chenery and A. Baker, NERC Isotope Geochemistry Laboratory)

Work has continued on several ice cores retrieved during the 1992–93 field season from a transect of sites across the Antarctic Peninsula. Two 30 m cores, from Gomez Nunatak (74°01′ S; 70°38′ W), and Dolleman Island (70°55′ W) have been used to update the records obtained previously from deeper cores drilled at these sites. A new medium-depth core from Beethoven Peninsula, Alexander Island (71°34′ W), extends back to about 1940. Major cation and anion analysis of these cores is underway and oxygen and deuterium isotope analysis isotopes has been conducted. Data from these three sites, and from a longer core collected from the Dyer Plateau (70°53′ W) are being used to help reconstruct the spatial pattern of climate-related changes in the Antarctic Peninsula region during the past several centuries. The Dyer Plateau oxygen isotope profile is now complete back to 1505, making this the longest ice-core record from the region.

Dielectric profiling of the GRIP ice core

(E. W. Wolff and J. C. Moore, BAS)

The electrical data obtained from the Greenland Ice Core Project (GRIP) with the BAS dielectric profiler (DEP) have been investigated. The instrument was used at 2 cm resolution along the entire core. One of the parameters determined, the high-frequency limit of the conductivity, is controlled by the concentrations of chemicals (acid and neutral salt) in the ice. The detailed nature of this relationship was investigated by comparisons of the DEP data with chemical data obtained by Danish, French and Swiss workers. The conductivity responds most strongly to acids in the ice, which influence the conductivity at both low and higher frequencies. Overall, the crucial importance of impurities in determining the electrical properties of natural ice has been confirmed by the GRIP study, which has increased the amounts of dielectric data available for natural ice by orders of magnitude. It appears that all the thousands of electrical peaks seen in the GRIP core may be explained by just three chemical species: acidity, ammonium salts, and a third component that is probably chloride.

CONTAMINANTS IN SNOW AND ICE

Air and snow sampling at Halley, Antarctica

(E. C. Pasteur, J. S. Hall, E. W. Wolff and R. Mulvaney, BAS)

In order to improve our ability to interpret ice-core data, a series of collections of surface snow and aerosol has been made at Halley over the last few years. Analysis of the surface snow samples collected every day over the first 18 months of the study has now been completed, revealing the seasonal pattern of chemical input to this coastal site. Chloride shows considerable scatter, with high peaks occurring throughout the year, probably corresponding to sporadic input of sea salt from storm events. Nitrate shows a slight maximum in February, but the average concentration in surface snow over a year is considerably higher than the concentration seen in ice cores. This is consistent with the idea that there are major post-depositional losses of nitrate from the snowpack, and this process will be studied in detail. Sulphate shows a very clear seasonal signal, with a maximum in February, probably corresponding to high production of the precursor species dimethylsulphide (DMS) from marine organisms near to Halley.

Heavy metals in Antarctic snow

(E. W. Wolff and E. D. Suttie, BAS)

Analysis of a sequence of snow blocks representing 70 years of snowfall from Coats Land has provided a profile of heavy metal concentrations through this period. The Pb data have now been interpreted in terms of emissions from the Southern Hemisphere continents. Between 1920 and 1950, the Pb profile shows significant variations around a mean snow concentration of about 2.5 $ng\,kg^{-1}$. Between 1950 and 1980, there is a clear increase to 6 $ng\,kg^{-1}$, with a slight reduction apparent after that. A few high concentration spikes in the late 1970s may be due to overflights by aircraft using leaded aviation gasoline, but the remaining variations certainly reflect varying input from the other continents of the Southern Hemisphere. The reduction in Pb concentration in snow seen after 1980 has been related to the increasing use of unleaded and low-lead fuels, both in the Northern Hemisphere, and in Brazil, which has the largest number of cars in South America.

ANTARCTIC ICE SHEET

Temperature measurements at ice-stream margins, Antarctica

(R. M. Frolich, K. W. Nicholls and K. Makinson, BAS)

As part of a study into the rheology of ice at ice-stream margins a light-weight version of the BAS hot-water drill was used to install thermistor cables across a shear margin. Four thermistor cables were installed to a depth of 300 m along an 8 km line across the shear zone separating Rutford Ice Stream from the near-stagnant Carlson Inlet. These cables will be re-measured during the 1994–95 season, when the ice temperatures will have recovered from the disruption of the hot-water drilling; initial measurements indicate a strong warming signal (about 1°C) in the region of maximum shear. An 18 m core was drilled from ice thought to be in the region of maximum shear. This core will be used in structural testing in collaboration with UCL.

Investigations of Antarctic subglacial lakes from radio-echo sounding

(M. J. Siegert and J. A. Dowdeswell, UWA)
Radio-echo sounding data, collected by the Scott Polar Research Institute during the 1970s, has been examined in order to determine an inventory of sub-ice lake recordings. Information on the location, size and topographic setting of the lakes will be compared with satellite surface altimeter data in order to examine the dynamic response of the central ice sheet to significant regions of basal water. In particular, a very good RES dataset exists from a large (50 km by 200 km) sub-ice lake near Vostok Station, East Antarctica, from which a highly detailed investigation has been made

Radar sounding on the Ronne Ice Shelf

(H. F. J. Corr and M. Popple, BAS)
A new high-powered airborne ice-sounding radar was flown on a Twin Otter aircraft for a total of 75 h and profiled ice thickness for over 10 000 km. An array of high gain, wide bandwidth antennae mounted under the aircraft wings allowed the return echoes from ice depths of over 2500 m to be digitally recorded. The amplitude of a reflected echo can give information about the nature of the ice base, whilst the variation in amplitude along a flight line can indicate its texture. One of the principal regions overflown in a grid pattern was an area of the Ronne Ice Shelf where it is fed by one of its tributary glaciers, the Evans Ice Stream. The radar system was used to map this area of the Ronne where marine ice, derived from freezing sea water, has accreted to the base of the floating ice shelf.

Seismic sounding on the Rutford Ice Stream

(A. M. Smith, BAS)
High-resolution seismic data collected during the 1991–92 and 1992–93 field seasons on Rutford Ice Stream are being processed to give information on the ice stream bed and on the nature of the ice–bed interface. Profiles transverse to the direction of ice-stream flow show a rough bed topography (indicated by large numbers of hyperbolas) which varies in the character of its seismic reflection over short distances. Parallel to ice flow, the bed is much smoother. At one site at least, high seismic wave velocities, typical of solid rock values, occur within a very short depth below the bottom of the ice. Between the ice and the rock there may be a very thin, discontinuous layer of softer material with much lower seismic wave velocities. The presence of a hard ice-stream bed with a thin, discontinuous soft layer implies that the ice motion may be lubricated at the bed by processes other than sediment deformation alone, as has been proposed for other Antarctic ice streams. On Rutford Ice Stream, high subglacial water pressures or softening of the ice at the base may thus make a significant contribution to controlling the ice flow.

Glaciological mapping of the Ronne-Filchner Ice Shelf

(D. G. Vaughan, BAS)
In collaboration with the Institut für Angewändte Geodäsie in Frankfurt and the Alfred-Wegener-Institut in Bremerhaven, a glaciological map series of the Ronne–Filchner Ice Shelf and its hinterland is being compiled. These compilations have been long awaited by the glaciological and oceanographic communities. The maps of bedrock elevation and water depth are now close to completion and others are in preparation.

ANTARCTIC GLACIER MASS BALANCE

Snow-accumulation history for the Antarctic Peninsula

(D. A. Peel, BAS)
Evidence for accumulation-rate changes during the past century has been examined in all records available for the Antarctic Peninsula, based on high-resolution time series of stable isotopes, major anions and dust, species that exhibit a well-preserved seasonal stratigraphy, allowing accurate dating. The four widely dispersed sites, Gomez Nunatak, Dyer Plateau, Dolleman Island and James Ross Island, all indicate that there has been a slight, albeit <95% significant increase in snow-accumulation rate during the past century, averaging $8.6 \pm 4\%$. The overall increase is consistent with the relative increase in the atmospheric saturation-mixing ratio arising from the 1.7°C temperature increase recorded at Orcadas, and with the estimated temperature increases at the individual sites inferred from the stable isotope records. Larger increases since 1950 seen at three of the sites (Gomez Nunatak, James Ross Island and Dolleman Island) may simply reflect a return to near long-term average levels after a period of low accumulation in the 1950s.

Surface elevation changes in the Antarctic Peninsula ice sheet

(E. M. Morris and R. Mulvaney, BAS)
One consequence of a warming climate in the Antarctic Peninsula may be changes in the surface elevation of the ice sheet. In areas where the mean annual temperature is above about −11°C, where summer ablation occurs, the ice volume may shrink in response to a warmer climate. In colder regions of the Peninsula, the ice sheet may thicken as accumulation rate increases as a consequence of the greater moisture loading of the atmosphere. A series of eight over-snow level lines was set up in Palmer Land and on Alexander Island during the period 1972–86, with the height of the snow surface measured relative to fixed stations on local nunataks. During the 1992–93 season, six of these lines were remeasured using differential GPS and the change in surface elevation has been calculated. Short ice cores spanning about 10 years (approximately 7–10 m) were collected at each site to determine the recent accumulation-rate history.

ICE–OCEAN INTERACTIONS

Ice–ocean interactions beneath the Ronne Ice Shelf

(K. W. Nicholls and A. V. Robinson, BAS)
Analysis of oceanographic data from beneath Ronne Ice Shelf has been continuing. The data were collected from two sites during the 1990–91 and 1991–92 field seasons, and consist of sequences of salinity and temperature profiles obtained by lowering an oceanographic probe through hot-water-drilled access holes. Thermistor cables were also left suspended beneath the ice shelf at the two sites. Data from Site 1, about 100 km north-east of Korff Ice Rise suggest that the water originated either on the continental shelf north of Berkner Island, or from the western slope of the Ronne Depression, near the Antarctic Peninsula. Data obtained from Site 2, 100 km north of Site 1 and above the Ronne Depression, show that although it is 200 km from the open sea, the deepest water is at the surface-freezing temperature, and seems to be unmodified by its journey from the ice front.

Marine ice formation beneath the Ronne Ice Shelf

(A. Jenkins, BAS; A. Bombosch, Universität Münster, Germany)
The problem of marine-ice accumulation beneath Filchner–Ronne Ice Shelf has been addressed using a model of buoyancy-driven circulation in the underlying ocean. The model incorporates, in a relatively simple manner, the physics of ice-crystal growth within parts of the water column that are supercooled. The crystals can be held in suspension as long as the ocean currents are strong enough, but in areas of weak flow they are deposited on the ice-shelf base, much as transported sediment is deposited from a river where the flow slackens. The model has proved successful in producing intense bursts of ice-crystal deposition at the locations we would anticipate from the observed extent of the marine-ice layers.

Marine-ice desalination and ice-shelf basal accumulation

(A. Jenkins and K. W. Nicholls, BAS)
Deposition of ice platelets on to the base of an ice shelf forms an initially slushy layer which, over decades and centuries, is compressed by further accretion from beneath and cooled by the ice above, transforming it into solid ice. Considering its origin, this marine ice is surprisingly free of salts. In an attempt to understand the purity of the ice, a study of the physical processes that it undergoes after deposition has been initiated. Preliminary results suggest that convective processes in the ice, before it becomes impermeable, may play an important role by creating vertical channels through which compressive processes may finally expel salty water.

Tidal modelling for the Ronne Ice Shelf

(A. V. Robinson and D. G. Vaughan, BAS; M. Smithson, Proudman Oceanographic Laboratory)
The role played by tidal motion in modifying the oceanographic regime beneath Ronne Ice Shelf is largely unknown. A tidal model developed at the Proudman Oceanographic Laboratory has been used to model the tides of the southern Weddell Sea, including the portion covered by the Ronne and Filchner ice shelves. Initial results show encouraging agreement with the available datasets. The work will yield maps of tidal currents, phases and amplitudes for the primary tidal species, and a dataset that will be used to generate tidal corrections for satellite altimeter data.

Ice-shelf flexure

(D. G. Vaughan, BAS)
Owing to the dissipation of energy by tidal processes on Earth, the rotation of the Moon around the Earth is gradually slowing down. It has been estimated that up to one third of the energy loss could be accounted for by tidal flexing of Antarctic ice shelves. A study based on GPS surveys of the flexing of ice shelves casts doubt on the material properties of ice that were assumed when the original estimate was made. This mechanism of energy dissipation may actually be relatively insignificant.

GLACIMARINE SEDIMENTS AND SEDIMENTATION

Sedimentation on glaciated passive continental margins: the Polar North Atlantic and comparison with low latitudes

(J. A. Dowdeswell, UWA; N. H. Kenyon, Institute of Oceanographic Sciences; A. Elverhøi, University of Oslo; J. S. Laberg, University of Tromsø; F.-J. Hollender, University of Kiel; M. J. Siegert, UWA)
Long-range side-scan sonar (GLORIA) imagery of almost 300 000 km^2 of the Polar North Atlantic, together with associated acoustic data, provide a three-dimensional picture of large-scale sedimentation on a glacier-influenced continental margin. Major high-latitude fans (of up to 350 000 km^3), although comparable in size to those at lower latitudes (e.g. Amazon and Mississippi fans), are built up mainly of stacked debris flows derived from sediment delivered along a line source when glaciers reach the continental-shelf edge. High-latitude margins are influenced strongly by (i) glaciation in the form of glacial history and ice dynamics and (ii) the rate of sediment supply and geotechnical properties of this debris. By contrast, low-latitude margins, unaffected by debris derived from ice and fed mainly by fluvial sediments from a point source, typically have shelf-cutting canyons on the continental slope and rise, leading to fans with extensive sinuous submarine channel-levee systems.

Iceberg production, debris rafting, and the extent and thickness of Heinrich layers (H-1, H-2) in North Atlantic sediments

(J. A. Dowdeswell, UWA; M. A. Maslin, University of Kiel; J. T. Andrews, University of Colorado; I. N. McCave, UCES)
The pattern of Heinrich-layer distribution for the last two events (H-1, ~14.5 and H-2, ~21.1 ka), mapped from magnetic susceptibility analysis of over 50 North Atlantic cores, provides the most detailed information to date on their extent and thickness. An integrated spatial average thickness for the layers is 10–15 cm, and there is a strong distance decay eastward. The pattern of deposition over the North Atlantic is similar for events H-1 and H-2, indicating that icebergs followed similar drift tracks. Rates

of iceberg production and sediment flux from the Hudson Strait drainage basin of the North American Laurentide ice sheet, the major iceberg source for the events, were calculated by using a mass-balance approach. This provides an envelope of sedimentation rates and the prediction that it would take between 50 and ~1250 yr of iceberg sediment delivery to accumulate a Heinrich layer averaging 10 cm thick over the North Atlantic, depending on the model assumptions used. The most likely duration of Heinrich events is 250–1250 yr.

Glacial sedimentary record from the Antarctic Continental shelf

(M. J. Hambrey and K. Crawford, LJMU)
Drilling undertaken on the Antarctic continental shelf by the Ocean Drilling Program and the New Zealand Antarctic Research Programme (Prydz Bay and McMurdo Sound respectively) has yielded a record of glaciation extending back to Eocene time (at least 40 m yr.) Core material spanning the Miocene–Pliocene interval is currently being investigated in order to refine palaeoenvironmental interpretations, especially the role of grounded ice versus floating ice in building up the sedimentary sequence and identifying provenance changes through time. The work suggests that the East Antarctic ice sheet was temperate, highly dynamic and subject to considerable fluctuations until the Pliocene epoch. However, this view is at variance with the concept of a stable ice sheet as established from onshore geomorphological evidence by Denton, Sugden and others. Resolution of this problem is important for understanding global sea level and climatic changes. Comparative sedimentological work is being undertaken on Holocene cores from the southwest Weddell Sea in association with the Alfred Wegener Institute for Polar and Marine Research.

GLACIER BASAL PROCESSES

Basal-ice investigations at predominantly temperate-based Alpine glaciers

(B. P. Hubbard, UWA; M. Sharp, University of Alberta)
Research at 11 glaciers in the western European Alps has resulted in the identification and definition of seven basal-ice facies. The origin of each has been investigated on the basis of facies stratigraphy, sedimentology and stable isotope composition. Debris textures have been described quantitatively in terms of their component Gaussian modes, and isotopic data are interpreted within an analytical framework that allows for variations in the isotopic composition of source waters. Basal-ice facies formed by the metamorphism of glacier ice are distinguished from those formed by open-system refreezing within basal cavities and those formed by closed-system refreezing at the glacier bed. Genetic interpretations have allowed a number of inferences to be made that relate to the physical conditions present at the beds of temperate-based glaciers where these facies are observed.

Glacier surging: subglacial sediment deformation and ice-bed coupling

(P. R. Porter, T. Murray, ULG; J. A. Dowdeswell, UWA)
Using hot-water drilling we have instrumented the bed of Bakaninbreen, a surging glacier situated in the High Arctic. We aim to characterise the glacier's thermal and basal hydrological and mechanical regimes, and to measure how the velocity of the glacier is partitioned between sliding and bed deformation. Our drilling has shown the glacier to be underlain by a soft sediment, and has identified several englacial-sediment layers. Samples of material from these layers suggested they consist of material forced up from the glacier bed. Preliminary analyses of data from ploughmeters and sliding sensors shows the bed to be inhomogeneous, and reveals diurnal fluctuations in basal forcing. Data collection will continue through 1995.

Basal conditions beneath palaeo-ice masses inferred from subglacial microstructures

(A. J. Evans, T. Murray, ULG; A. J. Maltman, UWA)
Much of the beds of British Quaternary ice masses were soft sediment. This project aims to use thin-sectioning techniques to examine sediment microstructures and infer small-scale processes. We thus gain insights into the basal mechanical and hydrological regimes of past ice masses. Samples have been collected from both the East Coast and the Lleyn Peninsula. Sections from these field samples will be interpreted in conjunction with analogue sections produced in laboratory deformation experiments under known conditions. Of special interest are those structures related to subglacial sediment deformation.

GLACIER HYDROLOGY

Solute provenance and transport pathways, Small River Glacier, B.C., Canada

(G. H. Brown, UWA; C. C. Smart, University of Western Ontario)
The aqueous geochemistry of subglacial meltwaters has been investigated in the ablation area of Small River Glacier, B.C. During the 1994 summer ablation season, in-situ subglacial waters were sampled via a suite of more than 50 boreholes drilled to the glacier bed, providing a unique opportunity to investigate chemical weathering processes and subglacial hydrology in a glaciated catchment underlain by carbonate bedrock. Subglacial meltwater quality samples were supplemented by twice-daily (at approximately maximum and minimum diurnal discharge) samples for meltwater quality from the three major outlets at the glacier snout and periodic supraglacial meltwater sampling, which will allow links to be made between the quality of meltwaters input to the hydroglacial system, their modification during transit, and their subsequent discharge from the subglacial hydrological system.

Solute acquisition by Alpine glacial meltwaters

(G. H. Brown, UWA)
The first phase of dissolution experiments have concentrated on weathering reactions occurring in the channelised component of the subglacial hydrological system, where dilute meltwaters come into contact with large quantities of reactive suspended sediment. Experimental variables have been constrained by field data from the Haut Glacier d'Arolla, Switzerland, in order to facilitate a direct evaluation of potential chemical weathering processes operating in a known hydroglacial system. The weathering experiments have investigated the effect of changing particle size, water : rock ratio, crushing, repeated wetting, initial solution chemistry and CO_2

supply on the rate and magnitude of solute acquisition. A second phase of experiments, concerned with coupled reactions between sulphide oxidation and carbonate dissolution operating in the distributed component of the subglacial hydrological system, is in progress.

Borehole investigations at the Haut Glacier d'Arolla

(B.P. Hubbard, UWA; M. Sharp, University of Alberta; I.C. Willis, UCG)

Seventy five boreholes have been drilled to the bed of the ablation area of the Haut Glacier d'Arolla, Valais, Switzerland. A continuous, perennial record of subglacial water pressure, EC and turbidity variations has been provided by automated sensors located at the base of 36 of these boreholes. These data have been supplemented by manual, melt-season records of water level and borehole EC profiles. Reconstructed piezometric surfaces indicate that a major, melt-season subglacial channel develops within the borehole array. This channel flows along the centre of a variable pressure axis (VPA), some tens of metres wide, that is characterised by low base water pressures and high diurnal water pressure variations. The VPA merges over about 70 m with the surrounding distributed drainage system, characterised by high base water pressures and low water pressure variations. Large melt-driven water pressure variations in the channel result in a diurnally reversing, transverse hydraulic gradient that drives water through subglacial sediments into the distributed system during the afternoon and back to the channel overnight. Borehole turbidity records indicate that diurnal flooding and draining is responsible for the mobilisation and transport of fine debris in suspension. A model of subglacial erosion is therefore proposed whereby fine material is flushed from basal sediments located next to major, melt-season drainage channels beneath warm-based glaciers.

The seasonal evolution of meltwater discharge, quality and routing at a High Arctic glacier

(R. Hodgkins, SPRI)

Meltwater, solute and suspended sediment fluxes were monitored during two melt seasons at a Spitsbergen valley glacier. Two distinct patterns of meltwater storage and release were observed. In the early season, substantial storage of water occurs in supraglacial locations, from which there is rapid release in mid-season. In the late season, water is stored in passive englacial or subglacial locations adjoining the main ice-marginal channels, and drains slowly during winter to form a proglacial icing, which is extremely concentrated in solute. The statistical dependence of discharge on meteorology, and of suspended-sediment flux on discharge, increases significantly following the cessation of drainage from surface stores: the predictive capability of regression and time-series models is consequently improved. Bulk meltwater is characterised by high $p(CO_2)$ closed-system characteristics, resulting from rapid weathering and short residence times (giving a kinetic constraint on CO_2 diffusion) in turbid ice-marginal channels.

Hydrological influences on basal flow dynamics in valley glaciers

(P.W. Nienow, UEG; D.W.F. Mair and I.C. Willis, UCG; M. Sharp, University of Alberta)

The aim of this project is to make a detailed ice-motion study of the Haut Glacier d'Arolla, Switzerland, to determine the influence that changes in the subglacial drainage system have on basal motion. More specifically, the research will address the following issues: (a) the effect on basal motion of longitudinal variations in water pressure resulting from the subglacial drainage configuration and its evolution over time; (b) the effect on basal motion of transverse water-pressure variations and their effects on basal friction; and (c) the effect of discharge-related temporal changes on basal motion resulting from water-pressure effects on bed friction. To investigate the influence of subglacial drainage systems on basal motion, four key variables are being monitored during the course of the 1994 and 1995 melt-seasons: (i) the drainage system structure; (ii) meltwater discharge; (iii) basal water pressure; and (iv) ice motion. During the 1994 season, over 50 surveys were carried out on 49 velocity markers distributed across the glacier. The resolution of these surveys will provide a detailed history of the ice dynamics during the course of the melt-season.

Production and propagation of glacial and fluvial sediment slugs

(M.D. Crabtree, T. Murray, P.J. Ashworth and G. Sambrook Smith, ULG)

In a glacierized catchment, the glacier controls the input of water and sediment to the proglacial outwash plain. This project forms part of the SUPERSLUGS research initiative and aims to characterise the production and propagation of sediment slugs and water flow, both subglacially and proglacially. Proposed field techniques include borehole instrumentation to quantify the transport of water and sediment beneath the glacier, proglacial instrumentation, video and radio-tracer pebbles. Two field seasons are planned in Iceland for 1995 and 1996.

STRUCTURAL GLACIOLOGY

Structural evolution of a valley glacier during a surge: Bakaninbreen Svalbard

(M.J. Hambrey, LJMU; J.A. Dowdeswell, UWA; T. Murray, ULG)

Bakaninbreen is a tributary of Paulabreen which terminates in tidewater. In 1985/86 Bakaninbreen began surging and a 50 m high bulge propagated downglacier, more-or-less ceasing 3 km from the snout in 1994. The lower part of the glacier has been structurally mapped and the structural sequence is currently being assessed. Stratification with englacial debris layers has moved downstream with relatively little modification. A longitudinal foliation pervades the whole glacier, and commonly has an axial planar relationship to gently folded stratification. A series of high-angle thrusts and shear zones, associated with the passage of the surge front are widely developed; some of them have raised subglacial debris from the bed to the surface. Various other structures, notably high-angle, down-dipping fractures, have yet to be interpreted.

Glaciotectonic phenomena at Uvêrsbreen and Comfortlessbreen, Svalbard

(M.J. Hambrey and D. Huddart, LJMU)

The sedimentary facies, structures and landforms associated with these two valley glaciers, the letter terminating in tidewater, have been documented. Uvêrsbreen shows a thrust-moraine complex up to 90 m high comprising mainly glaciofluvial gravels, with lesser amounts of dead ice and diamicton. Thrusts are at a high angle and demonstrate brittle failure of the sedimentary sequence when it was uplifted. Similar features occur within the present glacier snout. Localised ductile deformation has affected thin horizons of diamicton, which sometimes behave as zones of décollement. The Comfortlessbreen thrust-moraine complex, in contrast, comprises glaciofluvial material, glaciomarine mud and diamicton. Thrust faulting has occurred in glaciofluvial sediments well beyond the maximum limit reached by the ice. In the remaining facies there is evidence of considerable ductile deformation and recumbent folds are prominent. The thrusts in this complex are of low angle. These contrasting structural styles are linked to the rheological properties of different facies associations. Structures within these two glaciers show no unequivocal signs of surging characteristics, in contradiction to some previous reports.

GLACIER FLUCTUATIONS

Glacier fluctuations on the North Patagonian Icefield

(S. Harrison, Department of Geography, Middlesex University and V. Winchester, Department of Geography, University of Oxford)

Post Little Ice Age fluctuations of outlet glaciers of the North Patagonian Icefield (NPI) have been investigated since 1991. The glaciers studied are all situated on the western side of the icefield. They are the tidewater San Rafael glacier; the large piedmont San Quintin glacier which lies to the south of Laguna San Rafael and the Gualas and Reicher glaciers on the northwestern flanks of the icefield. Moraines mapped in the field have been dated by a combination of lichenometric and dendrochronological methods and reveal a complex series of glacier fluctuations from the beginning of the nineteenth century.

Glacier recession in Iceland and Greenland

(J. Wright, Webbs Farmhouse, West Wittering, PO20 8LG)

A return visit to Hagavatn, Iceland in 1992 revealed that glacier retreat in 1939 and subsequently had created a new lake exit from that used in 1934. In Greenland, the Moltke Glacier, surveyed in 1938, had retreated about 4 km by 1993.

GLACIER HAZARDS

Glacier hazard assessment and mitigation

(J. M. Reynolds, Reynolds Geo-Sciences Ltd., Clwyd, North Wales)

High-altitude glacial lakes dammed by moraines which may be partially ice-cored may pose a considerable hazard to local communities downstream. Such lakes occur in most geologically young tectonically active mountain chains (e.g. Andes, Himalayas). Failure of a lake dam can result in a massive and catastrophic flood which may reach for hundreds of km downstream. However, identification of the size of the hazard or an assessment of the possible urgency associated with a given glacier-lake system may be beyond the capabilities or experience of the local authorities. Reynolds Geo-Sciences has been involved with the successful assessment and implementation of glacier hazard mitigation schemes in the Cordillera Blanca, Peru. A major project has been initiated in the Rolwaling Himal in northern Nepal where an assessment of a glacier-lake system was completed in 1994.

Abbreviations

BAS = British Antarctic Survey, Cambridge
LJMU = School of Biological and Earth Sciences, Liverpool John Moores University
SPRI = Scott Polar Research Institute, University of Cambridge
UCG = Department of Geography, University of Cambridge
UCES = Department of Earth Sciences, University of Cambridge
UEG = Department of Geography, University of Edinburgh
ULG = Department of Geography, University of Leeds
UWA = Centre for Glaciology, Institute of Earth Studies, University of Wales, Aberystwyth

Submitted by J. A. Dowdeswell

International Glaciological Society

BRANCH NEWS

NORDIC BRANCH

The 1995 annual meeting of the Nordic Branch of the International Glaciological Society will be held in Lammi Biological Station, southern Finland, 8–9 December 1995. This meeting is the third since the reactivation of the Nordic Branch in 1993.

The objectives of the meeting are to present Nordic activities in snow and ice research and to enhance further research and education cooperation in this field. Those interested in participating should contact the undersigned by 31 October.

Although the Nordic Branch meetings normally do not involve proceedings, we may write an informal report describing Nordic interests, research projects, field stations, course activities, etc., as a catalogue for the future, especially for newcomers. Anticipating some non-Scandinavian participants, the English language is recommended, though, due to our long tradition, Scandinavian languages are alternatives.

The Lammi station is 130 km north of Helsinki. We shall arrange transportation from Helsinki to Lammi in the evening of 7 December, returning the evening of the 9th, but it is possible to stay in Lammi overnight until the 10th. Accommodation, including meals, costs 125 Finnish marks per day, students get a one-third reduction. More information about Helsinki–Lammi travel connections is available on request. The programme, list of participants, and detailed travel information will be mailed in early November.

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FIN-00014 University of Helsinki, Finland
Phone +358-0-19122028, fax +358-0-19123385
e-mail lepparan@kruuna.helsinki.fi

INTERNATIONAL GLACIOLOGICAL SOCIETY

INTERNATIONAL SYMPOSIUM ON REPRESENTATION OF THE CRYOSPHERE IN CLIMATE AND HYDROLOGICAL MODELS

Victoria University, Victoria, British Columbia, Canada 12–15 August 1996

CO-SPONSORED BY

Atmospheric Environment Service
Institute of Ocean Sciences
University of Victoria Centre for Earth and Ocean Research
Canadian Meteorological and Oceanographic Society

SECOND CIRCULAR

The International Glaciological Society will hold an international symposium in 1996 on Representation of the Cryosphere in Climate and Hydrological Models at the University of Victoria, British Columbia, Canada. Registration will take place on Sunday 11 August and sessions will be from Monday 12 through Thursday 15 August. There will be two short post-symposium excursions on Friday, 16 August. As Victoria is a major tourist destination offering a wide range of experiences, no extended post-symposium tour has been planned. Information on commercial tours offered by local operators will be made available to any participant who wishes to visit the area after the symposium. For those wishing to plan their tour activities prior to the Symposium, tourist information telephone numbers are included in this circular.

PARTICIPATION

This circular includes a booking form for registration and the post-symposium excursions. The form and accompanying payments should be returned, in accordance with instructions given, before 15 May 1996. There will be a UK£45 surcharge for registrations received after this date. Full refunds will not be possible for cancellations received after June 21.

Participants' registration fees cover organization costs, copies of abstracts, the icebreaker, banquet, and a copy of the Proceedings volume. The accompanying persons' registration fees include organization costs, icebreaker and banquet. There is an administration charge for participants who are not members of the IGS or CMOS.

LOCAL ARRANGEMENTS COMMITTEE B. Goodison (Chairman), G. Flato, R. Brown

CHIEF SCIENTIFIC EDITOR J. E. Walsh

INFORMATION ABOUT THE SYMPOSIUM MAY BE OBTAINED FROM:

Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, UK

Local:	Tel: 01223-355974	Fax: 01223 336543
International:	Tel: + 44 1223 355974	Fax: + 44 1223 336543
E-mail:	100751.1667@compuserve.com	
IGS'96 WWW site:	http://www.dow.on.doe.ca/CRYSYS/igs96.htm	

REGISTRATION FEES	UK£
Participant (IGS, CMOS)	175
Participant (not a member of above)	205
Student	75
Accompanying person aged 18 or over	45
Late registration surcharge (after 15 May 1996)	45

Refunds on registration fees will be made on a sliding scale, according to date of receipt of notification, up to 1 August 1996. After that date it may be impossible to make any refund. See booking form for methods of making payment. All who preregister will receive a copy of the third circular and programme prior to the meeting.

TOPICS

The symposium will focus on how cryospheric processes, cryosphere/atmosphere/ocean coupling and cryosphere/terrestrial interactions are represented in climate and hydrological models. The emphasis will be on large-scale cryospheric components, such as snow cover (including snowfall), sea ice, large ice sheets and permafrost. Of particular interest are the results of model experiments that identify the sensitivity of the climate system to cryospheric processes and/or parameters. Suggested topics include:

(1) Representation of the cryosphere in models: parameterization, validation and identification of knowledge gaps; scaling of cryospheric processes.

(2) Coupling of cryosphere/atmosphere/ocean/terrestrial processes.

(3) Uses of models: sensitivity assessments of various cryospheric processes; data assimilation, and; priorizing cryospheric observations and field measurements.

(4) Validation of cryospheric components in models: remote sensing, conventional observations and process studies — including the accuracy, reliability, errors and availability of these data.

Sessions will be held over four full days including a special session for poster displays. Two excursions are planned for the day following the conclusion of the symposium.

PAPERS

(i) SUBMISSION OF PAPERS

Participants who want to contribute to the Symposium should submit an abstract of their proposed paper in English. This abstract must contain sufficient detail to enable us to form a judgement on the scientific merit and relevance of the proposed paper. It should not exceed one page of typescript, on international size paper A4 (210 × 297 mm). References and illustrations are not required at this stage. Place the title and authors' names and addresses at the top of the abstract, not on a separate sheet. Indicate at the bottom which specific topic it intends to address, and whether a poster presentation is preferred. When selecting their material, authors should bear in mind that the final version of the paper should not normally exceed 5 *Annals* printed pages. Send abstracts by E-mail, fax or regular mail to: Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, U.K.

LAST DATE FOR RECEIPT OF ABSTRACTS: 1 FEBRUARY 1996

(ii) SELECTION OF PAPERS

Each abstract will be assessed on its scientific quality and relevance to the topics of the Symposium. Authors whose abstracts are acceptable will be invited to make either an oral or poster presentation at the Symposium. There will be no distinction between oral or poster papers in the Proceedings. First or corresponding authors only will be advised by the end of March 1996 of the acceptance or otherwise. Authors who have not received notification by 15 April should contact the IGS office in Cambridge. Acceptance of an abstract means that the paper based on it must be submitted to the Proceedings volume and not to another publication. Note: Abstracts alone will not be published in the Proceedings volume.

(iii) DISTRIBUTION OF ABSTRACTS

A set of the accepted abstracts will be provided to all registered participants upon registration on 11 August.

(iv) SUBMISSION OF FINAL PAPERS AND PUBLICATION

Papers presented at the Symposium will be considered for publication in the Proceedings volume (*Annals of Glaciology*, Vol. 25). Final typescripts of papers should be sent to the Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, U.K. by 15 June 1996. They should be written in English and prepared in accordance with the style instructions sent to authors with the acceptance notification. Papers will be refereed according to the usual standards of the Society before being accepted for publication. Final, revised versions of papers, diskettes and original art work must be submitted by the end of September 1996. Speedy publication of the Proceedings will depend upon strict adherence to deadlines.

LAST DATE FOR RECEIPT OF FINAL PAPERS: 15 JUNE, 1996

ACCOMMODATION

Dormitory

Dormitory rooms have been booked on the University of Victoria campus. The rate, including breakfast and taxes, is Can$36.95 per night for a single room and Can$51.65 per night for a twin room (both with shared hallway bathroom). Quad cluster suites are available, with 4 bedrooms, bathroom and sitting room, for Can$128.70 per night. Reservations should be made directly with: University of Victoria, Housing and Conference Services, Victoria, B.C., V8W 2Y2, Canada (tel: +1-604-721-8396 [08301630 hours Monday to Friday]; fax: +1-604-721-8930).

Hotel
For those not wishing to stay in student accommodation, a block booking for the Symposium has been made at the Coast Victoria Harbourside Hotel in downtown Victoria (a 20 minute bus ride from the Symposium venue). Transportation will be provided to take participants to the University every morning and return them to the hotel after the sessions have finished. The rate per room (single or double occupancy) is Can$130 + taxes, not including breakfast. Reservations should be made directly with the hotel (Coast Victoria Harbourside Hotel, 146 Kingston Street, Victoria, B.C., V8V 1V4, Canada. tel: +1-800-663-1144 [within North America] or +1-604-360-1211 [from outside North America]; fax: +1-604-360-1418). When making reservation, please tell the hotel you are with the "IGS Symposium". PLEASE NOTE: The block booking will be released 60 days before the meeting so reservations must be made by 10 June 1996. Victoria is very popular in the summer and hotel/motel rooms are not likely to be available at short notice.

Other Accommodation
The Tourism Victoria Office can provide information and make reservations for other accommodation (e.g. bed and breakfast establishments, other hotels/motels, etc. tel: +1-800-663-3883 [within North America] or +1-604-953-2022 [from outside North America].

Although participants must make their own reservations, please indicate your choice on the attached Registration Form to assist local organizers.

TRAVEL
Air Canada has been appointed the Official Airline for the Symposium. Selecting Air Canada or one of its Partners (Continental Airlines) or Connector Carriers means that you can take advantage of special convention rates for travel within North America. To make use of this special offer, call AIR CANADA at +1-800-361-7585 (within North America), your nearest Air Canada office, or your travel agent to take advantage of:

Special convention rates for travel within North America;
Substantial savings with Air Canada and Continental Airlines' joint convention fares;
Aeroplan or OnePass miles that can be redeemed on any Air Canada or Continental route worldwide;
Savings of up to 50% on Regular Economy Class Fares (overseas passengers will receive the best available fare).
When purchasing your ticket, please ask that Event Number CV960087 be entered in the Tour Code box of your ticket, regardless of the fare purchased. Please note that certain rules and conditions apply on all tickets purchased.

HALF-DAY EXCURSIONS
The following post-symposium excursions will be arranged provided there is sufficient interest. Payment for the excursions(s) selected must be included with the registration fees as indicated on the Registration Form:

Excursion 1:
Friday, 16 August, from 0800–1500 hours. A scientific tour highlighting Quaternary sediments in and around Victoria. A box lunch and guide book will be provided. Some walking will be involved. The tour will end in time to join the second excursion.

Excursion 2:
Friday, 16 August, from 1700–2000 hours. Scenic buffet dinner cruise along the Victoria waterfront aboard the historic steamship S.S. Beaver.

TOURIST INFORMATION
Information on tourist activities in and around Victoria can be obtained from Tourism Victoria (tel: +1-604-953-2033). Information and reservations for tourist activities throughout the Province of British Columbia can be obtained from the British Columbia Tourist Information Office (tel: +1-800-663-6000 [within North America] or +1-604-387-1642 [from outside North America].

In the Victoria area during August, the mean daily minimum/maximum air temperature is 11–21°C, with a 23% chance of precipitation, and an average of 9 hours of bright sunshine per day.

IMPORTANT DATES:
Abstracts due: 1 February 1996
Notification of acceptance: 31 March 1996
Preregistration deadline 15 May 1996
Papers due: 15 June 1996
Final revised papers due: 30 September 1996

SYMPOSIUM ON REPRESENTATION OF THE CRYOSPHERE IN CLIMATE AND HYDROLOGICAL MODELS

Victoria, British Columbia, Canada, 12–15 August 1996

Reservation Form

Family Name . . . . .First Name/s . . . .

Address . . . .

. . . .

Tel: . . . . .Fax: . . . . .E-mail: . . . .

I will be making my reservations in Student Dormitory: [ ] Coast Hotel: [ ]

Accompanied by:

Name . . . . Age (if under 18) . . . .

Name . . . . Age (if under 18) . . . .

Name . . . . Age (if under 18) . . . .

REGISTRATION FEES	UK£
Participant (IGS, CMOS)	175
Participant (not a member of above)	205
Student	75
Accompanying person aged 18 or over	45
Late registration surcharge (after 15 May 1996)	45
Excursion 1	22
Excursion 2	28
Total registration fees sent £	

Cheques should be made payable to the **International Glaciological Society**.
Payment may also be made directly to our Bank: National Westminster Bank plc, account no: 54770084, 56 St. Andrew's Street, Cambridge CB2 3DA, UK, or to our Post Office GIRO account no: 240 4052.

NOTE: If you send payment in a currency other than £ sterling, please add the equivalent of £10 to cover the charges levied by banks on such transactions.

Payment may also be made by Access/Eurocard/MasterCard or VISA/Delta: Amount: £....................

Card Number: [| | | | | | | | | | | | | | |] Expires: [| | |]

Name as shown on card: ________________________________

Signature: ________________________________

INTERNATIONAL GLACIOLOGICAL SOCIETY

INTERNATIONAL SYMPOSIUM ON SNOW AND AVALANCHES

Chamonix Mont-Blanc, France 26–30 May 1997

CO-SPONSORED BY
Association Nationale pour l'Etude de la Neige et des Avalanches (ANENA)
METEO FRANCE, Centre d'Études de la Neige
CEMAGREF, Division Nivologie
Laboratoire de Glaciologie et de Géophysique de l'Environnement, (CNRS)
Pôle Grenoblois d'Etudes et de Recherche pour la Prévention des Risques Naturels
Ville de Chamonix Mont-Blanc

FIRST CIRCULAR
October 1995
Registered Charity

The International Glaciological Society will hold an international symposium on Snow and Avalanches in 1997. The symposium will be held in the Salle des Congrès Majestic, Chamonix Mont-Blanc, France with registration on 25 May, and sessions from 26–30 May.

THEME The properties of snow in mountain and polar regions and the processes taking place within the snow cover are critical factors in the interpretation of climate and remote sensing signals and in our ability to model the movement of snow. In most mountain regions, avalanches pose a significant threat to human life and property. Improved scientific knowledge of mountain snow and avalanche dynamics opens up new and powerful prospects for reducing this threat.

This Symposium will focus on those aspects of snow science related to understanding the snow cover, its properties and movement.

TOPICS The suggested topics include:

snow properties, mechanical, snow hydrology physical, electromagnetic and radiative
modelling snow and ice chemistry processes
snow-cover distribution, stability, evolution and modelling
snow structure
snow drifting/blowing snow
avalanches
avalanche dynamics
avalanche snow rheology
risk assessment
model verification
slush flows

SESSIONS Oral presentations will be held on four full days and one half-day. There will be ample opportunity for poster displays.

PUBLICATION The Proceedings of the symposium will be published by the Society in the *Annals of Glaciology*. All papers (including poster papers) will be refereed and edited according to the Society's regular standards before being accepted for publication.

ACCOMMODATION Details will be given in the Second Circular. A full range of hotel accommodation will be available.

EXCURSIONS There will be a mid-week excursion to the Aiguille du Midi (3800 m a.s.l.) or Mer de Glace and a post-symposium tour from Chamonix to Nice.

FURTHER INFORMATION If you wish to attend the symposium please return the attached form as soon as possible. The Second Circular will give information about accommodation, the general programme, and preparation of abstracts and final papers. Copies of the Second Circular will be sent to those who return the attached reply form. Members of the International Glaciological Society will automatically receive one.

SYMPOSIUM ORGANIZATION S. Ommanney (Secretary General, International Glaciological Society)

CHIEF SCIENTIFIC EDITOR D. M. McClung

LOCAL ARRANGEMENTS COMMITTEE François Sivardière (Chairman), Gérard Brugnot, Eric Brun, Christophe Genthon

SYMPOSIUM ON SNOW AND AVALANCHES

Chamonix Mont-Blanc, France, 26–30 May 1997

Family Name . . . . .First Name/s . . . .

Address . . . .

. . . .

Tel: . . . . .Fax: . . . . .E-mail: . . . .

I hope to participate in the Symposium in May 1997 [ ]

I expect to submit an abstract [ ]

My abstract will be most closely related to the following topics . . . .

I hope to join the post-symposium tour [ ]

I am interested in an accompanying persons programme [ ]

PLEASE RETURN AS SOON AS POSSIBLE TO:

Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, U.K.

Local:	Tel: 01223 355974	Fax: 01223 336543
International:	Tel: +44 1223 355974	Fax: +44 1223 336543
E-mail:	100751.1667@compuserve.com	

JOURNAL OF GLACIOLOGY

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

R J BRAITHWAITE
Aerodynamic stability and turbulent sensible heat flux over a melting ice surface, the Greenland ice sheet

B P HUBBARD, M J SHARP, I C WILLIS, M K NIELSEN AND C C SMART
Borehole water-level variations and the structure of the subglacial hydrological system of the Haut Glacier d'Arolla, Valais, Switzerland

H FISCHER, D WAGENBACH, M LATERNSER AND W HAEBERLI
Glacio-meteorological and isotopical studies along the EGIG-line, central Greenland

M NOLAN, R J MOTYKA, K ECHELMEYER AND D C TRABANT
Ice thickness measurements of Taku Glacier, Alaska, and their relevance to its recent behavior

J L DWYER
Mapping tidewater glacier dynamics in East Greenland using Landsat data

J K HART
An investigation of the deforming layer/debris rich basal ice continuum, illustrated from three Alaskan glaciers

D B BAHR AND J B RUNDLE
Theory of lattice Boltzmann simulations of glacier flow

E F FERRARO AND C T SWIFT
Measuring geophysical parameters of the ice sheet using airborne radar altimetry

M S PELTO
Annual net balance of North Cascade glaciers, 1984–94

J K HART
Recent drumlins, flutes and lineations at Vestari-Hagafellsjökull, Iceland

G S BOULTON
A theory of glacial erosion, transport and deposition as a consequence of subglacial sediment deformation

D V THIEL, D JAMES AND P JOHNSON
VLF surface impedance measurements for ice-depth mapping — an assessment of some commonly encountered interference effects

J T HEINE AND D F McTIGUE
A case for cold-based continental ice sheets — a transient thermal model

H BJÖRNSSON, Y GJESSING, S-E HAMRAN, J O HAGEN, O LIESTØL, F PÁLSSON AND B ERLINGSSON
The thermal regime of subpolar glaciers mapped by multi-frequency radio-echo sounding

N S ARNOLD, I C WILLIS, M J SHARP, K S RICHARDS AND W J LAWSON
A distributed surface-energy balance model for a small valley glacier. I. Development and testing for the Haut Glacier d'Arolla, Valais, Switzerland

R D WEST, D P WINEBRENNER, L TSANG AND H ROTT
Microwave emission from density-stratified Antarctic firn at 6 cm wavelength

C RAYMOND
Shear margins in glaciers and ice sheets

S URATSUKA, F NISHIO AND S MAE
Internal and basal ice changes near the grounding line derived from radio-echo sounding

P W NIENOW, M SHARP AND I C WILLIS
Sampling rate effects on the properties of dye breakthrough curves from glaciers

T A HEINRICHS, L R MAYO, K A ECHELMEYER AND W D HARRISON
Quiescent phase evolution of a surge-type glacier: Black Rapids Glacier, Alaska, U.S.A.

T NAKAMURA AND M SHIMIZU
Variation of snow, winter precipitation and winter air temperature during the last century at Nagaoka, Japan

D M COLE
Observations of pressure effects on the creep of ice single crystals

J A DOWDESWELL AND R D POWELL
Submersible remotely operated vehicles (ROVs) for investigations of the glacier–ocean–sediment interface

L E HUNTER, R D POWELL AND D E LAWSON
Flux of debris transported by ice at three Alaskan tidewater glaciers

A T MANNINEN
Surface morphology and backscattering of ice-ridge sails in the Baltic Sea

I JOUGHIN, D WINEBRENNER, M FAHNESTOCK, R KWOK AND W KRABILL
Measurement of ice-sheet topography using satellite radar interferometry

ANNALS OF GLACIOLOGY

The following papers have been published in Volume 21, *Proceedings of the International Symposium on the Role of the Cryosphere in Global Change* held at Columbus, Ohio, USA, 7–12 August 1994

A FABRE, A LETRÉGUILLY, C RITZ AND A MANGENEY
Greenland under changing climates: sensitivity experiments with a new three-dimensional ice-sheet model

R GREVE AND K HUTTER
Polythermal three-dimensional modelling of the Greenland ice sheet with varied geothermal heat flux

K STEFFEN
Surface energy exchange at the equilibrium line on the Greenland ice sheet during onset of melt

A FRIEDMANN, J C MOORE, T THORSTEINSSON, J KIPFSTUHL AND H FISCHER
A 1200 year record of accumulation from northern Greenland

N N CUTLER, C F RAYMOND, E D WADDINGTON, D A MEESE AND R B ALLEY
The effect of ice-sheet thickness change on the accumulation history inferred from GISP2 layer thicknesses

J F BOLZAN, E D WADDINGTON, R B ALLEY AND D A MEESE
Constraints on Holocene ice-thickness changes in central Greenland from the GISP2 ice-core data

I H H ZABEL, K C JEZEK, P A BAGGEROER AND S P GOGINENI
Ground-based radar observations of snow stratigraphy and melt processes in the percolation facies of the Greenland ice sheet

R D BROWN, M G HUGHES AND D A ROBINSON
Characterizing the long-term variability of snow-cover extent over the interior of North America

T KAMEDA, H NARITA, H SHOJI, F NISHIO, Y FUJII AND O WATANABE
Melt features in ice cores from Site J, southern Greenland: some implications for summer climate since AD 1550

C M ROWE, M R ANDERSON, T L MOTE AND K C KUIVENEN
Indications of melt in near-surface ice-core stratigraphy: comparisons with passive-microwave melt signals over the Greenland ice sheet

R B ALLEY AND S ANANDAKRISHNAN
Variations in melt-layer frequency in the GISP2 ice core: implications for Holocene summer temperatures in central Greenland

D A ROBINSON, A FREI AND M C SERREZE
Recent variations and regional relationships in Northern Hemisphere snow cover

M C SERREZE, M C REHDER, R G BARRY, J E WALSH AND D A ROBINSON
Variations in aerologically derived Arctic precipitation and snowfall

B CHEN, D H BROMWICH, K M HINES AND X PAN
Simulations of the 1979–88 polar climates by global climate models

J R MILLER AND G L RUSSELL
Climate change and the Arctic hydrologic cycle as calculated by a global coupled atmosphere–ocean model

I MARSIAT
The waxing and waning of the Northern Hemisphere ice sheets

G S BOULTON, N HULTON AND M VAUTRAVERS
Ice-sheet models as tools for palaeoclimatic analysis: the example of the European ice sheet through the last glacial cycle

P HUYBRECHTS AND S T'SIOBBEL
Thermomechanical modelling of Northern Hemisphere ice sheets with a two-level mass-balance parameterization

D H BROMWICH, B CHEN AND Ren-Y TZENG
Arctic and Antarctic precipitation simulations produced by the NCAR community climate models

H J ZWALLY AND M B GIOVINETTO
Accumulation in Antarctica and Greenland derived from passive-microwave data: a comparison with contoured compilations

E MOSLEY-THOMPSON, L G THOMPSON, J F PASKIEVITCH, M POURCHET, A J GOW, M E DAVIS AND J KLEINMAN
Recent increase in South Pole snow accumulation

J J van ROIJEN, K van der BORG, A F M de JONG AND J OERLEMANS
Ages and ablation and accumulation rates from ^{14}C measurements on Antarctic ice

G W PALTRIDGE AND C M ZWECK
Climate, the Antarctic ice sheet and ground heat flux

W F BUDD, P A REID AND L J MINTY
Antarctic moisture flux and net accumulation from global atmospheric analyses

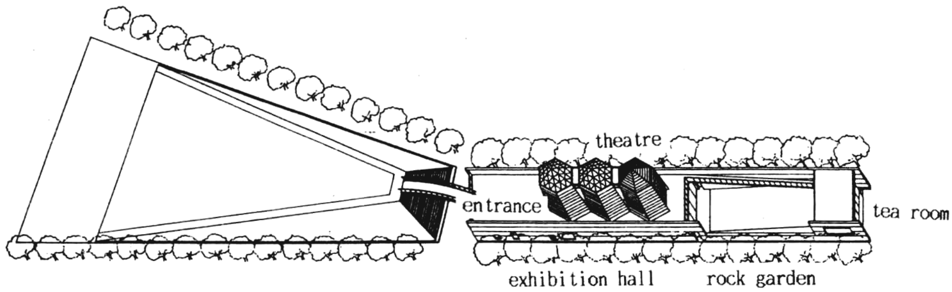
R BINTANJA AND M R VAN DEN BROEKE
The climate sensitivity of Antarctic blue-ice areas

C E BØGGILD, J-G WINTHER, K SAND AND H ELVEHØY
Sub-surface melting in blue ice fields in Dronning Maud Land, Antarctica: observations and modelling

E C PASTEUR, R MULVANEY, D A PEEL, E S SALTZMAN AND P-Y WHUNG
A 340 year record of biogenic sulphur from the Weddell Sea area, Antarctica

L G THOMPSON, E MOSLEY-THOMPSON, M E DAVIS, P N LIN, J DAI, J F BOLZAN AND T YAO
A 1000 year climatic ice-core record from the Guliya ice cap, China: its relationship to global climate variability

J C DAI, L G THOMPSON AND E MOSLEY-THOMPSON
A 485 year record of atmospheric chloride, nitrate and



NAKAYA UKICHIRO MUSEUM OF SNOW SCIENCE

The late Professor Ukichiro Nakaya (1900–62) was well known for his pioneer work on snow crystals carried out at Hokkaido University, Sapporo, Japan in the 1930s and '40s. A science museum to commemorate his achievements in various aspects of snow and ice research has been open in Kaga City, Ishikawa Prefecture, Japan since 1 November 1994. The concept for the museum was proposed by the mayor of the city, which now includes Nakaya's home town of Katayamazu. The museum building, designed by the famous architect Arata Isozaki, is illustrated above. Three hexagonal towers on top of the exhibition hall (589 m^2) constitute the entrance hall and a small TV theatre in which a wide-screen film "Spirit of Science, the World of Ukichiro Nakaya" is regularly shown.

The exhibition hall consists of five sections: the career of Ukichiro Nakaya; snow crystals; ice crystals, research in Hawaii and Greenland; and his international activities. Although most of the exhibitions are photographs and diagrams produced by Nakaya and his colleagues, there are several models of experimental apparatus. The most impressive is one for growing artificial snow crystals made out of a double glass cylinder. It is in a model cold room, an imitation of the first cold room laboratory built at Hokkaido University in 1936. A chronological sequence about Nakaya's research on snow starts with the taking of photomicrographs of natural snow crystals on the university campus, then in a mountain hut on Mount Tokachi for several years, and is followed by his experiments on growing artificial snow crystals under various conditions, using the apparatus shown. The famous Nakaya diagram, drawn using data from many patient experiments, shows how combinations of air temperature and moisture supersaturation determine the various shapes of snow crystals. Using this diagram we can estimate the meteorological conditions in snow clouds from observations of the crystal shape of falling snow. Really, "Snow crystals are letters from heaven"! In addition to the original black-and-white photographs taken in the 1930s, there are also beautiful colour photographs of snow crystals taken by R. Yoshida, a nature photographer. Some colour photos, of peculiar shaped snow crystals taken in the Arctic and Antarctica by K. Kikuchi, one of the successors of the research at Hokkaido University, are added attractions for visitors.

After the war, Nakaya was consulted in planning for the establishment of a snow and ice research institute in the United States. On completion of this plan he was invited as a visiting scientist to the USA's Snow, Ice and Permafrost Research Establishment (SIPRE) in Wilmette, Illinois in 1952. During his two-year stay there, he carried out two experiments using the precious single crystals of ice which a SIPRE team had previously brought from the Mendenhall Glacier in Alaska and stored in a cold room at SIPRE. One was on the growth and morphological change of vapour figures left in the crystal when Tyndall figures were refrozen. The other was on the plastic deformation of an ice single crystal in which ice bars were bent with different orientations with respect to the *c* axis. In both experiments, many photographs were taken successively in order to analyse the dynamic processes. Enlarged copies of these photographs, with Nakaya's marginal notes, are an impressive testament to the care with which he analysed his experiments.

Near the exhibition about research on ice single crystals is an experimental booth in which visitors themselves can observe the growth and development of Tyndall figures in a strongly illuminated ice crystal. The phenomenon is shown on a screen using an overhead projector. This is a new generation of science museum in which visitors can participate and should help interest young people in science.

Observations of snow crystals on the top of Mount Mauna Loa, Hawaii in 1956 were carried out to investigate the influence of atmospheric nuclei on the shape of snow crystals. This was a new development in research on snow initiated from electromicroscopic studies of crystal nuclei at Hokkaido University in the early 1950s. In 1957, Nakaya joined a SIPRE research expedition to Greenland, one of the International Geophysical Year (IGY) projects that started that year. He spent the whole summer at Site Two investigating the viscoelastic properties of snow and ice transformed from snow by the overburden pressure of the ice sheet. This work continued for 4 years until 1960. Unfortunately this hard work accelerated the progress of the disease that led to his untimely death in 1962.

Between the exhibition room and the tea-room, facing the beautiful lagoon of Shibayama-gata and Mount Hakusan beyond, is a rock garden designed by Fujiko Nakaya, the second daughter of Nakaya. Rocks brought from the Thule area, Greenland, thanks to the Danish Government, are arranged to form patterned ground (polygons). Fujiko's expertise in fog art has captured the rugged atmosphere of Greenland in this garden.

Important treasures in the museum are the many dry plates of photomicrographs of snow crystals (more than 3000) and other objects of research from the 1930s and 1940s, part of which are exhibited in an original cabinet near the model cold room. Many materials, including drafts, manuscripts and reprints of Nakaya's own papers and books, and those collected by Nakaya, are all kept in the archives. They should be important materials for further studies, not only of Nakaya's scientific achievements, but also for the study of the history of science in Japan in the early 20th century.

All members of the IGS are encouraged and invited to visit the Nakaya Ukichiro Museum of Snow Science if they have an opportunity to come to Japan. Kaga City is near Kanazawa, a central city of the Japan Sea side of Honshu Island. It is also near Komatsu airport from where the regular flight to Tokyo takes about one hour. Hot springs in Kaga City are an additional attraction for visitors.

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Akira Higashi

Recent meetings (of other organizations)

MIDWEST GLACIOLOGISTS

The fourth annual Midwest Glaciology Meeting was held in Chicago, 21–22 April 1995. The two day conference was hosted by the Department of Geophysical Sciences at the University of Chicago, and organized by Christina Hulbe and Charles Jackson. Although the meaning of the U.S. "midwest" had been redefined every time by the participants of the previous meetings, its geographic boundary is apparently still expanding. The 43 scientists and graduate students attending the fourth annual MGM came from of Alaska, Washington, California, Colorado, Minnesota, Wisconsin, Illinois, Ohio, Virginia, Maryland and New Hampshire.

Presentations covered a wide range of subjects, both geographically and scientifically. If judging from geographic locations of the presentation topics, the already great "midwest" region appears to be even greater. It also includes areas of Antarctica and Hudson Strait/Labrador Sea. It seems that the center of MGM is located in Antarctica because more than half of the 33 presentations were related to the recent progress made towards the understanding of Antarctic ice sheets. Topics included those on ice-stream flow velocities, mass balance, ice thermal gradients, basal shear stress, subglacial drainage patterns and water-infiltration models, horizontal and vertical ice deformation and strength within an ice stream, migration of ice domes, controls and frequencies of huge iceberg-calving events, and till sediment characteristics, as well as determining a safe and economic traverse route from McMurdo Station to establish a new South Pole station. One exciting feature of these presentations is the wide application of new techniques, such as observations of grounding-line systems and ocean-floor sediment beneath ice shelves using a remote-controlled submersible, monitoring ice-stream flows by differential GPS systems, and detecting ice motion and hidden crevasses from ice-penetrating radar profiles and AVHRR, SAR Interferometry and satellite images. The great details of glacier-surface features shown on these high-resolution color images provided useful tools for obtaining more accurate spatial and temporal glaciological data.

While most of the presentations and discussions were centered on Antarctica, the "midwest" region was not forgotten. Presentations related to the southern margin of the Wisconsinan Laurentide Ice Sheet included the mechanism and characteristics of deforming and deformed tills, the formation of boulder horizons in tills, and the origins of different landscapes in Illinois, Iowa and Wisconsin. Other presentations that initiated spirited discussions were those on the existence of an ice shelf in Hudson Strait/Labrador Sea during the last glacial period, the influence of mass loss from the Laurentide Ice Sheet in the Northern Hemisphere atmospheric circulation, glacimarine depositional processes and sediment characteristics in southeastern Alaskan fjords, and using a laboratory shear device to recognize grain-size fractal dimensions in deformed tills. All presentations were oral with no abstracts or manuscripts submitted.

Besides the technique presentations, some attendees from more exotic locales also enjoyed a bus tour led by Christina Hulbe to downtown Chicago and its lake front during rush hour on Friday afternoon. Friday evening was spent socializing at Douglas MacAyeal's home. Of course, testing and evaluating a selection of beers was also on the agenda. Mechanisms of till deformation and boulder horizon generation in tills were debated on a one-day, post-meeting field trip on Sunday to Wedron, Illinois led by Ardith Hansel and Hilt Johnson. The fifth annual Midwest Glaciology Meeting is planned for late April 1966, and will be hosted by the Department of Geology, Northern Illinois University, DeKalb, Illinois.

Jinkui Cai

CONFERENCE ON CHANGING GLACIERS: revisiting themes and field sites of classical glaciology

The Norwegian Glacier Centre, Fjærland, Sognefjord, Norway 24–27 June 1996
Excursions: 23 June and 28 June 1996

SPONSORED BY

International Glaciological Society (IGS), The Norwegian Glacier Centre (NGC),
The Norwegian Polar Institute (NP), Norwegian Water Resources and Energy Administration (NVE)

FIRST CIRCULAR

October 1995

Nearly half a century has passed since various glaciological field investigations were initiated in southern Norway. These studies combined the emerging mathematical approach to glaciology with the traditional field expedition. Numerous household names in glaciology participated and their efforts influenced the direction of modern glacier studies for many years.

The tributary glaciers of Jostedalsbreen are now undergoing a remarkable advance, providing a suitable occasion and setting to re-examine themes addressed 50 years ago.

TOPICS: The topics for presentation include:

1. Glacier response to climate change and other temporal changes in boundary conditions
2. Mechanical and hydraulic controls on ice velocity, including basal sliding and surging
3. Crystallography, ice structure, and the flow law of ice
4. Monitoring glacier changes using new methods

EXCURSIONS: An important part of the conference will be two field excursions, one before and one after the conference. The excursions will include visits to the advancing glaciers — Austerdalsbreen, where stakes from the early field investigations are still melting out, Nigardsbreen, Brigsdalsbreen and Bøyabreen.

PAPERS: The Proceedings will be published by the International Glaciological Society in the *Annals of Glaciology*. Papers will be refereed and edited according to the Society's usual standards before being accepted for publication.

DEADLINES: Abstracts: 15 January 1996. Papers: 15 April 1996.

LOCAL ORGANIZING COMMITTEE: Olav Orheim (Chair, NP); Elisabeth Isaksson (NP); Jack Kohler (NVE); Ole Martin Korsen (NGC).

PAPERS COMMITTEE: Ian Whillans (Chief Scientific Editor).

FURTHER INFORMATION: The Second Circular will be issued in November 1995 and will provide details of registration fees, accommodation, general programme, and submission of abstracts. A copy of the Second Circular will be sent to all members of the International Glaciological Society.

If you are interested in attending this conference, please send this form or an e-mail with the requested information to: Elisabeth Isaksson, The Norwegian Polar Institute, Postboks 5072, Maj., N-0301 Oslo, Norway. Fax: +47 22 95 9501, E-mail: elli@npolar.no.

CONFERENCE ON CHANGING GLACIERS

24–26 June, 1996, Fjærland, Sognsfjord, Norway

Last Name .... First Name/s ....

Address ....

....

Tel: .... Fax: .... E-mail: ....

I intend to participate in the conference [ ]

I expect to submit an abstract of a proposed paper [ ]

Title of presentation (if known) ....

I expect to join one or both of the excursions [ ]

TO BE SENT AS SOON AS POSSIBLE TO:
Elisabeth Isaksson, The Norwegian Polar Institute, Postboks 5072, Maj., N-0301 Oslo, Norway. Fax: +47 22 95 9501, E-mail: elli@npolar.no.

Glaciological Diary

1995

8-9 December

** IGS Nordic Branch Meeting, Finland (Matti Leppäranta, Department of Geophysics, University of Helsinki, Fabianinkatu 24 A, Helsinki, FIN-00014, Finland. Fax: +358 191 3385; lepparan@kruuna.helsinki.fi)

1996

23-28 March

International Conference of Ecohydrology of High Mountain Areas and Regional Workshop on Hydrology of Hindu Kush–Himalayan Region, Kathmandu, Nepal (Prof. A. Herrmann, Mountain Ecohydrology 96, Inst. für Geographie und Geoökologie, Technische Universität, D-38106 Braunschweig, Germany Fax: +49 531 391 8170)

16-18 April

Snow Hydrology in Western Watersheds, 64th Annual Western Snow Conference, Bend, Oregon (K. C. Jones, NRCS Water and Climate Center, 101 SW Main Street, Portland, OR 97204-3225, USA Fax: +1 503 414-3101; a16kjones@attmail.com)

17-19 April

Glaciation and Hydrogeology: Workshop on the Impact of Glaciations on Rock Stresses, Groundwater Flow and Hydrochemistry Past, Present and Future, Sweden (Dr Louisa King-Clayton, Intera Information Technologies Ltd., 47 Burton Street, Melton Mowbray, Leics, LE13 1AF, UK. Fax: +44 1664 411402)

26-31 May

6th International Offshore and Polar Engineering Conference, Los Angeles, California (ISOPE, P.O. Box 1107, Golden, CO 80402-1107, USA. Fax: +1 303 420 3760)

2-6 June

7th International Workshop on Atmospheric Icing of Structures, Chicoutimi, Quebec (IWAIS '96, Prof. M. Farzaneh, Dept. of Applied Sciences, UQAC, 555 boulevard de l'Université, Chicoutimi, Québec, G7H 2B1, Canada. Fax: +1 418 545 5012)

16-20 June

OMAE 1996, 15th International Conference on Offshore Mechanics and Arctic Engineering, Florence, Italy (OMAE'96 Conference Secretariat, via Trieste 230, I-48100 Ravenna, Italy. Fax: +39 544 518015)

17-20 June

International Conference on Quaternary Glaciation and Paleoclimate in the Andes Mountains, IVIC, near Caracas, Venezuela (M. Bezada, Departamento de Ciencias de la Tierra, Universidad Pedagogica Experimental Libertador, Ave. Paez el Paraiso, Caracas, Venezuela. Fax: +58 2 872 1443)

24-26 June

* Changing Glaciers: revisiting themes and field sites of classical glaciology, Norway (Elisabeth Isaksson, The Norwegian Polar Institute, Postboks 5072, Maj., N-0301 Oslo, Norway. Fax: +47 22 95 9501, E-mail: elli@npolar.no)

24-28 June

Interpraevent 1996: Protection of Habitat against Floods, Debris Flows and Avalanches, Garmisch-Partenkirchen, Germany (Interpraevent 1996, c/- Bayerisches Landesamt für Wasserwirtschaft, Lazarettstr. 67, D-80636 Munich, Germany)

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 (Dr Larry Bennett, School of Engineering, University of Alaska Fairbanks, P.O. Box 755900, AK 99775-5900, USA. Fax: 907-474-6087; fyasce@aurora.alaska.edu)

27-31 August

* IXth International Symposium on the Physics and Chemistry of Ice, Dartmouth College, Hanover, NH, USA (Victor 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 (Prof. Dr Heinz Slupetzky, Institut für Geographie, Universität Salzburg, Hellbrunnerstrasse 34/III, A-5020 Salzburg, Austria. Fax: +43 662 8044-525; slupetzky@edvz.sbg.ac.at)

23-24 November

** IGS Nordic Branch Meeting, Denmark (Claus Hammer, Department of Geophysics, The Niels Bohr Institute, University of Copenhagen, Copenhagen N, DK-2200, Denmark)

11-15 December

AGU Fall Meeting, San Francisco, California Special Sessions of interest: Mechanics of Earth Surface Processes: in honor of Ronald L. Shreve (H04); Glaciers and Ice Sheets: in honor of Mark Meier (H05); Glaciers and Volcanoes (H06); Frozen Ground Processes (H07); Snow Hydrology (H08); Sea Ice Properties: variability and interrelationships (O01) (details in EOS 76(28), 1995)

1997

25-29 May

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

4-18 July

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

1998

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

** IGS Symposia
* Co-sponsored by IGS

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