Number 106 *3rd Issue 1994*

ICE

NEWS BULLETIN OF THE INTERNATIONAL GLACIOLOGICAL SOCIETY

CORRECTIONS TO RECENT CIRCULARS

EISMINT

One of the symposium topics, Ice–ocean interactions, was omitted from the list in the second ESF circular. The full list should read:

TOPICS

The following topics will be open for discussion:

1. Model intercomparison
2. Mathematical and numerical methods
3. Ice–atmosphere interactions
4. Ice–ocean interactions
5. Basal processes
6. Mechanical properties of ice
7. Ice–lithosphere interactions
8. Former ice sheets
9. Standard databases for modelling

VICTORIA

The 30 November 1995 date requested for the return of the first circular should have been 30 November **1994**.

Please return your expressions of interest as soon as possible so the local organizers can proceed with making the necessary arrangements.

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CONTENTS

COVER PICTURE: Wind-eroded snow surface (photograph by E. Wengi, Swiss Federal Institute for Snow and Avalanche Research).

Recent work

For abbreviations, see end of these reports (p. 17)

DENMARK

Glacio-tectonic deformations in Denmark

(S. A. Schack Pedersen, DGU)

Geological mapping in Denmark is carried out as a systematic surface mapping and a correlation of geological data from water wells. Maps show lithological and hydrological information in cyclograms. The cyclogram mapping technique was invented and improved at the Geological Survey of Denmark (DGU). The water well data are managed by the DGU-developed ZEUS database system. It contains information on about 140 000 wells, 1257 of which contain records of dislocated sheets, including pre-Quaternary lithologies. The latter are in areas covered by the Weichselian as well as by older ice advances. Most wells containing dislocated pre-Quaternary sheets are connected with the two Weichselian ice margins: the Main Stationary Line and the East Jutland Stationary Line.

The distribution of pre-Quaternary sheets in wells does not show the exact degree of the glaciotectonic variability, but does show there are areas with a higher density of dislocations, and that the pre-Quaternary surface is highly affected by glaciotectonic deformations.

Late Weichselian limits in Scandinavia

(S. A. Schack Pedersen, DGU)

To locate the successive ice-border lines of the retreating Scandinavian ice sheet in the Late Weichselian, a map (1 : 3 000 000) is under preparation. It will show the major elongated hill systems with ice-contact sediments and isochrones of the position of the retreating ice margin, and describe the various spectacular localities related to the ice-border lines. It will help those dealing with landscape planning and natural preservation prevent the destruction of these geological features.

Late Pleistocene palaeoenvironments

(M. Houmark, GI/UCPH; E. Kolstrup, GCC; O. Bennike, GM/UCPH)

At the island of Møn, southeast Denmark, multidisciplinary studies, including lithostratigraphic classification, analyses of glaciotectonic structures, biostratigraphic studies, amino-acid chronology and radiocarbon and luminescence dating, indicate: a shallow boreo-Lusitanian sea, that characterized the Eemian interglaciation (130–115 ka BP), was followed by periglacial conditions during Early Weichselian (115–75 ka BP). In the early part of the Middle Weichselian (75 to c. 40 ka BP) Baltic glaciers invaded the region twice, interrupted by an ice-free and periglacial interval around 50 ka BP. The first ice stream left a reddish till dominated by exotic rock-types of eastern Baltic provenance. From about 40 ka BP to slightly before 20 ka BP ameliorated conditions with periglacial terrestrial and lacustrine environments are recorded. A Baltic lake basin was surrounded by a low relief mammoth-steppe. Increasing amounts of diamicton dominated by Palaeozoic shale and limestone towards the top of the muddy lake sediments suggest ice-rafting by the end of the late Middle Weichselian. Deposits suffered strong glaciotectonic deformation during the Late Weichselian glacial maximum (25–15 ka BP).

DENMARK–NORWAY

Okstindan Glacier, Norway

(N. T. Knudsen, GI/AU; W. H. Theakstone, MU/UK)

During 1991–93, mass-balance studies on Austre Okstindbreen were incorporated in the Norwegian national programme. Measurements of meteorological variables, meltwater discharge and ice velocity continue. The chemical and oxygen isotopic composition of snow and ice, liquid precipitation and glacier river water were measured for information on accumulation-area processes, and the temporal and spatial variability of water storage within and beneath the glacier. A digital-terrain model of the glacier catchment area was constructed, and ice thicknesses determined on most of the glacier. The Okstindan area is a test site for ESA–EMAC monitoring of snow- and ice-covered areas in Northern Scandinavia.

DENMARK–GREENLAND

Permafrost studies, West Greenland

(C. Kern-Hansen, GFU)

The design of a hydropower plant with underground and water-filled tunnels in permafrozen rock initiated a study of the prevailing subsurface and lake temperatures. Water temperatures were measured in two natural lakes/reservoirs at the edge of the Greenland ice sheet, near Ilulissat/Jakobshavn, using floating thermistor strings in a 40 m profile at different depths. The temperature of the intake water can be divided into a steady period (September–May, 0.0–0.5°C) and an unsteady period (June–September, 0.5–2.5°C).

The temperature of the subsurface rock was measured at various depths in seven core holes (30–250 m under the surface). Below 3 m the temperature is less than 0°C, at 15 m it has stabilized at 4°C, and further down it increases to +0.5°C at 250 m.

Polar North Atlantic Margins, Late Cenozoic evolution (PONAM)

(S. Funder, GM/UCPH)

Beginning in 1990, the PONAM project did Quaternary field work in East Greenland (1990, 1992) and on Svalbard (1991, 1993), as well as marine geologic work on both the shelves and fjords. The aim is to investigate the North Atlantic climate system through glacial/interglacial cycles, especially the last interglacial/glacial cycle (c. 135–10 ka).

Each summer about 30 scientists were in the field, and well over 100 sections have been logged. East Greenland especially has a rich and detailed record of environmental change during the last interglaciation and the early Ice Age, showing the interglacial marine and terrestrial biota were considerably richer and "warmer" than in the Holocene, but this was terminated rather abruptly by advancing fjord glaciers, probably fed by precipitation increase over the mountainous Inland Ice margin. On

Svalbard, this early record has generally been removed by glacial erosion, but a detailed record of events at the end of the Ice Age has been established. (Chairman of the PONAM steering group is A. Elverhøi, UOs).

Palaeoceanography in West Greenland fjords

(S. Funder, GM/UCPH; B. Buchardt, GI/UCPH; G. Jones, WHOI)

In 1991 and 1992, sections in raised marine sediments in West Greenland fjords were logged and sampled to provide a record of temperature/salinity changes in the shallow-water environment during the Early Holocene (c. 9–6 ka). The fjords housed a rich macrobenthic fauna during the "climatic optimum" (c. 8.5–5 ka), and the field work provides much new information on their composition. Oxygen-isotope analyses of the shells shows their appearance and disappearance were caused by hydrographical change, only indirectly connected with atmospheric warming.

Weichselian ice-cored moraine

(M. Houmark, GI/UCPH; C. Kronborg, GI/AU)

At Kap Herschell, Wollaston Forland, East Greenland (74°15′ N, 19°30′ W), exposed sections in an ice-cored moraine contain fragmented redeposited marine shells that most likely belong to an Eemian or Early Weichselian marine episode. Buried glacier ice, with folded and sheared debris bands, is overlain by till. Isotopic analyses (δ^2H vs. δ^{18}O) suggest correlation with the GMWL (Global Meteoric Water Line). The ground ice is a remnant of Late Pleistocene glacier ice from low altitudes (< 1000 m) in the inner fjord region or the nunatak zone of central East Greenland.

A complex of glacio-lacustrine deposits and beds of fluvial and deltaic origin overlie the till and ground ice. Luminescence datings of the lacustrine sediments suggest deposition during isotope stage 3.

Deposits have often suffered strongly from glaciotectonic deformation, caused by renewed glacier advance through the fjords reaching the inner shelf during the Late Weichselian.

Neoglacial changes, Greenland ice sheet

(A. Weidick, GGU; N. Reeh DPC/GGU; H. Oerter, AWI)

The present work involves ^{14}C-dating of organic material to determine the extent and timing of deglaciation during the Holocene and the subsequent neoglacial advance. The study of Holocene deglaciation was extended to the western (Godthåbsfjord, 64°–65° N), southern (Qagssimiut region, 61° N) and the northeastern slope (Storstrømmen, 77° N) of the ice sheet. GGU investigations around Storstrømmen, in Germania Land, northeast Greenland, are coordinated with AWI and DPC/GGU studies of mass balance and oxygen isotopes on the ice margin. Results indicate Germania Land was an island, at least 5–2 ka BP. Such a reduced state of the ice sheet also occurred at two older events of the Quaternary epoch which must be correlated to interstadials and interglacials from deep ice-core isotopic climate records.

Expansion of the southern Inland Ice

(A. Weidick, GGU)

The activity of a c. 1200 km long segment of the Inland Ice margin was investigated from c. 1850 to 1985. Around 1950 major parts of the ice margin were in a state of thinning and recession; exceptions mainly confined to restricted highland areas where evidence of advance could be located. By 1985 the margin advances had spread to parts of the adjoining lowland areas indicating the general period of recession since the last century to around 1950 was being substituted by a major tendency for advance.

Calving glacier fluctuations, West Greenland

(A. Weidick, GGU)

Fluctuations of the calving outlets and land-based parts of the Inland Ice from 1850 to 1985 are nearly in phase, but locally the calving glaciers have a far greater amplitude. Differences between them can also be found in the response mode, where the "smooth" change of the land-based glaciers is substituted by a "jump-wise" behaviour of calving glaciers due to the morphological control of the fjord.

Calving rates, West Greenland glaciers

(N. Reeh, DPC/GGU)

To examine the implications of global climate change for sea-ice and iceberg conditions off the East Coast of Canada, a workshop was held at the Danish Polar Center, 13–15 September 1993 to focus on how calving rates of West Greenland glaciers might respond; it was assumed the source term does not change very much. These glaciers are the dominant source of icebergs off the eastern coast of Canada. The workshop addressed: the historical variability of the iceberg calving; modelling the calving process; the controlling factors and their time scales; the key uncertainties; the sensitivity of calving rates to changes in environmental forcing, and; calving rates in a 2 × CO_2 world. There are too many significant knowledge gaps to be able to say with confidence how calving rates might respond. These include insufficient knowledge or data on: under-ice topographic data to know how topographic forcing might affect glacier response; the sensitivity of the mass balance of the Greenland ice sheet to climate changes; ice-velocity data to understand the mechanisms responsible for seasonal and interannual variability; ice temperature, strain, velocity, surface elevations for running and verifying dynamic models; possible feedback mechanisms between ice-stream dynamics and calving; the physics of the calving process. Glaciologists should undertake detailed case studies. Remote-sensing methods should be used more to monitor fluctuations and ice-calving rates. More work on ocean-core studies is needed to throw light on the calf-ice discharge during the decay of the ice sheet at the end of the Ice Age.

Greenland ice sheet mass and energy balance workshops

Workshops have been held in Copenhagen (1990), Zermatt (1991), Bremerhaven (1992), Amsterdam (1993) and Innsbruck (1994). They respond to the need for coordination and exchange between different European groups working in Greenland. Most contributions have come from the ice margin and ablation area, and a better representation of the accumulation area is required.

Glacier inventory and atlas, West Greenland

(A. Weidick, C. E. Bøggild, GGU; N.T. Knudsen, GI/AU)

The glacier inventory and atlas provide the location and description of over 5000 glacier units in western Greenland between 59°30′ and 71°00′N. Registration is based on natural hydrological basins, in accordance with the ICSI recommendations, but modified and simplified to meet Greenland conditions. The work is divided in three parts: description of the procedure used; a tabulation of the information and description of the individual glacier units; and a 1 : 300 000 map showing position and delineation of the individual glacier units.

Greenland ice sheet database

(N. Reeh, DPC/GGU)

Within the European Ice Sheet Modelling Initiative (EISMINT) a workshop on "A Database for the Greenland Ice Sheet" was held at the GGU, Copenhagen, 10–12 May 1993. It brought together data experts and modellers to establish a database to be used primarily for ice-dynamics model studies of the Greenland ice sheet. It aimed to define the format and mode of access of the database, as well as to obtain commitments from participants to provide data. Much of the Greenland data have already been collected in Copenhagen, but need to be organized into an accessible, systematic database for all European modellers, which will be housed at the GGU. Important data e.g. on mass balance and surface topography, are filed outside Denmark. Participants, and those unable to attend, supplied information about Greenland data, making it possible to prepare the first data catalogue for the Greenland ice sheet.

Surface elevation model of Greenland

(S. Ekholm, KMS)

Satellite-radar altimetry, airborne-radar altimetry, survey data and elevation information from various maps and aerial photographs have, for the first time, been combined into a common surface model, covering all Greenland. The model is of significantly higher resolution than previous models: the grid spacing averages about 2 km and many surface details, particularly on the ice sheet, can be deduced from it. The model was improved through inclusion of data from low-altitude aircraft, which help remove some of the errors in satellite altimetry related to the surface slope and distance to the satellite. Furthermore a large amount of coastal digitizing and data from aero-triangulation were included, improving the accuracy and the degree of detail on the ice-free parts. On the near-level parts of the ice sheet (< 0.2°), the mean error is likely 1–3 m, along the sloping sides of the ice it is probably 5–15 m, and along the coast, due to undersampling and the variable terrain, it might be as much as 50–100 m.

Radar map of the Greenland ice sheet

(P. Gudmandsen, N. Kruopis, L.T. Pedersen, H. Skriver, EMI/TUD)

A method for geometrical correction of ERS-1 SAR scenes of the Greenland ice sheet has been worked out. It corrects for the lay-over effect due to the altitudes of the ice sheet surface so that the scenes may be placed geographically. Hence, interesting surface effects may be related to other data from the ice sheet, including the radio- echo sounding data acquired in the 1970s and satellite passive-microwave radiometer data. A radar map of the northeast corner of the ice sheet was produced including 40 scenes of 100 km × 100 km.

Hydrometeorological data base

(C. Kern-Hansen, GFU)

Automatic climate stations have operated at about 80 locations during the last 15 years. Today stations in 40 different locations record every 3 hours. All data are stored in the Greenland Home Rule's official hydro-meteorological data base run by Greenland Fieldinvestigations. Data are available on magnetic media or paper output with a variable price structure depending on use.

Hydropower potential for industrial use

(H. H. Thomsen, R. J. Braithwaite, A. Weidick, O. B. Olesen, GGU)

The first hydropower station in Greenland began operation in autumn 1993 in the Buksefjorden basin, southeast of Nuuk, and interest in other hydropower developments continues. A 1992 report from the Greenland Power Board describes two types of hydropower plants: (1) small ones to supply energy to nearby towns, and (2) larger ones to supply energy-intensive industries, or energy-storage systems. The largest hydropower potential is in basins receiving meltwater from the Greenland ice sheet. GGU has evaluated the runoff conditions from two basins in the Nuuk area, one involves water from one of the largest ice-dammed lakes in Greenland.

Drainage basins were delineated using low sun-angle Landsat satellite images and mass balance and runoff simulations made using data from nearby climate stations. Tapping events for the ice-dammed lake were studied using aerial photographs and Landsat images and the lake volume estimated from existing maps. Artificial transfer schemes, to avoid the natural periodic tapping, were evaluated. The results form a basis for the ongoing planning and re-evaluation of Greenland hydropower potential.

Positive degree-day factor and energy balance modelling

(R. J. Braithwaite, GGU)

As part of a project on world sea level, degree-day and energy-balance models for ice ablation were compared. Positive degree-day factors were calculated for both measured ablation and for ablation simulated by GGU's energy balance model (see *ICE*, No. 94). Positive degree-day factors of around 8 mm d^{-1} deg^{-1} were found for ice ablation at Nordbogletscher and Qamanârssûp sermia, West Greenland, but much higher values are reported for other sites in Greenland. Experiments with the energy-balance model show that positive degree-day factors vary with summer mean temperature, surface albedo and turbulence but large positive degree-day factors only occur for ice at low temperatures with low albedo. Current estimates of Greenland's contribution to sea-level rise may be too small by several tenths because they use a positive degree-day factor that is too small for the colder parts of the ice sheet, i.e. the upper ablation area and northern margin.

Ablation variations 1980–88, Qamanârssûp sermia, West Greenland

(R. J. Braithwaite, O. B. Olesen, GGU)

Ablation was measured at Qamanârssûp sermia, with very low stake densities such that missing data at only a few stakes causes loss of information. Missing data for individual stakes were estimated by assuming that annual net ablation varies with time and space according to a simple linear model. Ablation variations were then studied using both measured and estimated data. Annual ablation decreases with elevation with a mean ELA of 1480 m a.s.l. for 1980–87. Time-variations of annual net ablation at the glacier centre and at the edge are broadly similar, and are correlated positively with summer mean temperature and negatively with annual precipitation. If mean temperature rises by about 0.3°C per decade, mean ablation here will increase by about 0.1 m water per decade. It will take several decades to detect such a trend of increasing ablation against the background of year-to-year ablation fluctuations.

Firn density, Paakitsoq, West Greenland

(R. J. Braithwaite, GGU; M. Laternser, ETH; W. T. Pfeffer, INSTAAR)

Firn density variations were studied in 1991–92 in the lower accumulation area (1440–1620 m a.s.l.) of the Greenland ice sheet near Paakitsoq. The main control on density in the near-surface firn layer (of 5–10 m depth) is the formation of ice layers by the refreezing of meltwater, reaching depths of 2–4 m below the surface. The density variations are described by the ratio of annual surface melt M to the annual accumulation C; M/C is about 0.6 at the runoff limit (c. 1400 m a.s.l. in the study area) where refreezing of meltwater transforms snow to impermeable ice. The mean density of near-surface firn decreases with elevation, reflecting a decrease in melt with elevation. There is a surprising decrease in density at about 4 m below the 1991 summer surface that reflects lower melt rates and/or higher accumulation in the early 1980s and late 1970s when this firn was passing through the surface layer. This low density firn may have partially contributed to the 1978–85 thickening of the ice sheet observed by satellite radar altimetry. Near-surface firn density is therefore very sensitive to climate change and might be an attractive target for climate monitoring.

Energy balance studies, north Greenland

(R. J. Braithwaite, O. B. Olesen, GGU; T. Konzelmann, C. Marty, ETH)

A 2 year study has been made of ablation on the ice sheet margin in Kronprins Christian Land (8–27 July 1993) and on Hans Tavsen Ice Cap (2 July–5 August 1994), western Peary Land. It involved daily measurements of ablation in a 10-stake cluster and continuous logging of radiation components, ice albedo, simple climate data, and englacial temperature. The ablation from radiation is determined directly from the data while the turbulent fluxes are estimated from the climate data using aerodynamic formulae. The measurements cover most of the melt season at this high latitude. Net radiation is the largest source of ablation energy, as elsewhere in Greenland, but heat conduction into the ice is a significant heat sink and uses energy that would otherwise be available for melting.

Surge of Storstrømmen, northeast Greenland

(N. Reeh, DPC/GGU; C. E. Bøggild, GGU; H. Oerter, AWI)

During the initial fieldwork in 1989 on Storstrømmen (77° N, 22.5° W), the glacier had advanced more than 10 km from its position in 1978. Satellite images showed this took place from 1978 to 1984. Scattered observations back to 1913 show a general retreat until 1978. During the advance, ice discharge was as much as 10.8 $km^3 a^{-1}$, about half that of Jakobshavn Isbræ, the largest calving glacier in Greenland. Surface-elevation and velocity changes show all the characteristics associated with a surge.

Mass-balance studies, north and north-east Greenland

(H. Oerter, AWI; N. Reeh, DPC/GGU; C. E. Bøggild, GGU)

A line of ablation stakes was installed in 1989 through the ablation zone of Storstrømmen, from the ice margin at 200 m to 1100 m a.s.l., slightly above the ELA on the more than 80 km profile. The work continued through to 1993 when a similar mass-balance programme was initiated on the Inland Ice margin in Kronprins Christian Land (80° N, 24.5° W). Here the ablation zone is relatively steep and only 15 km wide. An automatic climate station was installed and measurements of surface albedo and surface roughness made to understand the highly variable ablation pattern. $\delta^{18}O$ samples were collected from the ice margins to establish climate records over the last glacial–interglacial cycle.

Mass-balance reconstruction and climate sensitivity, Inland Ice margin, northeast Greenland

(C. E. Bøggild, GGU; H. Oerter, AWI; N. Reeh, DPC/GGU)

Ablation and air temperature data are input for a degree-day model of the ice margin of Storstrømmen. The mass balance could be constructed back to 1949 using meteorological data from the coastal station Danmarkshavn. It shows no trend from 1949–91, despite the fact that both mean annual air temperatures and precipitation have increased. However, there was a change in mass-balance distribution toward less net ablation around the ELA and enhanced ablation at sea level.

Experiments with variable seasonal distributions of temperature rises show enhanced winter heating leads to increased accumulation whereas summer ablation is less. The change in mass-balance of the ablation zone of Storstrømmen is differs greatly from previous estimates using equal summer and winter heating. Studies are continuing to improve the estimates.

Snow and ice reflectance, north Greenland

(C.E. Bøggild, GGU)

Using a Spectron Ingeneering SE 590 spectral radiometer, data were collected digitally and stored on a PC, which controls the operation mode during data collection. Reflectance was measured in 252 discrete bands from 300 nm to 1200 nm with beam cones ranging from 1 to 10; giving a footprint typically of 5 cm with a standard ground setup. Observations and numerical modelling reveal that surface reflectance, especially in Kronprins Christian Land, greatly controls summer ablation at the installed ablation stakes. This calls for a climate-ablation model type which includes spectral reflectance as an important data input.

Micro-meteorological studies, northeast Greenland

(C.E. Bøggild, GGU)

Results from German-Danish studies at Storstrømmen reveal that the ablation/elevation profile is nonlinear with much scatter. This ablation gradient poses difficulties when trying to extrapolate to other regions. More attention is now being concentrated on the micro-climate governing the gradient. In summer 1994, five micro-meteorological stations at ablation stakes on Storstrømmen recorded wind, temperature, humidity and short-wave radiation every 20 min. When data from a permanent station near the ice margin are included, it will be possible to retrieve general climatological gradients of the area.

Hans Tavsen Ice Cap Project: ice margin studies

(N. Reeh; DPC/GGU; R. J. Braithwaite, GGU; J. Landvik, UNIS; O. B. Olesen, H. H. Thomsen, A. Weidick, GGU)

The Hans Tavsen Project (1993–97) plans to carry out: (1) ablation-climate studies on the margin; (2) isotope analysis of ice samples for comparison with the deep drilling records and to establish the long-term climate and dynamic history; (3) observation of surface- and bed profiles, ice-flow velocity, ice temperature, and mass balance along a flow line from the top of the ice cap to the study area on the ice margin, for ice-dynamic model studies; (4) glacial-geological studies in the foreland to establish the Holocene (and earlier?) history of the ice cover of the area, to control modelling of the ice cap response, and to supply data on glacio-isostatic changes; (5) development of an ablation–climate model for assessing snow- and ice-melt, and a local ice dynamic model to synthesize the recent as well as ancient history of climate, mass balance, and ice dynamics in North Greenland.

Hans Tavsen Ice Cap Project: drilling and ice-core analysis

(H. B. Clausen, N. Gundestrup, C. U. Hammer, NBI/UCPH)

The Hans Tavsen Ice Cap project will also: drill through this north Greenland ice cap, and develop a dynamic model of it based on ice-margin studies. The UCPH group concentrates on logistics, drilling, and ice core analysis. In 1993, the ice cap was surveyed and maps of bedrock topography, surface elevations and ice thickness produced. The maps were used to locate approximately the optimal drill-site; to be further identified by detailed surface measurements in 1994. The main in situ activities will take place during the early summer of 1995.

Greenland Ice Core Project, GRIP

(H. B. Clausen, W. Dansgaard, N. Gundestrup, C. U. Hammer, S. J. Johnsen, NBI/UCPH)

The glaciological group of the Geophysical Department (now the Niels Bohr Institute of Astronomy, Physics and Geophysics) continued its participation in the GRIP deep drilling at Summit, Central Greenland. Eight European nations participated in the project and collaboration and close logistic coordination were made with the corresponding US GISP2 drilling 28 km west of the GRIP site. The GRIP camp was established in 1989–90 and the deep drilling and in situ core analysis took place in 1990–92. Bedrock was encountered on 12 July 1992 at a depth of 3029 m. Core analysis, data treatment, and first publication of the isotopic record took place in 1992 and 1993. In 1991–93 research efforts were concentrated on the 250 000 year-long isotopic climate record, which includes Holocene, Weichselian, Eemian and Saale ice; Danish work focused on oxygen-isotope composition, past volcanism, stratigraphic dating, various chemical measurements, ice-flow modelling and bore-hole logging. A major effort is now underway to investigate the Eemian climate variability, considering both the GRIP and GISP2 records.

Palaeo-environmental studies, Paakitsoq, West Greenland

(N. Reeh, DPC/GGU; H. H. Thomsen, C. E. Bøggild, GGU; H. Oerter, AWI)

Earlier $\delta^{18}O$ studies on the Greenland ice sheet margin at Paakitsoq (69°27′N, 50°15′W) showed old ice, found at depth in the central region of the Greenland ice sheet, could be retrieved at the surface of the ice sheet margin; ice of different ages lying in sequence with the oldest nearest to the ice edge. The $\delta^{18}O$ record from Paakitsoq shows a zone of ice about 600 m wide, parallel to the ice margin, is of Pleistocene origin. Comparison with deep ice-core records (DYE 3, Camp Century and Vostok) show that ice dating back at least 150 ka is exposed at the ice margin. In August 1992, a 500 m section of the ice margin covering the Pleistocene period was continuously sampled at 0.2 m intervals. Interpretation of this is still underway. A stake net was established at the ice margin to measure near margin ice deformations.

Offshore ice conditions, West Greenland

(H. H. Thomsen, GGU)

For an offshore West Greenland petroleum licensing round, a brief review of offshore ice conditions for West Greenland was prepared. Based on published sea-ice and iceberg data, it comprises a description of the different types of ice present, including multi-year pack ice mainly transported to the area from East Greenland, first-year ice, fast ice formed in fjords and along the coast, and icebergs from calving glaciers. Statistics for sea-ice conditions in the licensing area were compiled from 1966–81 data.

Greenland Sea Project

(P. Gudmandsen, H. Skriver, L. T. Pedersen, EMI/TUD)

The Remote Sensing Unit at EMI/TUD contributed to the international Greenland Sea Project, a five-year programme which ended in 1992. A monograph of results will appear in 1995. It constitutes an essential contribution on Arctic waters with frequent ice cover. It includes development of numerical models of the ocean and atmosphere as well as methods for analysis of field and remote-sensing data and their assimilation into the models. It describes a number of case studies demonstrating the use of the models and the data-analysis methods. The work was extended by studies of methods to retrieve the ice concentration from fine and coarse-resolution data from the ERS-1 Synthetic Aperture Radar (SAR). Methods for the derivation of ice movement have also been developed.

PIPOR

(P. Gudmandsen, EMI/TUD)

Co-operation within the framework of PIPOR (Programme for International Polar Ocean Research) continued, although to a smaller extent than previously. The programme was initiated in 1986 with a view to applications of ERS-1 SAR data and has recently been reviewed. Papers with results from $2\frac{1}{2}$ years of ERS-1 data acquisition will be published in a special issue of the

International Journal of Remote Sensing. Some results were presented at the Second ERS-1 Symposium in Hamburg, October 1993.

Data-analysis system

(N. J. Bagger, L. T. Pedersen, H. Skriver, EMI/TUD)
A data-analysis system for remote-sensing data is being designed and implemented on Unix workstations; currently being used for sea-ice and ice-sheet work. It allows the use of imagery with wide ranging spatial resolutions, and due to its unique geometric capabilities, combinations of data from many different sources are possible; at present, passive-microwave data from ESMR, SMMR and SSM/I, visual and infrared data from AVHRR, and SAR data from ERS-1 and the airborne EMISAR of the EMI. Line and polygon data can be seamlessly transferred between images of different scales and projections. Newer facilities include semi-automatic ice-feature tracking, mosaicking of ERS-1 SAR data, and interface to the GEPCO digital bathymetric charts of the World.

Project North East Water

(B. B. Thomsen, H. B. Mortensen, P. Gudmandsen, L. T. Pedersen, EMI/TUD)
This is an extension of the Greenland Sea Project described in 1992. It involves exploration of the polynya that forms every summer at the coast of northeast Greenland. In 1993, a one-month field campaign was carried out by the USCGC *Polar Sea*, providing local information on the ice situation and the weather conditions in support of analysis of the relatively large satellite-observation material acquired. The data comprise SAR data from ERS-1 and visual/infrared data from the NOAA TIROS series of meteorological satellites. The data are important for studies of the interaction between the atmosphere and the sea and the sea ice. Annotated catalogues of the satellite data acquired in 1992 and 1993 were produced and various aspects of the work have been reported. Attempts to transmit SAR scenes of reduced spatial resolution from the Institute to the icebreaker failed because of difficult communication conditions at these high latitudes. The work is done in cooperation with Brookhaven National Laboratory, Long Island, NY.

European Subpolar Ocean Project (MAST II)

(L. T. Pedersen, EMI/TUD)
Another extension of the Greenland Sea Project, this project is concerned with air–sea–ice interactions in the Greenland Sea, to understand dynamic features, particular the Bukta/Odden phenomenon. A base of NOAA-AVHRR, ERS-1 SAR and SSM/I (visual/infrared and active- and passive-microwave satellite) data from the area was established and is available on-line via Internet. In connection with signature studies, airborne campaigns are carried out to coincide with satellite passes. A historical analysis of passive-microwave data from 1978–93 is being carried out.

DENMARK–ANTARCTICA

Denmark and Norway in Antarctica

Two Danish–Norwegian research projects in blue-ice fields were carried out under the Norwegian Antarctic Research Expeditions, NARE 1992/93 and 1993/94, respectively.

Oxygen isotopes of blue ice, East Antarctica

(H. H. Thomsen, GGU; J. O. Hagen, NVE)
Blue ice, ablation areas with an upward emergence ice velocity, is exposed at several locations in Antarctica especially around nunataks. Ice dynamic modelling, and many meteorite finds, indicate that old ice is exposed at the surface in these blue-ice areas. A pilot study to map the oxygen-isotope signature of them was made around Jutulsessen, a nunatak about 300 km inland from the ice-shelf margin in Dronning Maud Land. About 600 snow and ice samples for $\delta^{18}O$ analysis were collected. Initial results show large marked $\delta^{18}O$ variations along one profile parallel with the ice-flow direction from the ice margin and 1 km further upstream. These variations have a certain similarity with records from deep ice cores in Antarctica, but with far larger shifts in δ-values. The blue-ice record indicates that combined information about palaeoclimate and ice source areas are present in the $\delta^{18}O$ signature.

Blue-ice field, Dronning Maud Land, Antarctica

(C. E. Bøggild, GGU; J. G. Winther, K. Sand, NHL; H. Elvehøy, NVE)
In 1993–94, ablation studies were carried out on a blue-ice field at Jutulgryta, Dronning Maud Land. Most melting occurred beneath the surface of the blue ice, a consequence of solar radiative penetration and absorption within the ice, i.e. the "solid-state greenhouse effect". Temperature and water-level measurements and pump tests all indicated the subsurface melt layer was widespread under the ice. Temperatures proved the layer to persist, at least during the one month of observations. Results from subsequent experiments, using a combined thermodynamic and radiative transfer model, suggest this melt-layer must be rather stable from 20 cm to 100 cm below the surface, and can develop in a matter of a few days, when snow cover is removed or melted away. Surface albedo greatly controls the formation and vertical extent of the melt layer. Comparison with an adjacent snow field show 5–7°C higher temperatures in the bare ice down to depths beyond the seasonal influence. Therefore the melt phenomenon most probably occurs every summer. This sub-surface melt layer can form an efficient mechanism for runoff from the bare ice fields since drainage from the gently sloping surfaces is not restricted to days with surface melting. The phenomenon may serve as an indicator of climate fluctuations in the area.

European Project for Ice Coring in Antarctica (EPICA)

(H. B. Clausen, N. Gundestrup, C. U. Hammer, S. J. Johnsen, NBI/UCPH)
The goal of EPICA is to retrieve two deep ice cores to bedrock in East Antarctica. The Danish contribution is presently to participate in the planning of a new deep drilling concept and test it in Greenland.

Submitted by H. H. Thomsen

NORWAY

Glacier monitoring in Norway

(J. O. Hagen, N. Haakensen, M. Kennett and B. Kjøllmoen, NVE)

Mass balance measurements continue on 12 Norwegian glaciers. Six have been measured continuously for more than 30 years. The long data series show a generally increasing/decreasing volume for the most maritime/ continental glaciers respectively. Large positive balances have been measured on all of them in four of the last five years, largely due to increased winter precipitation. Many have begun to advance, thus increasing the risk of ice avalanches. Austedalsbreen continues to retreat and ice velocities to increase due to increased water levels in the reservoir into which it calves. Measurements continue on Engabreen to investigate the effects of the Svartisen hydropower scheme on glacier dynamics. Over 90% of the glacier discharge was captured subglacially in summer 1994 through an intake 2600 m upstream from the glacier front.

Response of glaciers to climate change

(M. Kennett, NVE; T. Jóhannesson, Icelandic National Energy Authority)

A degree-day glacier mass balance model has been applied to glaciers in Iceland, Norway, and Greenland, for which detailed mass balance and climate data are available over several years. Model results explain 60–80% of the variance in yearly mass balance using a single parameter set for each glacier. A warming scenario of 2°C is predicted to cause an increase in ablation from up to 1 m w.e. at the highest elevations to about 2.5 m at the lowest. Predicted changes in the winter balance (measured between fixed dates) are small, except at the lowest elevations where there is a significant reduction due a higher proportion of rain in the annual precipitation. ELAs are expected to rise by 200–300 m. Model parameters seem to be stable through the 30 year period of data for the Nigardsbreen glacier in Norway, and are thus assumed not to change significantly for the climate scenarios considered. The mass-balance model has been coupled to a dynamic model to estimate future changes in glacier geometry. Two Icelandic glaciers are predicted to decrease in volume by 40% over the next century, resulting in a substantial increase in runoff. Nigardsbreen (Norway) is expected to retreat significantly.

Ice radar studies

(M. Kennett, NVE)

A map of the bed topography of Jostedalsbreen has been constructed based on extensive radar sounding from 1984 to 1991. This map, currently exhibited in the Jostedal Glacier Centre, should be published shortly. Radar was used on Finsterwalderbreen (Svalbard) in 1994 for information on depth and internal structure as part of an EU-project on surging glaciers. NVE's helicopter-borne low-frequency radar is being developed to reduce centre frequency and thus increase the maximum sounding depth above the current ca. 350 m limit.

Svartisen Subglacial Observatory

(J. Kohler, J. Bogen, J. O. Hagen and B. Wold, NVE)

As part of a large hydropower scheme, a tunnel has been constructed beneath Engabreen. The project includes the establishment of a permanent research facility, the Svartisen Subglacial Observatory (SGO), dedicated to all aspects of glaciology, which should be open within the next year or two. The centrepieces of this facility are the special research tunnels, or "windows", that go right up to the underside of Engabreen in a location where the ice is 200 m thick. Experiments currently in progress include measurements of: subglacial water pressure through rock boreholes and load cells mounted at the bed; basal sliding using instrumented drag spools; and surface velocity from repeat aerial photography and conventional surveying.

Basal ice properties, Engabreen

(J. Kohler , NVE; V. Pohjola and P. Jansson, Physical Geography, University of Stockholm)

Tunnels were melted from one of the intakes into the basal ice of Engabreen at the SGO and crude stratigraphic sections were mapped along the tunnel walls. Several 1–2 m ice cores were collected and are being analyzed for: (1) ice-crystal size and orientation; (2) sediment content and grain-size distribution; and (3) oxygen- and hydrogen-isotope content.

Channel networks under Svartisen

(J. Kohler and M. Kennett, NVE)

Tracer experiments were conducted to help locate subglacial streams beneath Engabreen. Tracers injected at the glacier surface or in lateral streams were sampled not only at the glacier front, but also at two subglacial intakes within the construction tunnel. Water drainage divides and the positions and discharges of subglacial drainage channels are calculated using GIS applications of Röthlisberger's subglacial channel model. The results will be compared with the tracer tests. GIS will be used to map drainage divides for the entire ice cap.

Small valley and outlet glaciers, Svalbard and Norway

(J. L. Sollid and B. Etzelmüller, UOs; G. Vatne, UTr; R.S. Ødegård, UNIS)

Studies of glacial dynamics, hydrology and the thermal regime of small valley glaciers in Svalbard were started in 1990. The program includes surface ice velocities, mass balance, ice and firn temperatures, radio-echo sounding, water discharge, suspended sediment load, dissolved material and tracer studies. Erikbreen and Hannabreen, in Liefdefjorden on the north coast of Spitsbergen (79°40′ N, 12°30′ E), were studied from 1990–92, with some comparative measurements on Austre Brøggerbreen (78°55′ N, 12°00′ E) near Ny-Ålesund. In 1992, a similar program was started on Larsbreen and Longyearbreen, near Longyearbyen (78°15′ N, 15°10′ W), and Midtdalsbreen, an outlet of Hardangerjøkulen (60°30′ N, 7°20′ E). The results show great variations with respect to glacial dynamics and thermal regime. On Erikbreen maximum measured surface ice velocity was 45 m a^{-1}, five to ten times more than other Svalbard glaciers of the same size. There are no indications that Erikbreen has surged. Erikbreen has a two-layered thermal structure with a surface layer of cold ice which is only 20–50% of the glacier thickness. Preliminary results from the glaciers near Longyearbyen indicate much more extensive cold ice. Tracer studies indicate very different internal drainage systems for these Svalbard glaciers. However, concentrations of suspended sediment load and dissolved material are similar.

Mass balance, Kongsvegen and Kronebreen, Svalbard

(K. Melvold, UOs; J. O.Hagen, NVE)
During the last 7 years, field investigations have been carried out on the surge-type glacier Kongsvegen. They included mass-balance and velocity measurements, radio-echo sounding and englacial temperatures. From these measurements, the balance flux and balance velocity along the centre line of the glacier will be modelled to see whether Kongsvegen and Kronebreen are in a quiescent phase prior to a surge.

Mass balance and glacier dynamics, Jutulstraumen ice stream, Dronning Maud Land, Antarctica

(K. Melvold, UOs; J. O. Hagen, NVE)
To determine the present mass balance of Jutulstraumen, to reconstruct snow accumulation over the previous 20–30 years, and to monitor the coming changes, a study was started in the austral summer 1992/93 and continued during the 1993/94 season. 42 stakes were set out in two profiles across the glacier at about 1000 m a.s.l. and five stakes along the centre line from 1000–2350 m a.s.l., for both velocity and accumulation measurements. Ten shallow firn cores (13–32 m) were drilled in different parts of the drainage area up to about 2400 m a.s.l. They will be analyzed for oxygen isotopes and total β-activity to identify annual layers and mean accumulation back to 1964/65.

Remote sensing of snow and glaciers

(M. Kennett and G. Atterås, NVE)
An operational system for monitoring of snow cover in the Norwegian mountains using satellite data has been developed. Good weather AVHRR images are imported into a GIS where they are geocoded, classified and combined with data on catchment boundaries and a DEM to produce maps and tables showing snow areal coverage vs. elevation within each catchment. The results are used as input to runoff models, primarily for flood forecasting and hydropower planning. SAR is being tested as a possible source of information on snow cover when optical techniques cannot be used and as a tool for determining the transient snow line and ELAs on glaciers.

Snow depth measurements

(M. Kennett, NVE)
Two new methods of measuring snow depth are under investigation. Three commercial GPR (ground penetrating radar) systems have been tested for performance and suitability. All perform well even in difficult snow conditions. One of the systems will also be used for investigating englacial features and for mapping snow on glaciers. The second method uses a barometer with μBar resolution connected to a PC. Snow-surface elevation is derived from air-pressure measurements along predefined traverses over which ground elevation is already known. The snow-depth profile is simply the difference between these two elevation profiles. Results suggest that errors in the average snow depth are less than 10 cm.

Slushflow terrain in Norway

(E. Hestnes, NGI)
Slushflows occur all over Norway. Quantitative and qualitative aspects of landforms and ground conditions related to slushflow activity have been investigated. They vary widely in size, shape and geomorphic configuration. Slushflows are part of the process of break-up of drainage channels and streams, but may also start from inclined bogs, depressions and open slopes, snow-embanked, water-saturated snowfields and lakes. Bare rock or frozen ground restrain infiltration. The average inclination from the crown to the bottom boundary of the main accumulation of slush varies from 4 to 20°. Crown surfaces are normally on sloping rock or at local reductions in slope associated with irregularities in ground conditions; the former are typical for the starting zones with highest frequencies.

Slushflow weather and snowpack conditions

(E. Hestnes, S. Bakkehøi and F. Sandersen, NGI; L. Andresen, NMI)
Objective criteria for slushflow prediction and control are sought. The work focuses on snowpack properties, meteorological parameters, meltwater estimation and ground conditions related to slushflow release and downslope propagation. 30 slushflow periods have been analyzed using data from more than 80 meteorological stations, and 80 slushflow sites examined. Calculation of snowmelt is primarily based on an energy-balance model. In winter, cyclonic warm fronts entered the areas 6–36 h before the slushflows occurred, and meltwater accounted for 5–45% of the total water supply. During spring break-up, water accumulated in the snowpack for 6–28 days before slushflow release. Rainfall contributed from less than 5% to as much as 65% of the water supply. Net radiation constituted 20–50% of the energy budget for the spring break-up situations. Slushflows are released when the gravity component parallel to the slope exceeds the basal friction and the tensile strength of the snowpack. Whether the snowpack will reach a critical stability depends upon the ground conditions, the snowpack properties and the relative rates of formation and discharge of free water. The normal downslope progress in fine-grained snow and stratified snow forms channelled flowpaths. Homogeneous coarse-grained snowpacks provide the most favorable conditions for large slushflows. Observed temperature, wind speed, humidity and precipitation are transformed to the starting zones using empirical formulas involving distance, height difference and roughness parameters, for estimating water supply at slushflow sites. In Rana, North Norway, two starting zones are monitored with an automatic weather station, precipitation gauge, snow-depth recorder and pore-pressure transmitters registering water level in the snowpack and a brook.

Glacier mass balance, Svalbard

(J. O. Hagen, NVE; B. Lefauconnier, NP)
In northwestern West Spitsbergen, mass-balance measurements were started in 1967 on Broggerbreen and Lovènbreen (79° N, 12° E), both about 6 km^2, and have been continued annually since then. In addition to the direct observations of winter and summer balance, detection of dated radioactive layers in shallow ice cores permits determination of net accumulation on ten different glaciers on West Spitsbergen. Results show continuous retreating glaciers. The mean annual net balance on Broggerbreen is –0.42 m w.e. for 1967–93. Only two years show positive net balance. In 1987, mass-balance investigations started on Kongsvegen (105 km^2).

The results indicate glaciers covering higher accumulation areas are closer to a steady state than lower cirque glaciers closer to the coast.

Glacier surges and ice dynamics, Svalbard

(J. Dowdeswell, SPRI; B. Lefauconnier, NP/LGGE; J. O. Hagen, NVE)
This project will: (1) investigate and model the dynamics of a surging glacier in the sub-polar setting of Svalbard; (2) test the generality of the findings from this glacier by examining key parameters on several additional surging glaciers in Svalbard; (3) place the behaviour of surge-type glaciers in Svalbard within the context of climatic change over the past 200 years and predict their response to future global warming during different scenarios.

Submitted by Michael Kennett

USA - WESTERN

ANTARCTIC STUDIES

Glaciers of Taylor Valley

(A. G. Fountain, USGS-D; B. Vaughn and K. Lewis, INSTAAR)
A mass-balance study has been initiated in Taylor Valley, a dry valley in southern Victoria Land, to quantify the principal components of mass loss and those that directly influence water runoff. Furthermore, the study examines hydraulic processes that control the rate of runoff from the glaciers. Ablation stake networks have been established on Commonwealth, Canada and Howard Glaciers. Time-lapse cameras have been deployed on two glaciers to estimate the rate of ice calving. This project is part of a Long Term Ecological Research (LTER) investigation of the physical controls on chemical and biological processes in the perennially ice-covered lakes of Taylor Valley.

Interaction between Mt. Murphy volcano and the West Antarctic ice sheet

(W. E. LeMasurier, D. M. Harwood and D. C. Rex, UCD)
Geologic and paleontologic studies of volcanic rocks, glaciogenic sediments and recycled marine microfossils provide evidence for large-scale fluctuations in the mass of the West Antarctic ice sheet during the Neogene, including multiple intervals of nearly complete deglaciation 24 to 3.5 M years BP. The evidence and timing of events at Mt. Murphy are similar to the record in East Antarctica, suggesting continent-wide synchroneity of major glacial and interglacial intervals, in conflict with some interpretations of marine data.

Ice-rafted debris in Ocean Drilling Project cores from the Southern Ocean

(D. A. Warnke, CSUH)

Radar and satellite remote-sensing studies of West Antarctic ice streams

(R. Jacobel, SO)
Recent work used radar and satellite remote sensing to define the grounding lines of Ice Streams D and E. Radar profiles across their mouths will be used with velocity data to determine the mass flux of ice. Enhanced satellite imagery of Siple Dome, the ridge between Ice Streams C and D, suggests that this feature may have been crossed by ice streams in the recent past. Ice velocities have been determined by tracking a crevasse field near the relict ice-stream margin. If this relict feature can be confirmed by ground-based studies, it will provide evidence that the present ice-stream configuration is significantly different than in the recent past.

NSIDC and CIRES information for ice dynamics

(T. A. Scambos, NSIDC/CIRES)
NSIDC's Antarctic activities consist of archiving 1 km Advanced Very High Resolution Radiometer (AVHRR) scenes covering most of the continent and surrounding sea ice, and using this data, as well as SPOT and Landsat TM imagery, to assess the ice dynamics of the ice sheet, West Antarctica in particular. Upcoming field work by NSIDC researchers will focus on the history of the large ice streams in the Siple Coast area using GPS surveying and ice-penetrating radar techniques.

Velocities of shelves and ice tongues along the Walgreen Coast, Marie Byrd Land, West Antarctica

(B. K. Lucchitta, K. F. Mullins and C. E. Smith, USGS-F)
Velocity measurements were made using Landsat images for 1973–88 and 1988–90 on the Smith Glacier tongue and 1972–88, 1973–88, 1988–90 on the Dotson Ice Shelf. Average velocity of the Smith Glacier tongue was about $0.5\,km\,a^{-1}$ near the grounding line during both intervals, but near the ice front it increased from about $0.6\,km\,a^{-1}$ during 1973–88 to $0.7\,km\,a^{-1}$ during 1988–90. Average velocity of the Dotson Ice Shelf remained virtually constant from one interval to another. Acceleration of the Smith Glacier tongue may be due to general loss of densely packed icebergs that provided buttressing during the 1970s, but drifted out to sea during the late 1980s.

ERS-1 SAR studies, Pine Island Glacier, West Antarctica

(B. K. Lucchitta, C. E. Smith, J. A. Bowell and K. F. Mullins, USGS-F)
Average velocity of Pine Island Glacier in both its grounded and floating parts was determined by tracing crevasse patterns on sequential ERS-1 SAR images acquired in 1992. Average velocity is about $2.5–2.8\,km\,a^{-1}$ in the floating part, $1–1.5\,km\,a^{-1}$ in the grounded part, and $2\,km\,a^{-1}$ at the grounding line. Using these velocity values and data from other investigators, mass balance was determined to be negative to slightly positive.

Production of cosmogenic ^{14}C in ice

(A. Lal, SIO; A. J. T. Jull and D. J. Donahue, UAz)
Ablation ice in the Allan Hills and Cul-de-sac areas of Antarctica contain appreciable amounts of in situ cosmogenic ^{14}C. Experiments with accumulation ice show the same effect, consistent with theoretical predictions. The in situ cosmogenic ^{14}C results in appreciable addition of ^{14}C to the trapped ^{14}C; consequently, conventional ^{14}C dates based on trapped ^{14}C yield apparently younger ages if the in situ cosmogenic component is ignored.

Longwave radiation spectrum, Antarctic Plateau

(V. Walden, S. Warren, UW-A)
In collaboration with investigators at Denver University, the spectrum of downward longwave radiation was measured throughout 1992 at South Pole Station. These data have been analyzed to examine the contributions of the various greenhouse gases, as well as clouds and diamond-dust, to the downward infrared radiation. Ancillary information from radiosondes, ozonesondes, a pyrgeometer, a ceilometer and ice-crystal photomicroscopy, are being used to help explain the spectral measurements.

Temperatures in Antarctic snow

(R. Brandt and S. Warren, UW-A)
Snow temperatures to 3 m were measured at South Pole Station through 1992 at 15 minute intervals. 12 precision thermistors with absolute accuracy of 0.1 K were installed with a vertical spacing ranging from 0.1 m at the surface to 1 m below 1 m depth. Two thermistors were suspended at 0.10 and 0.2 m above the surface, and were subsequently buried by snowfall during the winter. Snow-density profiles were measured before and after the experiment. A one-dimensional heat flow model utilizing the temperature record as input is under development to examine the contribution of three mechanisms of heat flow: conduction, sensible-heat transfer due to vertical air exchange (wind pumping) and radiative heating.

Correction of radiosonde profiles for thermal lag in wintertime inversions

(A. Mahesh, V. Walden and S. Warren, UW-A)
Strong temperature inversions are present during winter in the lowest few hundred meters of the atmosphere over the Antarctic Plateau. Because the radiosonde's thermistor has a response time of several seconds, it does not equilibrate to the atmospheric temperature when attached to a balloon rising rapidly through a strong inversion. A deconvolution procedure is being developed to correct the temperature profiles. The procedure was tested by comparing temperature profiles obtained from balloon flights to those obtained by flying the radiosonde on a kite.

ICE CORES

Paleoclimate from ice cores

(P. M. Grootes and M. Stuiver, UW-QIL)
Studies are underway of cores from the summit of the Greenland ice sheet (Greenland Ice Sheet Project 2, or GISP2) and a small ice dome near the head of Taylor Valley, Antarctica (McMurdo Ice-dome Study, or MIST). GISP2 reached bedrock at 3053 m on 1 July 1993. An ^{18}O profile with 1 m resolution has been completed and compared with the European GRIP core recovered 29 km to the east. Excellent agreement down to 2700 m confirms the validity of the climatic and environmental record of both cores. Discrepancies in the lowest 10% of the cores must be attributable to flow deformation and show the need for caution in interpreting the deepest part of the cores.

A 5.2 inch core to bedrock was drilled on McMurdo Dome in the 1993–94 field season after 3 years of surface studies and site selection (with E. D. Waddington, UW-G). The core, which includes about 180 m of pre-Holocene ice, is stored at the NICL and will be studied by numerous investigators. The UW-QIL group will focus on ^{18}O and cosmogenic ^{10}Be and ^{36}Cl.

Ice core, Upper Fremont Glacier, Wyoming

(D. L. Naftz, USGS-SLC)
Isotopic and major-ion analyses have been completed for a 160 m continuous ice core from Upper Fremont Glacier in the Wind River Range. Chemical dating of the core indicates a 300 year long record. The ^{18}O profile provides an accurate paleoclimatic record that shows an abrupt termination of the Little Ice Age in the continental U.S. Global linkage between this ice-core record and that from the Quelccaya ice cap in Peru has been established.

Ice-core measurements

(K. Taylor, DRI)
Current projects include measuring electrical and optical properties of ice cores from GISP (Greenland) and McMurdo Dome (Antarctica), with special attention to developing methods for making high-resolution continuous measurements in the field.

CLIMATOLOGY AND PALEOCLIMATOLOGY

Arctic climate variability

(M. Serreze, J. Kahl, R. G. Barry, J. A. Maslanik and S. J. Khalsa, CIRES)
Research has been conducted on tropospheric temperature trends, low-level temperature inversions, synoptic activity, water-vapor transport and sea-ice surface characteristics, using satellite analyses and Arctic field studies. The major finding is that over the past several decades there has been no discernible tropospheric temperature increase over the Arctic Ocean attributable to greenhouse warming, contrary to predictions of most climate models. Both cyclonic and anticyclonic activity in the Arctic have increased since 1952, indicative of a circulation change. It is not clear why this circulation change is not expressed as a trend in temperature aloft.

Arctic System Science (ARCSS) Data Coordination Center at NSIDC

(C. Hanson, NSIDC/CIRES)
The first in a series of ARCSS CD-ROMs should be released in early May. "ARCSS/LAII Data Series Volume 1: Alaska North Slope Data Sampler" contains data from the North Slope of Alaska. Soil profile and type, climate data, river runoff records and GIS data from a multitude of studies comprise the contents. This CD-ROM will be provided to all ARCSS investigators, and available on request to others for US$50. Many of the data sets are already available from NSIDC via anonymous ftp.

Climate, hydrographic, nutrient, phytoplankton, and related data from the 1992–93 ARCSS Northeast Water Polynya Project (NEW) are being archived at NSIDC. Distribution of these data initially will be restricted to NEW investigators; wider release will follow in about a year. Efforts to acquire data for an Arctic solar radiation CD-ROM are underway.

The NSIDC ARCSS group continues to work closely with the National Geophysical Data Center's (NGDC)

Paleoclimate Division and the GISP2 Science Management Office, University of New Hampshire, on management and distribution plans for the GISP2 ice-core data. One distribution method being discussed is a CD-ROM with GISP2 and other relevant core data sets, developed collaboratively by NSIDC and NGDC/Paleoclimate with the cooperation of the GISP2 SMO. This disc would include the core curator's inventory from NICL, as well as any GRIP data that are documented and deposited in the World Data Center-A by GRIP investigators.

Variability in Arctic atmospheric moisture fluxes

(M. C. Serreze, R. G. Barry and M. C. Rehder, CIRES; J. E. Walsh, University of Illinois, Urbana-Champaign, Urbana, IL)
Several different rawinsonde archives, including records for fixed stations north of 50° N, the "North Pole" series of drifting ice station and ships, are being used to examine the characteristics of Arctic water vapor and its transports. Efforts have focused on analysis of the primary transport pathways of water vapor into and out of the Arctic Basin, providing improved estimates of precipitation minus evaporation (P–E) for the north polar cap (70°–90° N) and the Mackenzie River watershed, and the relationships between moisture flux, P–E and atmospheric circulation variability.

Modelling of ice sheets and climate

(T. S. Ledley, RU)
Numerical models have been used to examine (1) whether increasing CO_2 can initiate ice-sheet growth; (2) the effect of particulate matter in snow and ice on climate; and (3) mechanisms that produce large-scale glacial/interglacial cycles. A detailed sea-ice model is being applied to the Ross Sea and McMurdo Sound in Antarctica to study the effect of sea ice on the ecosystem and climate of the region.

East Antarctic ice sheet climate

(G. Wendler, UAk; U. Radok, CIRES; C. Stearns, UWisc; I. Allison, UTas)
Inland of Dumont d'Urville and Casey, up to eight automatic weather stations have been operating for several years, while four additional stations are now working along the coast in regions of intense outflow. Atmospheric surface pressures recorded by automatic weather stations on the East Antarctic ice sheet are being freed of elevation effects with a new differential analysis procedure. The inland observations are clarifying the link between katabatic flow intensity and synoptic systems, while the coastal ones and high-resolution satellite microwave images illuminate the frequency, size and persistence of coastal polynyas.

The Arctic radiation balance

(J. Key, M. Serreze, R. Stone, R. G. Barry and K. Steffen, CIRES)
A climatology of the Arctic surface radiation balance is being compiled from existing in situ and satellite data sources. Two decades of data collected at Canadian, Alaskan and Russian stations are being acquired. These data, primarily shortwave fluxes, will be combined with radiative fluxes estimated using the monthly cloud product of the International Satellite Cloud Climatology Project to examine spatial and temporal patterns. As a result, the spatial representativeness of the in situ measurements can be assessed. The data are also being used to examine the relationships between radiative fluxes and vapor fluxes, lower tropospheric water vapor, and synoptic-scale pressure fields.

SEA ICE

Sediment load of drifting pack ice

(E. Reimnitz, P. Barnes and M. McCormick, USGS-MP)
Studies are underway of the distribution of sediment-laden sea ice, the sediment load, and the distance of sediment from source areas. Spectral radiation and sediment concentration measurements were made together to evaluate reduction of albedo owing to sediment inclusions. These studies have been carried out in several Northern Hemisphere locations: the Beaufort Gyre, Northwest Passage, Fram Strait, areas north of Svalbard, and the Siberian shelf. Laboratory experiments on sediment-entrainment processes have also been done.

Sea ice–atmosphere interaction

(K. Steffen, CIRES)
The objective is to test the feasibility of using multispectral satellite data for polar flux estimates, with an emphasis on radiative flux estimates; comparison of cloud amounts from satellite and ground-based observations; radiative cloud forcing; calibration of AVHRR visible channels and comparison of two satellite-derived albedo data sets; and flux modeling for leads.

Assimilation of observations and 2-D ice models

(J. Maslanik, R. G. Barry, C. Fowler and W. Emery, CIRES)
Combining remotely sensed information and surface observations with a sea-ice model can constrain various elements of the model physics, and generate new fields that are difficult to observe (such as ice thickness). Through related projects to generate ice motions (Emery, P.I.), ice temperatures and ice albedos (J. Key, P.I.), we are revising our current two-dimensional sea-ice model to assimilate these data as well as information on cloud cover and ice concentration. Objectives are to determine the sensitivity of sea-ice simulations to different forcings, and to refine and simplify model physics to achieve realistic sea-ice treatments in global climate models.

Parameterization and scaling of sea ice

(K. Steffen, CIRES)
Recent emphasis has been on classification of sea ice using ERS-1 SAR imagery. Co-registered SAR and Landsat Thematic Mapper were used to evaluate SAR data for ice classification. Analysis showed that the backscatter coefficient of the C-band SAR can only be used to distinguish between multi-year and first-year ice; for young ice, thin ice and open water, the backscatter coefficient varies depending on surface wind speed and growth history of the particular ice type.

Sea-ice conditions in the Arctic

(J. A. Maslanik, H. Maybee and M. C. Serreze, CIRES)
Numerical models of Arctic sea-ice cover are used to test the sensitivity of the ice pack to thermodynamic and dynamic processes. A new sea-ice model was developed that includes a choice of ice rheology, tracking of different ice types, coupling to radiation parameterizations, fetch-

and stability-dependent turbulent fluxes from leads, and a bulk similarity theory model of the atmospheric boundary layer.

SSM/I-derived ice concentration grids

(NSIDC/CIRES)

In June 1993, the NSIDC DAAC began research and development of an SSM/I-derived ice-edge product. The ice-edge product would be used as a filter, masking known areas of sea ice from the AVHRR SST retrieval algorithm thereby minimizing any possible contamination of an SST product by the presence of ice. This product is now available. An NSIDC working group determined that a monthly averaged sea-ice concentration product could be generated easily from the DMSP SSM/I daily sea-ice concentration grids that were being generated and distributed by the NSIDC DAAC on CD-ROM. The monthly averaged sea-ice concentration grids would provide the necessary ice-extent information required by the SST retrieval algorithm. A review of sea-ice modeling requirements suggested that the grids would be useful for model comparisons and inputs.

IDL procedures were developed to calculate monthly averages from the existing daily averaged SSM/I sea-ice concentration grids produced using the NASATEAM algorithm. To accommodate as many potential applications as possible, ice extent was delineated using four concentration values (0%, 5%, 10%, 15%) that define the minimum concentrations included in the averages. For example, to minimize any possible contamination of an SST product by the presence of ice, the monthly averages using a 0% threshold may be most suitable. Other users interested in defining the general location of the marginal ice zone might prefer the 15% threshold. Products created using intermediate thresholds can be examined to study the nature of the ice margins and to highlight any residual weather or land contamination.

The monthly ice grids are in Hierarchical Data Format (HDF). Software to read and manipulate HDF is available from the National Center for Supercomputing Applications. The ice grids are available from NSIDC via anonymous ftp.

REMOTE SENSING

Climate variability of the Greenland ice sheet

(K. Steffen, W. Abdalati and J. Stroeve, CIRES)

This study involves the application of multispectral satellite data, in combination with ground-truth measurements, to monitor surface properties of the Greenland ice sheet, essential for describing the energy and mass exchange. In 1993, ground measurements were made at the semi-permanent field camp at the ELA (69.5° N, 49.3° W), approximately 60 km northeast of Jakobshavn. Measurements showed that during daytime, the surplus of energy from the net radiation goes mainly to heat the snow layer, and to a lesser extent to melting and evaporation. At night, sensible heat flux accounts for about 50% of the radiative flux from the surface. The surface albedo values were derived from AVHRR satellite data and compared to ground-based measurements. The agreement was within 2% based on radiative transfer model and radiosonde data as input values. Clear sky optical depth of 0.15 for the AVHRR 550–700 nm wavelength range were typical during the spring months. Radiative transfer modeling of the firn supports our beliefs that the observed trends in 18 and 19 Ghz passive microwave brightness temperatures as measured from space are attributed to accumulation rate changes.

Parameterization of downwelling radiative fluxes

(J. R. Key and R. Silcox, CIRES)

Shortwave and longwave downwelling surface-radiation fluxes, as parameterized through simple schemes commonly used in sea-ice models, were compared to fluxes calculated using a complex radiative transfer model and the International Cloud Climatology Project C2 cloud data set. The shortwave and longwave schemes require just a few input variables. Mean monthly fluxes for one parameterization scheme were accurate to within 5%, to within 20% for another.

Surface radiative fluxes from satellite data

(J. Key, CIRES)

Visible, near-infrared and thermal data from the AVHRR satellite sensor are being used to retrieve cloud and surface properties including surface temperature and reflectance, cloud optical depth, droplet effective radius, and cloud-top height. These parameters are then used in a radiative transfer modeling scheme to estimate surface and top-of-the-atmosphere radiative fluxes and cloud forcing. Preliminary results indicate that surface fluxes can be retrieved with an accuracy in the range of 5–15%.

Satellite retrieval of albedo and temperature

(J. R. Key, M. Serreze and J. Maslanik, CIRES; R. DeAbreu, WATER; R. Lindsay, UW-A; M. Haefliger, ETH)

An algorithm was developed to retrieve surface temperature from the thermal channels of the AVHRR using Arctic temperature, humidity and aerosol data. Surface albedo can also be estimated, although the procedure is more complex, involving atmospheric correction, adjustments for the anisotropic nature of surface reflectance and conversion of narrow-band spectral measurements to a broadband value.

Cryospheric indices of global change

(R. G. Barry, NSIDC/CIRES)

A collaborative study between R. G. Barry (WDC-A), V. M. Kotlyakov (Institute of Geography, Russian Academy of Sciences) and the Central Asian Hydrometeorological Research Institute (SANIGMI), Tashkent, Uzbekistan, is continuing. The project is focused on snow-cover observations from surface data and passive-microwave satellite remote sensing and on glacier mass-balance fluctuations in the Caucasus and Central Asia.

Special Sensor Microwave Imager (SSM/I) data for snow cover and climate research

(R. L. Armstrong, NSIDC/CIRES)

NSIDC is developing a capability for daily snow parameter products from the DMSP SSM/I satellite data. Satellite passive-microwave observations afford the best method to monitor temporal and spatial variations in snow cover on the hemispheric scale, avoiding the problems of cloud cover and polar night. The data system will produce, archive and distribute validated snow-cover products. Initial emphasis is on the Northern Hemisphere. NSIDC is also exploring the potential of the SSM/I for mapping snow water equivalent, snow depth, and the dry/wet snow boundary. This will contribute to a prototype snow-cover climatology based on the first six years of SSM/I data.

NSIDC coordinates the activities of the SSM/I Products Working Team (SPWT) focusing on extracting land surface information from SSM/I. Current emphasis is on optimal binning, gridding and global map projection methods, as well as selecting snow cover algorithms, for standardized NSIDC data sets. Snow-cover algorithm comparison and validation is being undertaken with several SPWT scientists. Test areas are the western United States, Prairie Provinces of Canada, and central Europe. A prototype version of the Equal Area SSM/I Earth (EASE) Grid was distributed on CD-ROM in February 1994. It contains sample data for all SSM/I channels for 13 January–29 February 1988. The EASE-Grid provides an optimal technique to interpolate from the data in swath format to the appropriate earth-located grid cell. It provides a data structure which is easier to use than swath format, while maximizing the radiometric, spatial and temporal integrity of the original swath data.

Spectral albedo of snow

(T. Grenfell and S. Warren, UW-A)
Spectral albedo was measured at South Pole and Vostok, Antarctica. A correction, devised for the cosine response of the instruments, varies with wavelength and with the ratio of diffuse to direct incidence. The effect of surface tilt on measurement of albedo was evaluated. Spectral albedos were explained using radiative-transfer models applied to measured grain-size distributions. The effects of solar zenith angle and soot content were also studied, and a contour map made of the soot contamination around Vostok Station. Albedos were integrated over spectral ranges 0.3–0.7 mm, 0.7–5.0 mm and 0.3–5.0 mm for use in energy-budget studies and climate models.

Artificial intelligence applications

(J. Maslanik and S. Bartholomew, CIRES)
A rule-based system was developed to explore the role of automated quality-control within NSIDC's SSM/I processing stream. The system assesses general conditions determined from the SSM/I brightness temperatures and, through a set of rules, creates metadata. These metadata are used to determine the relative quality of individual SSM/I scans prior to gridding of the brightness temperatures. The system allows the inclusion of a range of "expert" decisions typical of those a human analyst would take to assess the quality of the data. The automation of such intelligent decision-making may be particularly valuable for EOS-era processing.

Defense Meteorological Satellite polar data sets

(G. Scharfen and R. Bauer, NSIDC/CIRES)
DMSP data for the polar regions are available from NSIDC. Its archives analog visible and infrared hard-copy images from the DMSP Operational Linescan System (OLS) for the period 1973–90. These include daily global coverage at a resolution of 2.7 km and coverage of the western Arctic at a resolution of 0.6 km. Digital DMSP data are also available from via a cooperative effort with NOAA/National Geophysical Data Center (NGDC). NGDC's Digital DMSP Data Archive includes data from all of the DMSP sensors. NSIDC provides user services for the cryospheric/polar science research community. The first data to be available from the digital archive are the OLS data, beginning with data from March 1994. In the next few months this will expand to include data from the SSM/I passive microwave imager, the SSM/T passive microwave temperature sounder, and the SSM/T-2 water vapor profiler. All full resolution digital OLS data available at this time have a resolution of 2.7 km. Browse images with a resolution of approximately 12.5 km and image display software for the digital data are also available.

GLACIOLOGIC HAZARDS

Glacial hazards, Mount Hood, Oregon

(C. L. Driedger and T. C. Pierson, USGS-CVO)
Hydrologic hazards of glacial origin are being examined on Mount Hood volcano, Oregon. A chronology of events was compiled for the 11 glacierized basins and includes geothermally induced floods, outburst floods, and debris flows derived from glaciogenic sediments. The effect of tephra (volcanic ash) on snowmelt was assessed for several eruption scenarios.

Debris flows on Mount Rainier, Washington

(J. S. Walder and C. L. Driedger, USGS-CVO)
Debris flows originating as glacial outburst floods pose hazards in several drainages on Mount Rainier volcano, particularly along Tahoma Creek, where 15 such flows have occurred since 1986. Statistical analysis shows that the floods are associated with unusually hot or rainy weather. A possible mechanism for flood release may be destabilization of a basal linked-cavity network by rapid delivery to the bed of rainwater or meltwater. The volume of water released during a typical outburst is on the order of $10^5 m^3$.

Interaction of hot eruptive products with snow

(J. S. Walder, USGS-CVO)
Floods and debris flows are often triggered by eruptions of snow-clad volcanoes as pyroclastic flows (hot, dense granular flows) move down a volcano's flanks. To understand the basic physics of the interaction between pyroclasts and snow, experiments have been done in a small flume, using flows of hot sand moving over finely shaved ice. For a given sand grain-size, the flow behavior changes drastically as the emplacement temperature is increased. At moderately high temperatures, copious steaming occurs as the sand passes over the snow; the sand is fluidized by the vapor flux and travels farther than at low temperatures. At high temperatures, fluidization is so vigorous that the snow becomes scoured and mixed into the sand flow, causing copious melting and conversion of the sand flow into a mobile slurry.

Drainage of glacier-dammed lakes and flood-magnitude prediction

(J. S. Walder and J. E. Costa, USGS-CVO)
A minority of outburst floods from glacier-dammed lakes are associated with drainage through a subaerial breach, usually at the ice margin. Breach-drainage floods tend to have significantly higher peak discharges than tunnel-drainage floods for a given lake volume. Statistical

analysis of data yields empirical relations between lake volume and peak discharge for both types of floods, thereby updating the so-called Clague–Mathews relation. A physical model of the breach-widening process for non-tunnel floods, assuming that the rate of breach widening is controlled by melting of the ice, has been developed.

SNOW HYDROLOGY AND PHYSICS

Response of snowpack to rain

(H. Conway, R. Benedict and C. F. Raymond, UW-G)
When rain falls on snow, avalanches often release within minutes of the onset of rain and before any liquid water has penetrated to the sliding layer. Avalanche potential can remain high as water penetrates and weakens the snowpack, but avalanche activity is rare after a drainage system is established. In situ measurements of deformation indicate that low-density snow does not behave as a linear, isotropic, viscous material. Forces other than gravity contribute to the deformation.

Prediction of snowmelt runoff

(J. Zou and T. H. Illangasekare, UCB-C; M. F. Meier and W. T. Pfeffer, UCB-I)
Stochastic analysis was used to study the effects of local heterogeneities in thermal and hydraulic properties of snow on snowmelt, meltwater infiltration and runoff. A simple model was developed to simulate effects of such heterogeneities in a large-scale catchment, using effective parameters determined from the stochastic analysis and energy-balance concepts. The model was applied to the Greenland ice sheet under current and future climatic conditions to make predictions of expected sea-level rise due to the greenhouse effect.

Particle stratigraphy in temperate snow

(C. F. Raymond, T. Gades and H. Conway, UW-G)
Experiments were done to examine the mobility of particles of carbon ($< 1\,\mu$) and volcanic ash from Mount St. Helens ($< 8\,\mu$) through melting snow. Most sub-micron carbon particles are highly mobile. Consequently, carbon concentration in the stratigraphic record may be highly altered from original values. A relatively small residual concentration of carbon particles remains near a melting surface, but the impact on albedo is much less than would occur if the particles were immobile. Volcanic ash, which is relatively immobile and provides a stable stratigraphic horizon, continues to affect the albedo until it is buried by new snow.

Snow as an air filter

(S. Harder, UW-C and S. Warren, UW-A)
Experiments were carried out at South Pole Station on the filtering effect of snow for airborne particles. Air was drawn through columns of snow collected by pushing Plexiglas cylinders into the surface snow. The filtered air was then passed through a condensation-nucleus counter to determine the total number of particles, and simultaneously through an optical particle counter to give a particle-size distribution. The experiments are being analyzed in terms of standard filter theory to identify the relative importance of four mechanisms (sedimentation, diffusion, impaction and interception) for different particle sizes at different air-flow rates. Results will be used to evaluate the effectiveness of wind-pumping for aerosol deposition. Preliminary analysis indicates that the air is cleaned of particles with an characteristic depth of a few cm for all particle sizes and at all air-flow rates.

ICE PHYSICS

Effect of salt flowers on backscatter

(S. Martin, UW-O)
Salt flowers were grown in the laboratory to study their effect on radar backscatter. The flowers grew to a height of 10–15 mm and achieved 85% surface coverage within 24 h. A 1–5 mm thick slush layer formed beneath the flowers, with salinity of order 100 psu. X-band backscatter from the flowers is 10–12 dB greater than that from a clean surface.

Atmospheric-ice studies

(J. Hallett, P. Arnott and Y.Y. Dong, DRI)
Studies have been done of the following: (1) charge separation during ice evaporation, breakup and collision; (2) symmetry of dendrite branches in snow growth from vapor; (3) thermal infrared extinction by clouds of uniform ice crystals; (4) nucleation and growth of ice crystals in cirrus clouds and their role in the radiation balance.

Regelation through subglacial sediment

(N. R. Iverson and D. Semmens, UM)
In the laboratory, a confined block of temperate ice was pushed through idealized and real porous media in contact with a flat bed. Temperature distribution and regelation speed were measured and compared with the predictions of classical regelation theory, modified approximately for application to a 3-D array of spheres. Results indicate that the theory is successful for both gravel and medium-grained sand, but that it overestimates the regelation speed for materials with greater thermally conductivity.

SURGING GLACIERS

Black Rapids Glacier, Alaska

(C. F. Raymond, T. Gades and H. Conway, UW-G)
In collaboration with investigators at UAF, seismic and radar measurements were made on Black Rapids Glacier at closely spaced time intervals from May to July 1993, when the glacier experienced substantial changes in speed. The principal goal was to detect changes in the structure of the bed related to the changes in speed. Even though the glacier speed varied over a wide range ($0.2–1.0\,m\,d^{-1}$), reflection characteristics from the bed were relatively stable. This result places limits on the kind of structural changes in the basal zone that could be responsible for the changes in speed.

ICE DYNAMICS

Ice-stream margins

(C. Raymond and P. Jacobson, UW-G)
Coupled heat and mass flows at an ice-stream margin were modeled by finite-element methods to examine the stability of the position of an ice-stream margin under the assumption that it is a boundary between thawed bed under the ice stream and frozen bed under the inter-ice-

stream ridge. Results show that such a thermal boundary is unstable. For geometry like that of Ice Stream B (West Antarctica) and assumed normal geothermal heat flow, an ice-stream speed of about $100\,m\,a^{-1}$ represents a critical level. For speed smaller than this value, heat generated near the margin is insufficient to maintain a thawed bed, so the ice-stream margin would freeze inward and narrow the stream flow. For speed in excess of the critical value, heat generated near the margin is sufficient to cause thawing of the bed outside the zone of fast motion and thus allow the ice stream to widen. Some phenomenon other than a thermal boundary condition as examined is therefore needed to stabilize the widths of ice streams.

MASS BALANCE

Modeling glacier mass balance

(H. Conway, L. A. Rasmussen and P. Hayes, UW-G)
Use of radiosonde data for characterizing mountain climate has been investigated. Data from Quillayute (western Washington) are used to estimate daily variations of precipitation, wind, temperature, depletion of received solar radiation and cloud cover at Blue Glacier. The estimates, which are established from physical principles and by correlating measurements from the glacier with the radiosonde data, will be used as inputs to a physically based model of glacier mass balance. Detailed measurements of mass balance are available for Blue Glacier since 1958 and will be used to test the modeling effort.

Surface melt on the Greenland ice sheet

(M. Anderson, C. Rowe, K. Kuivinen and T. Mote, UNL)
More than half of the Greenland ice sheet is subjected to summer melting, but for much of that area the melting is intermittent. Changes in the magnitude of melt on the ice sheet may serve as an indicator of large-scale climate change in the Arctic. The primary objectives of this research are to characterize and map the melt zones; identify interannual changes in the extent of these zones; determine relationships between atmospheric circulation and the melt events; and determine relationships between the surface energy fluxes and melt.

MISCELLANEOUS

Rocky Mountain glacier modeling

(E. Leonard, CC)
The dynamics of late Pleistocene glaciers are being reconstructed, with focus on paleo-ice flow and paleo-mass and energy balances.

Subglacial erosion and deposition in Puget Sound, Washington, USA

(B. Goldstein, UPS)

Late Quaternary glaciation and periglacial processes, western and southern Colorado Rocky Mountains

(B. Goldstein, UPS)

Submitted by J. S. Walder

UZBEKISTAN

Glaciological investigations by Glavgidromet and SANIGMI are being made on mountain glaciers, snow cover and avalanches. They include the following:

GLACIERS

A data base containing information on the altitudinal distribution of glacierization and moraines was compiled from aerial photographs for the Gissar-Alay, Pamir and Tien-Shan river basins for the "Glaciers" data bank.

A method for predicting short-term runoff of snow- and ice-fed rivers along the left bank of the Syr Darya River was determined and distributed to users.

Year-round meteorological, hydrological and glaciological observations continue in the Abramov Glacier experimental basin. Winter, summer and annual glacier mass balances were determined; vertical and horizontal movement components calculated; and solar radiation balances and the ozone layer measured.

Samples of air, precipitation, soil, vegetation and water were taken for a baseline monitoring program. To estimate anthropogenic effects, the chemical composition of recent ice (from the firn line) and old ice (from the end of the ice apron) was analyzed.

A new method for describing and computing the temporal–spatial variability of the main meteorological characteristics affecting the long-term regime of glaciers, runoff, precipitation, solar radiation, temperature, humidity, and cloudiness has been worked out.

To extrapolate precipitation, temperature and humidity fields to areas of central Asia, between 67–81° E and 35–44° N, archives of these data were prepared using a standard grid of 0.25° of latitude and longitude for ten, four and nine altitudinal levels. The accuracy of methods for extrapolating temperature and precipitation from weather stations at Fedchenko Glacier, Severtsov Glacier, Dehauz, Daraut-Kurgan, Tavildara, and Abramov Glacier was estimated.

Files of long-term monthly cloud-cover amounts from 36 meteorological stations in central Asia have been prepared. Based on correlations, distribution maps were drawn, spatial dependencies analyzed, and methodologies for extrapolation determined.

Input information for calculating long-term annual glacier mass-balance ranges from 128 regions in the river basins of the Pamir and Gissar-Alay was prepared. Long-term glacier mass-balance and runoff ranges, for a $7067\,km^2$ glacierized area, covering 18 headwaters of the Pyandy River basin, were calculated. A set of programs and the methodology for calculating the annual mass balance of glaciers has been worked out.

SNOW

Work on creating a "Mountain Snow Cover" data base, including operational and regime information for central Asia, is continuing.

The formats for both input and output data for a range of specialised observations on mountain snow cover have been worked out. Quality control was carried out and general catalogues of basin and station observations (terrestrial and aerial snow-survey sites and meteorological stations) prepared. Data for the following regions were transferred to floppy disks: Uzbekistan (to 1992), and Tajikistan, Kirghizia and southern Kazakhstan (up to 1990). Computer programs have been written for quick access to the data and for statistical analysis.

Improvements were made in methods for: processing and presenting satellite data on snow-line height; analyzing helicopter gamma-survey and ground-truth data; and generalizing heterogeneous snow samples for determining mountain snow reserves.

Based on generalized snow-sampling data, the annual altitudinal distribution of snow for February, March and April and the snow reserves in the river basins of the western Tien-Shan (Chirchik, Ahangaran) were computed. Recommendations were made for using snow-sampling data to calculate snow reserves in mountain basins. Using data on the altitude of the seasonal snow line and total snow reserves, the relationship with runoff during the period April–September was established for some rivers of the Syr-Darya basin.

AVALANCHES

Work on establishing an "Avalanche" data bank and improving the software is continuing.

Snow-density determinations were made for avalanche observations in the Chimgan SANIGMI field station area. These included air temperature, snow wetness and snow temperature at several depths. Mass loss was determined from snow melt and evaporation. Methods for predicting wet-snow avalanches during clear weather and snowfall were developed. Work continues on assessing avalanche characteristics as a basis for future avalanche-hazard mapping.

Specialised software for the "Ruta" telemetry system has improved data acquisition and analysis capability.

Submitted by Vladimir G. Konovalov

Abbreviations

AWI = Alfred Wegener Institute, Germany
CC = Geology, Colorado College, Colorado Springs, CO, USA
CIRES = Cooperative Inst. for Research in Environmental Sciences, University of Colorado, Boulder, CO, USA
CSUH = California State Univ., Dept. of Geological Sciences, Hayward, CA, USA
DGU = Geological Survey of Denmark
DPC = Danish Polar Center
DRI = Desert Res. Inst., Univ. of Nevada, Reno, NV, USA
EMI/TUD = Electromagnetics Inst., Technical Univ. of Denmark
ETH = Geographical Inst., Swiss Federal Inst. of Technology, Zürich, Switzerland
GCC = Geological Consulting Company, Soenderborg, Denmark
GFU = Greenland Fieldinvestigations
GGU = Geological Survey of Greenland, Denmark
GI/AU = Geological Inst., Univ. of Aarhus, Denmark
GI/UCPH = Geological Inst., Univ. of Copenhagen, Denmark
GM/UCPH = Geological Museum, Univ. Copenhagen, Denmark
INSTAAR = Inst. of Arctic and Alpine Res., Univ. Colorado, Boulder, CO, USA
KMS = The National Survey and Cadastre, Denmark
LGGE = Lab. de Glaciologie et Géophysique de l'Environnement, Grenoble, France
MU/UK = Dept. Geography, Manchester Univ., UK
NBI/UCPH = Niels Bohr Inst. of Astronomy, Physics and Geophysics, Univ. Copenhagen, Denmark
NGI = Norwegian Geotechnical Inst.
NHL = Norwegian Hydrotechnical Lab.
NICL = National Ice Core Lab., Denver, CO, USA
NMI = Norwegian Meteorological Inst.
NP = Norwegian Polar Research Inst.
NSIDC = National Snow and Ice Data Center, CIRES
NVE = Norwegian Water Res. and Energy Admin.
RU = Rice Univ., Dept. Space Physics and Astronomy, Houston, TX, USA
SIO = Scripps Institution of Oceanography, La Jolla, CA, USA
SO = St. Olaf College, Northfield, MN, USA
SPRI = Scott Polar Res. Inst., Cambridge, UK
UAk = Univ. Alaska, Geophysical Inst., Fairbanks, AK, USA
UAz = Univ. Arizona, NSF-Arizona AMS Facility, Tucson, AZ, USA
UCB-CE = Univ. Colorado, Dept. Civil, Environmental and Architectural Engineering, Boulder, CO, USA
UCD = Univ. Colorado, Dept. Geology, Denver, CO, USA
UM = Univ. Minnesota, Dept. Geology and Geophysics, Minneapolis, MN, USA
UNIS = University Courses on Svalbard
UNL = Univ. Nebraska, Dept. Geography, Lincoln, NE, USA
UOs = Univ. Oslo, Dept. Physical Geography, Norway
UPS = Univ. Puget Sound, Dept. Geology, Tacoma, WA, USA
USGS-CVO = U.S. Geological Survey, Cascades Volcano Observatory, Vancouver, WA, USA
USGS-D = U.S. Geological Survey, Denver, CO, USA
USGS-F = U.S. Geological Survey, Flagstaff, AZ, USA
USGS-MP = U.S. Geological Survey, Menlo Park, CA, USA
USGS-SLC = U.S. Geological Survey, Salt Lake City, UT, USA
UTas = Univ. Tasmania, Hobart, Australia
UTr = Univ. Trondheim, Dept. Geography, Norway
UW-A = Univ. Washington, Dept. Atmospheric Sciences, Seattle, WA, USA
UW-C = Univ. Washington, Dept. Chemistry, Seattle, WA, USA
UW-G = Univ. Washington, Geophysics Program, Seattle, WA, USA
UW-O = Univ. Washington, School Oceanography, Seattle, WA,
USAUW-QIL = Univ. Washington, Quaternary Isotope Lab., Seattle, WA, USA
UWisc = Univ. Wisconsin, Dept. Meteorology, Madison, WI, USA
WATER = Univ. Waterloo, Waterloo, Ont., Canada
WDC-A = World Data Center - A Glaciology, CIRES
WHOI = Woods Hole Oceanographic Institution, USA

ANNUAL GENERAL MEETING 1994

MINUTES OF THE ANNUAL GENERAL MEETING OF THE INTERNATIONAL GLACIOLOGICAL SOCIETY

11 August 1994 in Columbus, Ohio, U.S.A.

The President, Dr Bjørn Wold, was in the Chair. 45 members from 18 countries were present.

1. The Minutes of the 1993 Annual General Meeting, published in ICE 102/103, p. 8–9, were approved and signed by the President.

2. The President gave the following report for 1993–94:

"Welcome to the 1994 Annual General Meeting of the International Glaciological Society.

We have had one symposium this year — that which you have been attending here in Columbus. Your Council met earlier this week on Monday night.

The past year has been one of great change for the IGS, with both a new President and a new Secretary General. December saw the end of Hilda Richardson's 40 year term as Secretary General. You are all aware of the tremendous debt of gratitude we owe her for her effective management and nurturing of the Society. Simon Ommanney succeeded her in January and I know he is finding the task very challenging. From all I have seen he is rising to it nobly. I hope that from your point-of-view the transition has gone smoothly and that the service you have received from our head office in Cambridge has been effective.

Sadly, during the past year, we lost two of our Honorary Members with the deaths of Bob Legget and Bill Field. Their distinguished careers and service to the Society has been and will be documented in *ICE*.

The IGS has worked closely with the Byrd Polar Research Center in organizing the International Symposium on the Role of the Cryosphere in Global Change. I am sure you will agree that this has been a very interesting and stimulating meeting. One innovation was the introduction of the two-minute oral poster presentations. Judging by your enthusiastic comments, this is a procedure we should attempt to continue at future meetings. One of our objectives in meeting here was to draw attention to the important work being conducted by the Byrd Center, give you the opportunity to meet its staff, and see the new facility. We thank The Ohio State University and Ken Jezek most warmly for this opportunity.

At the last Council meeting, we instructed the Secretary General to address the problem of delays in the publication of articles in the *Journal of Glaciology*. We have made substantial progress towards dealing with this matter. Many of you have already received the 2nd issue of the *Journal* for 1994, published, as it should be, in the middle of the year. This is some six months earlier than the equivalent issue was published last year. This essentially clears the backlog of papers received in the production office up to July of last year. New procedures have resulted in faster turnaround, enabling us now to focus our attention on other aspects of the production system that need consideration. We expect significant improvements on the printing side with Frans Zuidwijk of Lochendruk being given specific responsibility for handling all aspects of liaison with our printers in Holland. With declining membership and library sales, our next challenge is to secure sufficient resources to publish enough pages in the *Journal* to ensure the backlog does not re-occur. The dilemma we face is that as turnaround improves more papers will be submitted, increasing the chances of another backlog because of financial limitations on the number of pages we can publish.

Your Council is concerned about the cost of Society operations and our continued ability to meet them. Council has instructed the Secretary General to see if costs can be reduced. The other option is to increase our revenue. The only means of doing this that is open to us at the moment seems to be a concerted effort to increase membership. We need YOUR help in recruiting members and identifying new things we might do to attract them. Improving communication with the Cambridge office and making it easier to join the Society and renew memberships is an important part of this — which is why the Secretary General will be looking at implementing a credit-card option for payment and working with some of you on providing E-mail access.

Next year, the Society will organize the International Symposium on Glacier Erosion and Sedimentation in Reykjavik, Iceland from 20–25 August. We will be working with the EISMINT project of the European Science Foundation, publishing the proceedings of their meeting in Strasbourg. We have also agreed to sponsor a Workshop on the Structure and Dynamics of Valley Glaciers which will take us back to the roots of the original British Glaciological Society at Austerdalsbreen in Norway.

For 1996, Council has accepted a proposal from the Canadian Atmospheric Environment Service to organize a meeting on Representation of the Cryosphere in Climate and Hydrological Models to be held near Victoria, on Vancouver Island. Plans for the meeting in Hobart in 1997 on the Antarctic and Global Change were announced at a previous meeting. In line with our tradition of looking to the future, discussions have already started on possible venues for a meeting in 1998. Council is always interested in receiving proposals for future meetings. We have handled more than one a year in the past and can do so in the future.

It always gives a President of the IGS great pleasure to be able to announce decisions made by Council on recommendations from our Awards Committee. This year, I am particularly fortunate to be able to announce three awards.

The first is that of the Seligman Crystal to Tony Gow. He is the ultimate ice man, having made significant contributions to our understanding of ice in essentially all its natural states and settings. One would be hard pressed to name any glaciologist who has contributed fundamentally to more aspects of snow and ice studies. He is the quintessential field glaciologist: a person who invariably produces new insights into whatever aspect of glaciology he is investigating. By any standard, he is the world's foremost expert on crystal forms of ice.

We have decided to award Honorary Membership in the International Glaciological Society to Stan Paterson. As anyone who teaches a course in glaciology knows, Stan's book is a pre-eminent contribution that has certainly enriched glaciology, and the same can be said about his work with the Polar Continental Shelf Project. His book is an outstanding medium to introduce students to the field of glaciology, to facilitate communication with representatives from related fields, and to brush up on fundamentals. There is possibly no-one who has touched more people with respect to our discipline than Stan Paterson. An indication of his enormous influence can be seen at this meeting where some 10% of the submitted papers reference *The Physics of Glaciers*.

Council also voted unanimously to award Honorary Membership to Professor Shi Yafeng, from the Lanzhou Institute of Glaciology and Geocryology in China. Over many years, he has done more than any other scientist in China to establish glaciology as a recognised discipline in his country through rough and turbulent times. It was he who opened Chinese glaciology to the world, and, particularly to the IGS.

Last year saw the inauguration of the appropriately named Richardson Medal and its award, very properly, to Hilda. Council has taken steps to incorporate this into the Society's awards system. A Committee has been appointed to draft terms of reference for the award for us to consider at our next meeting in Iceland.

In 1993, we modified some of our procedures by appointing specific individuals to chair our Awards, Nominations and Publications Committees. Lorne Gold, Sam Colbeck and Garry Clarke will be chairing these during the coming year. We value your opinions in these and other areas of the Society's operations and hope you will take time to make them known to us so they can be brought before Council.

This year marks the 100th Anniversary of the Commission Internationale des Glaciers and the Silver Jubilee of the Snow and Avalanche Study Centre in Manali, India. To both we extend our congratulations, and will do so formally at the appropriate time.

On behalf of you all, I would like to express my thanks to our headquarters staff. To Simon Ommanney, our Secretary General, David Rootes our Production Manager and to Linda Gorman with whom most of you usually deal; as well as to Ray Adie, Sally Stonehouse, Brenda Varney, Sylva Gethin and Ken Moxham, who help maintain the high quality of our various publications. The quality of our *Journal* is sustained by a dedicated team of editors. To Doug MacAyeal, our Chief Scientific Editor and his editorial board, we express our warmest thanks, as well as to those who have helped them during the year. I would also like to pay tribute to those who have been working on the papers for this meeting, particularly to Drew Rothrock and his team of editors, for maintaining the high standards we have come to expect of the *Annals of Glaciology*. Thanks, too, to the referees, many of them present here today, whose advice is so vital to the whole process."

3. The Treasurer, Dr J. A. Heap, presented the following report with the audited Financial Statements for the year ended 31 December 1993.

"The state of the Society's finances is best summarised by considering the changes from 31 December 1992 to 31 December 1993 in the following funds:

Seligman Fund: Increased from £225 to £1,031 consequent on a transfer of £745 from the Accumulated Fund and the accrual of interest;
Accumulated Fund: Increased from £11,581 to £13,877 consequent upon a surplus of £3,041 in the General Income and Expenditure Account of which £745 was transferred to the Seligman Fund;
Contingencies Fund: Remains unaltered at £8,684;
Annals Fund: Increased from a deficit of £2,098 to a surplus of £6,531;
Publication Fund: Increased from £6,498 to £7,798.

In 1992 the Society published 420 pages in the *Journal of Glaciology*. In 1993 the number of pages published increased to 734. This was made possible primarily through the provision of pages charges upon which the *Journal* has become increasingly dependent. Last year I urged Members to do all they could to recruit members to the Society, maintain library subscriptions and encourage the provision of page charge support for published papers. If the Society is to maintain its service to the glaciological community world wide, I need, again, to ask you to bend your energies to achieving these three objectives."

W.F. Budd proposed and I.M. Whillans seconded that the Treasurer's report be accepted. This was carried unanimously.

4. Election of auditors for the 1994 accounts. J. A. Heap proposed and R. S. Williams, Jr seconded that Messrs Peters, Elworthy and Moore of Cambridge be elected auditors for the 1994 accounts. This was carried unanimously.

5. Election to the Council 1994–97. After circulation to all members of the Society of the Council's suggested list of nominees, no further nominations were received, and the following people were therefore elected unanimously:

Vice President:	N. Maeno
Elective Members:	T. J. H. Chinn
	T. H. Jacka
	D. M. McClung
	Qin Dahe

The President thanked those members who had served on the previous Council and were now retiring.

. . . .

After the formal business of the meeting was concluded, the President indicated a desire to provide more time for open discussion in the future. He also suggested that members with ideas about any aspects of the Society's business should pass them to himself, to the chairmen of the relevant committees or to the Secretary General.

INTERNATIONAL SYMPOSIUM ON GLACIAL EROSION AND SEDIMENTATION

Reykjavík, Iceland, 20–25 August 1995

CO-SPONSORED BY

University of Iceland, Iceland Glaciological Society, Icelandic Road Authority, Meteorological Office, National Energy Authority, National Power Company

SECOND CIRCULAR

LOCAL ARRANGEMENTS COMMITTEE:
Helgi Björnsson (Chairman), Elías Elíasson, Tómas Jóhannesson, Magnús Már Magnússon, Oddur Sigurðsson

SCIENTIFIC EDITORS:
David N. Collins (Chief Editor), Per E.J. Holmlund, Neil Humphrey, Tómas Jóhannesson, Ross D. Powell

INFORMATION ABOUT THE SYMPOSIUM MAY BE OBTAINED FROM:
Secretary General, International Glaciological Society, Lensfield Road,Cambridge CB2 1ER, UK
International: Tel: +44-(0)1223 355974 Fax: +44-(0)1223 336543

The society will hold an international symposium in 1995 on Glacial Erosion and Sedimentation. The University of Iceland has invited the Society to hold the Symposium in Reykjavík. Registration will take place on Sunday 20 August and sessions will be from Monday 21 through Friday 25 August. A one-day workshop on the "Historical Roots of Glaciology" will take place in Reykjavík on 20 August, immediately preceding the symposium, in collaboration with the Department of Philosophy, University of Iceland. There will be a half-day excursion during the week and an optional post-symposium tour.

PARTICIPATION
A booking form for registration, accommodation, the symposium banquet and the post-symposium tour can be obtained from the IGS or the Icelandic Tourist Bureau (ITB). The form and accompanying payments should be returned to the ITB before 1 June 1995. There is a UK£50 surcharge for registrations received after this date. Full refunds will not be possible for cancellations received after 1 July. Fees cover organization costs, copies of abstracts, Icebreaker, half-day tour, and a copy of the Proceedings volume (*Annals of Glaciology*, Vol. 22). Accompanying persons' registration fees include organization costs, Icebreaker, and half-day tour. There is an administration charge for participants who are not members of the IGS or the Icelandic Glaciological Society (JÖRFI).

REGISTRATION FEES (due before 1 June 1995)	UK£		UK£
Participant (IGS or JÖRFI member)	200	Banquet	45
Participant (not a member of above)	245	Post-symp. tour (single/double)	290/250
Student	125	Late surcharge (after 1 June 1995)	50
Accompanying person (18 or over)	75		

Refunds on registration fees will be made on a sliding scale, according to date of receipt of notification, up to 1 August 1995. After that date it may be impossible to make any refund. All who preregister will receive a copy of the third circular and programme prior to the meeting.

TOPICS
The following topics will be open for discussion:
1. Processes and rates of glacial erosion
2. Origin, transport and rates of deposition of sediment types in glacial environments
3. Erosion and sedimentation associated with normal, fast-flowing and surging glaciers
4. Erosion and transport of sediments during catastrophic floods
5. Dynamic, hydrological, geological and engineering aspects of glacier erosion
6. Glacio-marine sedimentation

Sessions will be held on four full days and one half-day. An excursion will be held on one half-day. There will be ample opportunity for poster displays, which are encouraged.

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 <u>and relevance</u> 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. <u>Indicate at the bottom which specific topic it intends to address, and whether a poster</u>

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

(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 present their contribution at the Symposium. First authors will be advised by the end of March 1995 of the acceptance or otherwise; other authors will not be informed separately. Authors who have not received notification by April 15 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: The accepted abstracts will be provided to all registered participants upon registration on 20 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. 22). Final typescripts of these papers should be sent to the Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, U.K. by 15 June 1995. They should be written in English and prepared in accordance with the instructions about style that will be sent to authors with the acceptance notification. The final version of the paper should not normally exceed 5 *Annals* printed pages.

The papers will be refereed according to the usual standards of the Society before being accepted for publication. Speedy publication of the proceedings will depend upon strict adherence to deadlines.

ACCOMMODATION

The principal symposium hotels will be the Hotel Saga and Scandic Hotel Loftleiðir, close to the University of Iceland. Special bed and breakfast rates have been negotiated here and with other establishments in Reykjavík. Bookings must be made through the Iceland Tourist Bureau prior to June 1, 1995. Payment can be by sterling bank draft or credit card (Visa, Mastercard, Eurocard). Accommodation will be confirmed on receipt of the £100 deposit. A full refund will be possible for cancellations received in writing by 1 July 1995.

TRAVEL

Reduced airfares with Icelandair will be available to those registering for the symposium. Participants should request the special conference rate when booking with the airline.

HALF-DAY EXCURSION

The half-day tour will be to the Reykjavík District Heating Company, a nearby Municipal geothermal heating plant, approximately 35 km from Reykjavík. From there the tour will proceed to Nesjavellir, Gullfoss, Geysir and Þingvellir, the site of the Althing, the original Icelandic Parliament, for a barbeque.

IMPORTANT DATES:

Last date for receipt of abstracts:	1 February 1995
Registration date:	1 June 1995
Last date for receipt of final papers:	15 June 1995

POST-SYMPOSIUM TOUR (26–29 August)

A three-day excursion by bus along the south coast and into the interior of Iceland.

Day one:
From Reykjavík across the southern lowlands of Iceland, over post-glacial sandur plains and lava fields. Past the villages of Selfoss, Hella and Hvolsvöllur to the ice caps of Eyjafjallajökull and Mýrdalsjökull, with their torrential glacial rivers, vast sandur fields, and glaciers which have been advancing for the last 25 years (Sólheimajökull). Then across Mýrdalssandur, created largely by the tremendous jökulhlaups released during the eruption of the subglacial volcano Katla, under Mýrdalsjökull, overnighting at the Hotel Edda Kirkubæjarklaustur.

Day two:
To the districts south of Vatnajökull. Crossing Skeiðarársandur (1000 km^2), the largest outwash plain in Iceland, built to a large extent by jökulhlaups from the subglacial lake Grímsvötn and marginal lake Grænalón. Visit to the front of Skeiarárjökull, which surged in 1991, and the Skaftafell National Park. Past the ice-capped strato-volcano Öræfajökull, through areas devastated by its eruptions in 1362 and 1727 A.D. The tour proceeds to Breidamerkursandur and the proglacial lake Jökulsárlón before returning to Kirkubæjarklaustur.

Day three:
To the interior of Iceland, to Landmannalaugar via the volcanic fissure Eildgjá. Passing the volcano Hekla and hydro-electric power stations in glacier-fed rivers, before returning to Reykjavík in the late afternoon.

Note that a one-day workshop on the "Historical Roots of Glaciology" will take place in Reykjavík on 20 August, immediate preceding the symposium.

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

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

CO-SPONSORED BY

Atmospheric Environment Service, Institute of Ocean Sciences and Centre for Earth and Ocean Research, University of Victoria

FIRST CIRCULAR

The IGS will hold an international symposium on Representation of the Cryosphere in Climate and Hydrological Models in Victoria, British Columbia, Canada, with registration on 11 August, and sessions from 12–15 August.

THEME

There is general concern about how well the cryosphere and its interactions with the atmosphere, ocean and land are represented within global and regional climate models, and hydrological and other process models. This symposium will focus on how cryospheric processes, cryosphere/atmosphere/ocean coupling and cryosphere/terrestrial interactions are represented in such models. The emphasis will be on large-scale cryospheric components such as snow cover (including snowfall precipitation), sea ice, large ice sheets and permafrost. Of particular interest are the results of model experiments that identify the cryospheric processes or parameters to which simulations of large-scale climate and climate change are most sensitive.

TOPICS

The 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) Use of models for 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.

Abstracts most likely to be accepted will be those most closely related to these topics.

SESSIONS: Oral presentations will be held on four full days and 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 posters) will be refereed and edited according to the Society's regular standards.

ACCOMMODATION: Details will be given in the Second Circular. Hotels and dormitories will be available.

POST-SYMPOSIUM TOUR: Further details will be given in the Second Circular.

FURTHER INFORMATION: If you wish to attend the symposium please return the form below as soon as possible. GIVEN THE THEME, THE LOCATION, AND THE TIME OF YEAR, IT IS IMPORTANT FOR ORGANIZERS TO HAVE AN EARLY INDICATION OF ATTENDANCE.

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

CHIEF SCIENTIFIC EDITOR: J. Walsh.

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

INTERNATIONAL SYMPOSIUM ON REPRESENTATION OF THE CRYOSPHERE IN CLIMATE AND HYDROLOGICAL MODELS, Victoria, Canada, 12–15 August 1996

Family name: .... Tel: ....

First name: .... Fax: ....

Address: .... E-mail: ....

....

....

I hope to participate in the Symposium in August 1996 [ ]
I intend to submit an abstract [ ]
My abstract is most closely related to topic [1] [2] [3] [4]

I would be interested in participating in a post-symposium tour [ ]
I would prefer a scientific excursion [ ]
I prefer a general tourist excursion [ ]
I prefer a 1-day general interest tour of the area [ ]
I am interested in an accompanying persons programme [ ]
I prefer accommodation in a hotel [ ] dormitory [ ] either [ ]

PLEASE RETURN AS SOON AS POSSIBLE TO:
Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, U.K.
Tel: +44-(0)1223-355974 Fax: +44-(0)1223-336543

JOURNAL OF GLACIOLOGY

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

M SHARP, G H BROWN, M TRANTER, I C WILLIS AND B HUBBARD
Comments on the use of chemically based mixing models in glacier hydrology

M T GUDMUNDSSON, H BJÖRNSSON AND F PÁLSSON
Changes in jökulhlaup sizes in Grímsvötn, Vatnajökull, Iceland, 1934–91, deduced from in-situ measurements of subglacial lake volume

M G GROSSWALD AND T J HUGHES
Paleoglaciology's grand unsolved problem

M R VAN DEN BROEKE AND R BINTANJA
On the interation of katabatic wind and blue ice area formation in East Antarctica

D J WINGHAM
The limiting resolution of ice-sheet elevations derived from pulse-limited satellite altimetry

C F RAYMOND, R J BENEDICT, W D HARRISON, K A ECHELMEYER AND M STURM
Hydrological discharges and motion of Fels and Black Rapids Glaciers, Alaska, U.S.A.: implications for the structure of their drainage systems

D K PEROVICH, J A RICHTER-MENGE, J H MORISON
The formation and morphology of ice stalactites observed under deforming lead ice

REN JIAWEN, QIN DAHE, J R PETIT, J JOUZEL, WANG WENTI, LIU CHEN, WANG XIAOJUN, QIAN SONGLIN AND WANG XIAOXIANG
Glaciological studies on Nelson Island, South Shetland Islands, Antarctica

H BLATTER
Velocity and stress fields in grounded glaciers: a simple algorithm for including deviatoric stress gradients

D R MACAYEAL, R A BINDSCHADLER AND T A SCAMBOS
Basal friction of Ice Stream E, West Antarctica

T JÓHANNESSON
Degree-day glacier mass-balance modelling with applications to glaciers in Iceland, Norway and Greenland

ANNALS OF GLACIOLOGY

The following papers will be published in Volume 20, *Proceedings of the Fifth International Symposium on Antarctic Glaciology (VISAG)* held at Jesus College, Cambridge, U.K., 5–11 September 1993.

J-G WINTHER
Spectral bi-directional reflectance of snow and glacier ice measured in Dronning Maud Land, Antarctica

P SKVARCA
Changes and surface features of the Larsen Ice Shelf, Antarctica, derived from Landsat and Kosmos mosaics

T H JACKA AND LI JUN
The steady-state crystal size of deforming ice

I SHERJAL AND M FILY
Temporal variations of microwave brightness temperatures over Antarctica

C S LINGLE, L-H LEE, H J ZWALLY AND T C SEISS
Recent elevation increase on Lambert Glacier, Antarctica, from orbit cross-over analysis of satellite-radar altimetry

M O JEFFRIES, A L VEAZEY, K MORRIS AND H R KROUSE
Depositional environment of the snow cover on West Antarctic pack-ice floes

R W JACOBEL, A E ROBINSON AND R A BINDSCHADLER
Studies of the grounding-line location on Ice Streams D and E, Antarctica

U C HERZFELD, C S LINGLE AND L-H LEE
Recent advance of the grounding line of Lambert Glacier, Antarctica, deduced from satellite-radar altimetry

J L BAMBER
A digital elevation model of the Antarctic ice sheet derived from ERS-1 altimeter data and comparison with terrestrial measurements

A L L M VERBERS AND V DAMM
Morphology and late Cenozoic (< 5 Ma) glacial history of the area between David and Mawson Glaciers, Victoria Land, Antarctica

A L VEAZEY, M O JEFFRIES AND K MORRIS
Small-scale variability of physical properties and structural characteristics of Antarctic fast ice

R LESTRINGANT
A two-dimensional finite-element study of flow in the transition zone between an ice sheet and an ice shelf

A HIGASHII AND Y FUJII
Studies on microparticles contained in medium-depth ice cores retrieved from east Dronning Maud Land, Antarctica

S FUJITA AND S MAE
Causes and nature of ice-sheet radio-echo internal reflections estimated from the dielectric properties of ice

T KAMEDA, H SHOJI, K KAWADA, O WATANABE AND H B CLAUSEN
An empirical relation between overburden pressure and firn density

T KAMEDA AND R NARUSE
Characteristics of bubble volumes in firn–ice transition layers of ice cores from polar ice sheets

B K LUCCHITTA, K F MULLINS, C E SMITH AND J G FERRIGNO
Velocities of the Smith Glacier ice tongue and Dotson Ice Shelf, Walgreen Coast, Marie Byrd Land, West Antarctica

U NIXDORF, H OERTER AND H MILLER
First access to the ocean beneath Ekströmisen, Antarctica, by means of hot-water drilling

C U HAMMER, H B CLAUSEN AND C C LANGWAY, JR
Electrical conductivity method (ECM) stratigraphic dating of the Byrd Station ice core, Antarctica

W GRAF, H MOSER, O REINWARTH, J KIPFSTUHL, H OERTER, A MINIKIN AND D WAGENBACH
Snow-accumulation rates and isotopic content (^{2}H, ^{3}H) of near-surface firn from the Filchner–Ronne Ice Shelf, Antarctica

S SHABTAIE AND C R BENTLEY
Electrical resistivity measurements on Ice Stream B, Antarctica

D YI AND C R BENTLEY
Analysis of satellite radar-altimeter return wave forms over the East Antarctic ice sheet

T UCHIDA, T HONDOH, S MAE, P DUVAL AND V YA LIPENKOV
Effects of temperature and pressure on the transformation rate from air bubbles to air-hydrate crystals in ice sheets

A N NOVICK, C R BENTLEY AND N LORD
Ice thickness, bed topography and basal-reflection strengths from radar sounding, Upstream B, West Antarctica

T S CLARKE AND C R BENTLEY
High-resolution radar on Ice Stream B2, Antarctica: measurements of electromagnetic wave speed in firn and strain history from buried crevasses

R BINTANJA AND M R VAN DEN BROEKE
Local climate, circulation and surface-energy balance of an Antarctic blue-ice area

C LIU, C R BENTLEY AND N E LORD
c axes from radar depolarization experiments at Upstream B Camp, Antarctica, in 1991–92

S RATRE AND C R BENTLEY
Indication of a dilatant bed near Downstream B Camp, Ice Stream B, Antarctica

S ANANDAKRISHNAN AND R B ALLEY
Ice Stream C, Antarctica, sticky spots detected by microearthquake monitoring

R B ALLEY, S ANANDAKRISHNAN, C R BENTLEY AND N LORD
A water-piracy hypothesis for the stagnation of Ice Stream C, Antarctica

I ALLISON AND A WORBY
Seasonal changes of sea-ice characteristics off East Antarctica

I D GOODWIN, M HIGHAM, I ALLISON AND R JAIWEN
Accumulation variation in eastern Kemp Land, Antarctica

A N SALAMATIN, V YA LIPENKOV AND K V BLINOV
Vostok (Antarctica) climate record time-scale deduced from the analysis of a borehole-temperature profile

D L MORSE AND E D WADDINGTON
Recent survey of brine infiltration in McMurdo Ice Shelf, Antarctica

E D WADDINGTON AND D L MORSE
Spatial variations of local climate at Taylor Dome, Antarctica: implications for paleoclimate from ice cores

KAZUO OSADA
Seasonal variations of major ionic concentration levels in drifting-snow samples obtained from east Dronning Maud Land, East Antarctica

A J GOW
Post-drilling recrystallization of the Byrd Station deep ice core and its relevance to current and future deep-core drilling on polar ice sheets

A J GOW AND JOHN W GOVONI
An 80 year record of retreat of the Koettlitz Ice Tongue, McMurdo Sound, Antarctica

S TAKAHASHI, Y AGETA, Y FUJII AND O WATANABE
Surface mass balance in east Dronning Maud Land, Antarctica, observed by Japanese Antarctic Research Expeditions

G CASASSA AND I M WHILLANS
Decay of surface topography on the Ross Ice Shelf, Antarctica

C L HULBE AND I M WHILLANS
Evaluation of strain rates on Ice Stream B, Antarctica, obtained using GPS phase measurements

C L HULBE AND I M WHILLANS
A method for determining ice-thickness change at remote locations using GPS

T J CHINN
Glacier disequilibrium in the Convoy Range, Transantarctic Mountains, Antarctica

O CASTELNAU AND P DUVAL
Simulations of anisotropy and fabric development in polar ices

A MINIKIN, D WAGENBACH, W GRAF AND J KIPFSTUHL
Spatial and seasonal variations of the snow chemistry at the central Filchner–Ronne Ice Shelf, Antarctica

W F BUDD, D JENSSEN, E MAVRAKIS AND B COUTTS
Modelling the Antarctic ice-sheet changes through time

T TAKIZAWA, K I OHSHIMA, S USHIO, T KAWAMURA AND H ENOMOTO
Temperature structure and characteristics appearing on SSM/I images of the Cosmonaut Sea, Antarctica

D WAGENBACH, W GRAF, A MINIKIN, U TREFZER, J KIPFSTUHL, H OERTER AND N BLINDOW
Reconnaissance of chemical and isotopic firn properties on top of Berkner Island, Antarctica

T A SCAMBOS, K A ECHELMEYER, M A FAHNESTOCK AND R A BINDSCHADLER
Development of enhanced ice flow at the southern margin of Ice Stream D, Antarctica

R A BINDSCHADLER, M A FAHNESTOCK, P SKVARCA AND T A SCAMBOS
Surface-velocity field of the northern Larsen Ice Shelf, Antarctica

R A BINDSCHADLER AND P L VORNBERGER
Detailed elevation map of Ice Stream C, Antarctica, using satellite imagery and airborne radar

P HUYBRECHTS
formation and disintegration of the Antarctic ice sheet

I MOORE, S D MOBBS, D B INGHAM AND J C KING
A numerical model of blowing snow around an Antarctic building

J SIEVERS, C S M DOAKE, J IHDE, D R MANTRIPP, V S POZDEEV, B RITTER, H W SCHENKE, F THYSSEN AND D G VAUGHAN
Validating and improving elevation data of a satellite-image map of Filchner–Ronne Ice Shelf, Antarctica, with results from ERS-1

A M SMITH AND C S M DOAKE
Sea-bed depths at the mouth of Rutford Ice Stream, Antarctica

J BAMBER AND C R BENTLEY
A comparison of satellite-altimetry and ice-thickness measurements of the Ross Ice Shelf, Antarctica

N BLINDOW
The central part of the Filchner–Ronne Ice Shelf, Antarctica: internal structures revealed by 40 MHz monopulse RES

D G VAUGHAN
Investigating tidal flexure on an ice shelf using kinematic GPS

K GROSFELD AND F THYSSEN
Temperature investigation and modeling on the Filchner–Ronne Ice Shelf, Antarctica

A ROBINSON, K MAKINSON AND K NICHOLLS
The oceanic environment beneath the northwest Ronne Ice Shelf, Antarctica

M JONAS, K GROSFELD AND F THYSSEN
Numerical flow simulation at local parts of Filchner–Ronne Ice Shelf, Antarctica

M FREZZOTTI AND M C G MABIN
20th century behaviour of Drygalski Ice Tongue, Ross Sea, Antarctica

M J HAMBREY AND J A DOWDESWELL
Flow regime of the Lambert Glacier–Amery Ice Shelf system, Antarctica: structural evidence from Landsat imagery

J G FERRIGNO, J L MULLINS, J A STAPLETON, R A BINDSCHADLER, T A SCAMBOS, L B BELLISIME, J-A BOWELL AND A V ACOSTA
Landsat TM image maps of the Shirase and Siple Coast ice streams, West Antarctica

J DETERMANN AND R GERDES
Melting and freezing beneath ice shelves: implications from a three-dimensional ocean-circulation model

L G THOMPSON, D A PEEL, E MOSLEY-THOMPSON, R MULVANEY, J DAI, P N LIN, M E DAVIS AND C F RAYMOND
Climate since AD 1510 on Dyer Plateau, Antarctic Peninsula: evidence for recent climate change

P CIAIS, J JOUZEL, J R PETIT, V LIPENKOV AND J W C WHITE
Holocene temperature variations inferred from six Antarctic ice cores

G W PALTRIDGE
Ice sheets and continental drift

R MULVANEY AND E W WOLFF
Spatial variability of the major chemistry of the Antarctic ice sheet

Glaciological Diary

1994
7-9 December
XVII Symposium on Polar Biology: Sea-ice Ecology, Tokyo, Japan (Dr Mitsuo Fukuchi, Nat. Inst. of Polar Research, 9-10, Kaga 1-chome, Itabashi-ku, Tokyo 173, Japan)

1995
5-8 February
10th International Symposium on Okhotsk Sea and Sea Ice, Mombetsu, Hokkaido, Japan (Secretariat, Okhotsk Sea and Cold Ocean Res. Assoc., c/- Dept. Planning and Coord., Mombetsu Municipal Office, Saiwai-2, Mombetsu, Hokkaido, Japan)
11-15 February
Glaciologie et Nivologie: État des Recherches et des Connaissances à la Fin du 20ième siecle, Grenoble, France (Secrétariat de la SHF, 199 rue de Grenelle, 75007 Paris, France)
18-24 March
NATO ARW on Processes of Chemical Exchange between the Atmosphere and Polar Snow, Tuscany, Italy (Eric Wolff, British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET, U.K.)
21-22 April
Midwest Glaciology Meeting, University of Chicago, USA (D. R. MacAyeal, Dept. of Geophysical Sciences, University of Chicago, IL 60637, USA)
11-16 June
5th International Offshore and Polar Engineering Conference, The Hague, The Netherlands (ISOPE, P.O. Box 1107, Golden, CO 80402-1107, USA)
3-14 July
Symposium on Biochemistry of Seasonally Snow-Covered Catchments (ICSI/ICWQ/ICT) (K. Tonnessen, US National Park Service, Air Quality Division, P.O. Box 25287, Denver, CO 80225-0287, USA)
20-25 August
** IGS International Symposium on Glacial Erosion and Sedimentation, Reykjavík, Iceland (Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, UK)
18–22 September
* EISMINT International Symposium on Ice-sheet Modelling, Chamonix, France (P. Pirra, EISMINT, European Science Foundation, 1 quai Lezay Marnésia, F-67080 Strasbourg Cedex, France)

1996
24-28 June
Interpraevent 1996: Protection of Habitat against Floods, Debris Flows and Avalanches, Garmisch-Partenkirchen, Germany (Interpraevent 1996, c/o Bayerisches Landesamt für Wasserwirtschaft, Lazarettstr. 67, D-80636 Munich, Germany)
12-15 August
** Representation of the Cryosphere in Climate and Hydrological Models, Victoria, B.C., Canada (Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, UK)
27-31 August
* IX 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)

1997
14-18 July
** Antarctica and Global Change, University of Tasmania, Hobart, Australia (Secretary General, International Glaciological Society, Lensfield Road, Cambridge, CB2 1ER, UK)

** IGS Symposia
* Co-sponsored by IGS

News

GLACIOLOGICAL ASSOCIATION (FSU)

A new association of Russian-speaking glaciologists has been formed in Moscow. The 85 members are drawn from Russia, Ukraine, Georgia, Kazakstan, Uzbekistan, Tadjikistan and Kirghizia, and include some from outside the Former Soviet Union. Membership is open to anyone on payment of an annual fee of $20.

The officers for 1994 are the following:

President: Vladimir Kotlyakov
Vice Presidents: Andrey Glazovskiy, Igor Seversky, Albert Bazhev
Secretary: Vladimir Mikhalenko.

For further information on the Association and membership, contact the Secretary,
Institute of Geography,
Russian Academy of Sciences, 29 Staromonetny Street,
Moscow, 109017 Russia
(Tel: 7-095-129-4408; Fax: 7-095-230-2090;
E-mail: mikhalenko@mikun.msk.su).

Project ATMOSPHERE

Project ATMOSPHERE is the American Meteorological Society's educational initiative to foster the teaching of atmospheric topics across the curriculum in grades K-12. It is designed to encourage teachers to use data that are readily available to them in classroom learning activities. The goal is to help teachers use atmospheric and other related topics to generate student interest and understanding in science, technology and mathematics.

The integral core of Project ATMOSPHERE is the Atmospheric Education Resource Agent (AERA), composed of some 80 educators from nearly all co-terminus 50 states of the U.S. This network of educators is involved in teacher in-service and enhancement; state and national curriculum assessment; liaison work with local, state, and national meteorological professionals; outreach extended beyond the meteorological professionals — such as the American Geophysical Union; and work with the state and local emergency management services. Project ATMOSPHERE has developed modules on single meteorological topics, such as radar, satellites and global climate change. Project ATMOSPHERE has developed software that enables teachers and students to download real-time data from cable television's The Weather Channel for multi-disciplinary studies in the classroom. It has also served as the model for Project ATMOSPHERE Australia and a physical oceanography program called the Maury Project.

As resource agents, it is our goal to instruct teachers, and ultimately students, that there is an ongoing interrelationship among atmosphere, ocean, land, and ice. We hope to establish professional relationships with scientists in order to: (1) gain knowledge and insight into scientific areas that are unfamiliar; (2) demonstrate to teachers and students that the scientific community is open to communication and exchanges of information; and (3) develop role models for students in the sciences.

For more information, please contact:

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Recent meetings (of other organizations)

PHYSICS OF ICE-COVERED SEAS

An Advanced Study Institute Summer School on the *Physics of Ice-Covered Seas* was held in Savonlinna, a small town in the lake district of Finland, from 6–17 June 1994. Organized by the Department of Geophysics, University of Helsinki and the Sea Ice Commission of IAPSO (International Association for Physical Sciences of the Ocean), it resembled the 1981 NATO Advanced Study Institute *Geophysics of Sea Ice* in Maratea, Italy.

Thirty top scientists from New Zealand, Russia, the U.S.A. and Western Europe served as teachers; thus much of the present polar oceanography and sea-ice physics knowledge was present. 30 of the 136 participants were teachers, and 63 under- or post-graduate students. They represented 23 countries, with five or more from Denmark, Finland, Germany, U.K., Norway, Russia, Sweden, and the U.S.A.

During the first week, basic geophysics was covered and included structure and properties, morphology, thermodynamics and dynamics of sea-ice; as well as the marginal ice zone, upper ocean, circulation in ice-covered waters, leads and polynyas, freezing estuaries, Arctic and Antarctic oceanography, snow physics, and climate. Mathematical modelling techniques and related disciplines, covered during the second week, included sea-ice/ocean and coupled modelling at all time scales; and polar meteorology, remote sensing, ice engineering, and biological and chemical oceanography. The physics–ecology connection was considered very important for better understanding environmental problems and developing multi-disciplinary research programmes.

A text book, based on the lectures, should be available at the end of 1995. The evening seminar and poster papers will be published in late 1994.

Generally, students preferred ordinary university-type lectures, starting from basics and then moving to more complicated topics. Presentations of high-level scientific results were regarded as being out of the summer-school scope. Don Perovich, Jim Overland and Zygmunt Kowalik were voted the best teachers.

Matti Leppäranta, Timo Vihma and Jari Haapala

New members

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INTERNATIONAL GLACIOLOGICAL SOCIETY

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INTERNATIONAL GLACIOLOGICAL SOCIETY

Lensfield Road, Cambridge CB2 1ER, England

DETAILS OF MEMBERSHIP

Membership is open to all individuals who have a scientific, practical or general interest in any aspect of snow and ice. Payment covers purchase of the *Journal of Glaciology* and *Ice*. Forms for enrolment can be obtained from the Secretary General. No proposer or seconder is required.

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ICE

Editor: C. S. L. Ommanney (Secretary General)
Assisted by D. M. Rootes and S. Stonehouse

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