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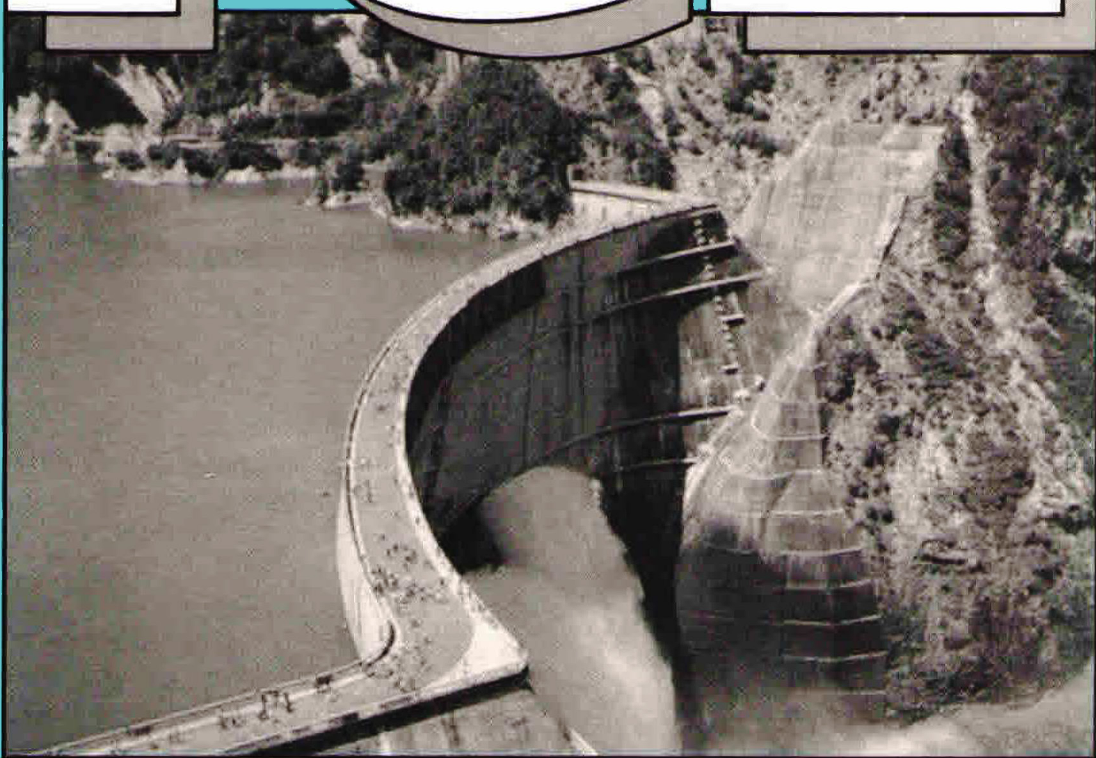

NEWS BULLETIN OF THE INTERNATIONAL GLACIOLOGICAL SOCIETY

INTERNATIONAL GLACIOLOGICAL SOCIETY

International Symposium on
the Role of the Cryosphere
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CONTENTS

COVER PHOTOGRAPH Kurobe Dam (1454 m), Chubu Mountains National Park, Japan. A visit to the dam, completed in 1963, formed part of the IGS Nagaoka post-symposium tour (see p. 23–24). The dam is sited in the Kurobe ravine, a heavy snowfall catchment area of west Honshu, and produces an average annual output of 906 000 MW h. Photograph courtesy of the Kansai Electric Power Company.

Recent work

JAPAN

Abbreviations:
KIT : Kitami Institute of Technology
NIED : National Research Institute for Earth Science and Disaster Prevention
NISIS : Nagaoka Institute of Snow and Ice Studies
SBSIS : Shinjo Branch of Snow and Ice Studies.

Ice core analyses for reconstructing recent climate/environment

(M. Nakawo and K. Goto-Azuma, NISIS, NIED)
Recent climate/environment is being reconstructed by analyzing shallow snow/ice cores collected at Himalaya, Kunlun and Tien Shan mountains in central Asia, East Antarctica and the Canadian Arctic. The study is in collaboration with many national and international institutions. The core data are to be correlated with local instrumental data such as discharge of rivers and dust storm records. The data are also to be correlated with indices of global change to assess their implications.

Spacial and temporal variations in falling/deposited snow

(T. Kimura, SBSIS, NIED; M. Nakawo and M. Shimizu, NISIS, NIED)
Automated snow stations, installed at various sites in snowy regions of Japan, collect data on glaciological and meteorological elements. Eight stations are in operation, including five stations at high elevations (roughly above 100 m a.s.l.), where no sytematic data have been collected so far. The data are to be used to analyze the variation of snow conditions in relation to global climate change.

Prediction of icing on pavements

(M. Shimizu and M. Nakawo, NISIS; S. Takahashi, KIT)
Surface temperature and other meteorological/glaciological elements have been monitored over a road surface. Analyses of these data in addition to an intensive heat budget observation indicated a relative importance of atmospheric radiation for predicting icing on pavements. A practical method for a precise monitoring of surface temperature of a pavement is under development with an infra-red thermometer and a long wave radiometer.

Hydro-meteorological study at an experimental watershed in Moshiri, Hokkaido

(N. Ishikawa, Y. Kodama, Y. Ishii and D. Kobayashi, Institute of Low Temperature Science, Hokkaido University)
In order to investigate the mechanism of hydrological cycle and the area heat balance in a snowy area a hydrometeorological automatic observation system was established at a small experimental watershed in Moshiri basin, central Hokkaido, Japan. Moshiri is well known as the coldest and snowiest place in Japan. The maximum depth of seasonal snow cover exceeds 2 m and the minimum winter temperature drops below –35°C easily. The system consists of six observational sites in the experimental watershed (area 1.4 km^2). Each site was selected to represent typical watershed figure (1. the highest point in the basin at 550 m a.s.l., 2 and 3. on the mountain ridge at 380 and 330 m, 4. near a small stream (330 m), 5. at an outlet stream of the watershed (300 m), 6. the lowest point of the basin at 285 m). Each site has an observation mast 10 or 15 m high which is equipped with meteorological sensors such as air, soil and snow temperatures, wind speed and direction, humidity, solar radiation and snow depth. Especially, direct measurements of net radiation, sensible heat, precipitation, atmospheric pressure and soil moisture are carried out at the highest and lowest sites. At the lowest site, the evaporation amount is measured by three different methods: one is an eddy correlation method, by using an ultra-sonic anemometer and an infrared hygrometer, the second is by a large vegetated soil-filled weighing lysimeter (maximum 650 kg) and the third is by an evaporation pan. The data at all six sites are recorded into a data logger every hour. Stored data at three sites (Nos 1, 2 5) are transmitted by radio to the lowest site every 24 hours. Hydrological observations such as water level, run-off, water temperature and chemical components are carried out at four different points along the stream in the watershed. The continuous observation started from December 1991 and is planned to continue for more than 10 years. The analysis of these accurate data sets is expected to reveal the characteristics of water cycles in a snowy area, especially seasonal variations of precipitation, snowmelt, evapo-transpiration and run-off in the near future.

Submitted by R. Naruse

SWITZERLAND

GLACIERS AND ICE SHEETS

Annual survey of Swiss glaciers

(M. Aellen, VAW and GK/SANW, H. Bösch, M. Funk and W. Schmid, VAW)

The results of the 110–112th annual surveys (1989–91) of glacier snouts in the Swiss Alps are summarized by the following figures:

Number of glaciers	1989	1990	1991
advancing	19	14	8
stationary	3	6	1
receding	83	91	100
classified	105	111	109

The number of advancing glaciers has decreased at an almost regular annual rate since 1984, while the number of receding ones has increased quite as regularly in all regions to a level which has never been observed during the last 27 years. It has, however, been a normal feature of the previous 36 years (1928–64), when mass losses prevailed. In the past seven years, advancing snouts were observed mainly on big flat valley glaciers (with the exception of the continuously receding two biggest ones: Aletsch and Gorner). In other cases, advances were due to particular mechanisms in glacier movement (such as tongue slidings, for example), to local excesses of winter snowfall or to snow avalanches deposited on a glacier's snout. Mass balances established for the glaciers of four high alpine river basins are summarized by the following figures (specific net values in $g\,cm^{-2}$):

Glacier	1988–89	1989–90	1990–91
Gries	−104	−189	−148
Aletsch	−19	−103	−54
Limmern and Plattalva	−42	−104	
Silvretta	−25	−53	−113

In all years from 1983–90, periods of mild and dry weather lasting for several weeks were typical features of autumn and winter seasons. Heavy snowfalls in spring seasons or periods of cold and rainy weather in summer seasons were effective in preventing severe glacier mass losses in most years, except 1990, and more so in the northern than in the southern parts of the Swiss Alps. In 1990, winter snow accumulation was still rather poor, when a very warm and long-lasting summer season started in early May. In 1991, abundant snowfalls during an early beginning and late ending winter season were overcompensated by extremely strong melting in a rather short, but very warm and dry summer season. Melt rates increased noticeably due to the effects of a Saharan desert dust layer which was deposited in March over the entire Alps and became exposed at the surface at all altitude levels during almost all the summer.

Mass balance of Gries Glacier 1961–84

(M. Funk, VAW; W. Stahel and R. Morelli, SI)

Mass balance measurements on Griesgletscher started in 1961. The number of stakes used was 20 in the first eight years and has been increased up to 78 ($\approx$13 per square kilometer) and kept constant until 1984. From 1984 until present, the measurements were continued with eight stakes. Until 1984, the mass balance for the whole glacier was determined with the traditional method, where contour lines of equal mass balances were drawn by hand, then calculated for elevation intervals and finally for the entire glacier. For that period (1961–84), 73% of the 23 × 78 point data are available. With this important data set, different statistical methods for determining the mass balance of the whole glacier were tested to assess their accuracy and to consider a reduction of the number of stakes. It could be shown that the linear model of Lliboutry leads to considerable uncertainty if applied for the entire glacier, but gives satisfactory results if the accumulation and ablation areas are treated separately.

Accelerated melt rates of Alpine glaciers

(W. Haeberli, VAW)

Average rates of 20th century glacier mass loss in the Alps were roughly one order of magnitude higher than in late-glacial times and increased further by more than 50% during 1980–90 with respect to the secular average. The higher rates of recent secular glacier mass losses as compared to late-glacial averages may first of all be attributed to higher warming rates since the end of the Little Ice Age and then to the higher sensitivity of the more humid modern glaciers with higher mass balance gradients. Present-day icemelt rates represent a most effective energy sink, considerably in excess of the estimated anthropogenic forcing ($2.5\,W\,m^{-2}$). Most of the excess, however, can probably be explained by the mass balance/altitude feedback effect. The recent appearance of a stone-age man from cold ice/ permafrost on a high-altitude ridge of the Oetztal Alps (Austria) confirms that the extent of Alpine glaciers is likely to be more reduced than ever before during the past 5000 years. Continuation of the observed trend could reduce glaciers in the Alps — and in other mountain ranges as well — far beyond natural ranges of Holocene variability within a few decades to come.

Alpine firn temperature measurements

(M. Laternser, A. Iken and W. Haeberli, VAW)

Firn temperatures were measured on four different glaciers in the Swiss Alps and produced the following conclusions: (1) The shadow of a 20–30 m high vertical rock face which parallels the steep and thin Altels Glacier between 2700–3100 m a.s.l. has a significant influence on the locally different warming-up of the firn body due to variable meltwater percolation during spring and summer. (2) The genrally temperate Jungfraufirn shows slightly cold temperatures in heavily crevassed areas at altitudes around 350 m a.s.l. (3) The Brithorn plateau at approximately 3800 m a.s.l. seems to be temperate at any depth, with the exception of the winter cold wave in the uppermost layer. (4) Measurements in clearly cold firn on the Colle Gnifetti and upper Grenz Glacier (4250–4450 m a.s.l.) were mainly used for analyzing the dissipation of the thermal disturbance caused by steam drilling. It is shown that the time of total adjustment to the undisturbed temperature varies between several days to two weeks. As early as a few hours after drilling, the correct temperature can be found by extrapolation procedures based on analytical solutions of the heat budget equation for various simplified conditions.

Deep hot-water drilling and borehole measurements at the confluence ("Konkordiaplatz") of Great Aletsch Glacier

(A. Iken, M. Funk, W. Haeberli, VAW)

In 1990 and 1991 several holes were drilled in the central branch of Aletschgletscher, "the Jungfraufirn", at "Konkordiaplatz". The deepest hole reached a debris-rich layer at 860 m depth, indicated by a reduction of the tension in the drilling hose. Drilling was continued by alternately lifting the drill until the full tension was re-established and then drilling deeper until the tension became reduced again. In this way, it was possible to advance to a depth of 900 m; when the drill was finally brough back to the surface it was severely scratched. A depth of 860–900 m agrees well with seismic depth soundings previously carried out by F. Thyssen and M. Ahmad in 1969. Konkordiaplatz is likely to be the deepest glacial overdeepening in the Alps. Boreholes, drilled subsequently some 100 m upstream of the deepest zone, reached the debris-rich layer at a depth of 720–730 m. Measurements of current between electrodes in the latter holes and at the glacier margin suggest that these holes extended nearly to the bed.

During drilling, the water levels dropped to a depth of 50–60 m below the surface in all holes. However, when a stream was diverted into a hole, the level eventually dropped deeper and, after one week, reached a depth of more than 150 m below the surface. Dye tracing experiments carried out in cooperation with the University of Freiburg (Germany) indicated a fast passage when the dye was added to streams flowing into moulins (upstream and downstream from the overdeepening). In contrast, dye inserted at the bottom of boreholes re-appeared in daily pulses over a long time. Readings of thermistors installed in the deep boreholes upstream of the centre of the overdeepening were disturbed by cable stretching which caused a gradual increase in resistance. In the initial phase, however, phase-equilibrium temperatures in the temperate ice could be measured down to several hundred meters depth.

Deformation measurements on the surface and in boreholes at the confluence of Unteraar Glacier

(H. Gudmundson, A. Ikena nd M. Funk, VAW)

The confluence of the Lauteraar and Finsteraar glaciers is being investigated as an example of strongly convergent flow. Surface flow velocities were measured using stakes and photogrammetric methods. Borehole deformation and the vertical movements of magnetic rings attached to the wall of a borehole were measured. The debrock topography beneath the glacier was mapped using radio-echo soundings. A non-linear 3D model employing the full form of Glen's flow law has been further developed and used for the calculation of flow velocities. The field data obtained is used to set constraints on the parameters going into the flow law.

Glacier hazards

(W. Haeberli, VAW)

A state-of-the art concerning ice avalanches and debris flows in high mountain areas was prepared for the Swiss National Research Programme on Climatic Changes and Natural Disasters. Besides the shrinkage of glaciers and the degradation of permafrost as caused by secular warming, the increase in human activities in long-known but sometimes also previously avoided areas of high risk essentially contributed to new hazard situations. Continuation or even acceleration of this trend may lead to a marked shift in hazard zones. Modelling of icemelt scenarios and corresponding ice avalanche and debris flow hazards are recommended. Highest priority, however, is attributed to adequate documentation of ongoing changes in nature.

Glacier and permafrost photogrammetry

(H. Bösch, W. Schmid, A. Kääb, VAW)

Newly installed nets of fix points enable photogrammetrical monitoring of glacier tongue behaviour at Silvretta, Morteratsch, Fee, Rhone Basodino, Great Aletsch and Mittelaletsch. A digital terrain model was established at Schwarzberg Glacier in order to investigate volume changes. Direct comparison of specially flown low-altitude aerial photography was applied to determine the flow field at Unteraar and Gruben glaciers. The creep and development of rock glacier permafrost was analyzed for Gruben (1979–1985–1990) and Muragl (1980–91).

Finite-element modelling of ice and permafrost at Alpine drilling sites

(S. Wagner, A. Iken and W. Haeberli, VAW)

Finite element modelling is being applied to data measured at Altels Glacier which exhibits periodic events of fast sliding. Borehole deformation within the permafrost of the rock glacier Ursina (Pontresina) is being analyzed in order to achieve a better understanding of the flow behaviour of ice–rock mixtures. To gain more information about the flow pattern and age of the lower parts of ice cores at the Colle Gnifetti drill site, the 3D configuration of the saddle is modelled.

Firn temperature measurements and snow pit studies on the EGIG-East-Traverse, Greenland

(M. Laternser, VAW, in cooperation with D. Wagenbach and collaborators, Institute of Environmental Physics, University of Heidelberg, FRG, H. Kock and collaborators, Geodetic Institute, Technical University of Braunschweig, FRG)

In combination with a repetition of the eastern part of the EGIG-Traverse in summer 1992, a glaciological field programme was carried out between the firn divide of central Greenland and the eastern ablation area. The route led along the line GRIP-Summit–Crête–Jarl-Joset–Cecilia Nuntak. Systematic firn temprature measurements in steam-drilled 15 m boreholes were done as well as stratigraphic snow pit studies. Samples were taken in snow pits and shallow firn cores for chemistry and isotope analysis. The main goals are to document the climatologically relevant firn temperature and annual accumulation along the survey line and to get an overview about the distribution of atmospheric aerosol components in central and eastern Greenland. It is particularly hoped that the firn temperatures can serve as a basis for comparison with future measurements in view of possible warming effects.

Modelling glacier/groundwater interactions

(Ch. Speck, J. Troesch and W. Haeberli, VAW)

In order to quantify the effects of freezing and thawing on groundwater flow in an aquifer beneath polythermal glaciers resting on sedimentary beds, two existing finite element models are coupled, calculating temperatures and hydraulic conditions interactively. If important parameters, such as hydraulic permeability, thermal conductivity, heat capacity, etc., are changed due to varying thermal properties under freezing and thawing conditions, the flow regime in the aquifer will also be influenced. The overlying glacier is considered as an additional boundary condition. It is hoped that the results of this study will improve assessment of deep-reaching effects of ice-age conditions on the long-term disposal of radioactive waste in the ground.

Modelling englacial temperature for Jakobshavn Isbræ

(M. Funk, A. Iken, VAW, ETH-Zurich, K. Echelmeyer, Geophysical Institute/University of Alaska)
Sound knowledge of the temperature field in the ice stream is important for analyzing the mechanisms by which the high speeds in the stream are obtained. The temperature model used computes a two-dimensional time-dependent temperature field for a prescribed surface and bed topography. The model requires data on near-surface englacial temperatures, surface flow velocities and geothermal heat flux at the bottom. It formulates two-dimensional flow in a sheet, allowing for convergence of flow to restore continuity. Since the dynamics and the temperature field are dependent on each other, a solution scheme has been used in which the temperature field and the dynamics are solved alternately. An important result of these model calculations is that a substantial temperate layer ($\approx$200–300 m thick) seems to exist at the bottom of the ice stream. All results of the model are compared to and discussed together with the data on englacial temperatures measured in deep boreholes in the stream.

Ice-sheet modelling

(H. Blatter, A. Abe-Ouchi, GGEZ; K. Hutter, TH Darmstadt and GGEZ)
A two-dimensional transient model for ice sheets and glaciers is currently under development. The model couples thermodynamics and mechanics and can handle a changing free surface. The thermodynamic part includes possible polythermal conditions and is coupled to the rock below the ice. The mechanical part includes longitudinal stress in order to account for discontinuities, such as transitions between sliding and sticking to the base, and to treat crests and margins more realistically.

SNOW AND AVALANCHES

Macrostructure of disturbed and undisturbed snowpack

(W. Good and G. Kruesi, FISAR)
A simple device was constructed to produce translucent snow profiles in a natural (disturbed or undisturbed) snowpack. With this device vertical sheets can be cut with a thickness of the order of 50 mm and a size of about half a square meter. The structure of the snowpack can be seen very clearly when the sheet is illuminated from the back. Photographs are taken and subseuqnelty eveluated by image analysis, much the same as with thin sections for microanalysis. Features like weak layers and ice lenses could be followed during the whole winter. As the snowpack was rather small in forested areas during two consecutive winters, no further investigations were made. Comparison is planned for the future between the snowpack in forests and in open areas with microclimatic parameters recorded by automated stations for the whole winter.

Microstructure, grain boundaries and 3D reconstruction of the material snow

(W. Good and G. Kruesi, FISAR)
Homogeneous and inhomogeneous snow samples were evaluated in series of sections. The results were displayed in computer images and with layered plastic models in order to visualise the bonds between grains. Some of the images were blown up to a size suitable to be used as models at an exhibition (HEUREKA). The infrastructure and know-how for the preparation of these cuts and the analysis of computer images were made available to local and foreign researchers for their own investigations. The relation between the 3-dimensional geometry and the mechanical properties could not be established definitively.

Acoustics of snow

(O. Buser, FISAR)
Two acoustic profiles were measured. Preliminary evaluations at the Open University, Milton Keynes (UK), showed that it should be possible to determine several layers in a snowpack of about one meter. The appropriate computer programmes still have to be developed to the point of giving definitive results.

Water percolation in the snow cover

(J. Martinec, FISAR)
Snow wetness was measured with a dielectric device at four slope sites (2000–2650 m a.s.l.). The analysis showed a good correlation with the lysimeter data from the study plot. Measurements of the liquid water content will be continued with regard to wet slab avalanche activity.

Permafrost, snow and avalanches

(F. Keller, W. Haeberli, VAW; B. Salm and H. Gubler, FISAR)
In an attempt to evaluate the snow cover influence on the ground temperature field and to determine permafrost-specific characteristics of snow-cover processes in high mountain areas, systematic snow pit analyses were carried out in the Murtèl rock glacier area (eastern Swiss Alps) together with snow and soil temperature measurements. Permafrost in the ground markedly reduces the heat flow through the winter snow cover. The analyses of the snow profiles show a great difference in snow structure in terms of crystal forms, hardness and humidity. As a consequence of low temperature gradients in the snow cover in permafrost areas, the snow metamorphism differs markedly from snow metamorphism in permafrost-free areas. An attempt is being made to calculate the spatial thermal resistance of the winter snow cover using snow density and snow depth data. Snow distribution is being observed with an automatic camera.

Interception and unloading of snow by spruce branches

(H. Gubler, FISAR)
Interception and unloading of snow during storms by trees

situated in potential avalanche release zones modify their ability to support the snow cover on the ground and the areal extent of weak layers. The triggering mechanism for snow dumping is investigated by measuring deflection of the tree branch, branch temperature, surface temperature of the intercepted snow, wind, short wave radiation and air temperature. So far wind, radiation and air temperature appear to be the most important parameters for triggering snow dumping.

Snowdrift generated by snow fences in mountain areas

(T. Vögeli and B. Salm, FISAR)

Snowdrift by snow fences is well investigated in more or less horizontal terrain but not for inclined, mountainous terrain. The aim of this study is to obtain guidlines for planning fences for avalanche control. In several selected places snowdrift is being measured by photogrammetry. Wind speed and direction are also recorded. Different terrain configurations are investigated in the field.

Development of weak layers in a seasonal snow cover

(H. Gubler, D. Issler, B. Salm and P. Weilenmann, FISAR)

DAISY, a model for calculating termpature distribution, energy and mass flow in a snowpack, is refined to allow for a detailed study of the formation of weak layers by recrystallization processes close to the snow surface. Thin weak layers or layer interfaces at the bottom of a snow slab are a necessary condition for slab avalanche formation. A detailed study of absorption of short-wave radiation will improve modelling of energy and mass flow close to the snow surface. A computer-controlled motor-driven shear apparatus with a shear area of $0.25\,m^2$ has been tested successfully in the field. This device is used to measure strength–strain–strainrate relationships for typical weak layers in situ at strain rates of $10^{-6}\,s^{-1}$ to $10^{-1}\,s^{-1}$, range of viscoplastic deformation to brittle fracture. This relationship forms the basis for improving our understanding of slab-avalanche formation.

Analysis of weak layers in snow

(P. Föhn, FISAR)

A weak layer is a prerequisite for a slab avalanche. Snow profiles and correspondent shear frame measurements on slopes (1980–90) will be analyzed to obtain characteristic values of weak layers. A relation between elements of the topography, the grain shape and the mechanical properties will be derived.

Influence of skiers on the stability of the snow cover

(J. Schweizer, FISAR)

The influence of the skier as a trigger of slab avalanches is studied. The forces induced are calculated by the finite element method. Attention is focused on the layered character of the snow cover. The aim is to give a more quantitative interpretation of the stability of snow profiles, especially in the cvase of skier triggering. The result will be incorporated in the operational avalanche warning.

Expert systems for avalanche warning

(P. Föhn and J. Schweizer, FISAR)

A statistically based expert shell (commercially leased) was adapted for the purpose of avalanche warning on a regional scale. Thirteen weather and snow-cover parameters, including stability of snowpack, were combined with the verified hazard. The expert system responds by indicating the degree of danger, the altitude and the aspect of dangerous slopes. The knowledge base covers seven winters. Until present, 60–75% of all situations have been interpreted in a satisfactory way.

A second expert system was developed on the level of physical processes. It follows more closely the reasoning of a human expert. Rules are incorporated. Though the experience gained is still limited, the preliminary results are very encouraging.

Remote instrumentation of snow in avalanche release zones

(H. Gubler, M. Hiller, F. Herzog and P. Weilenmann, FISAR)

The experimental snow cover monitoring system with four remote systems is used to measure snow height, snow temperature profiles, microwave snow profiles, snow infrasound acoustic emissions and meteorological parameters in avalanche release zones and at study plots. The first few stations of an operational high alpine snow-cover monitoring network have been installed. For this network a very sturdy Pitot anemometer for high-alpine wind measurements has been developed and successfully tested in collaboration with commerical enterprises.

Statistical distribution of slab avalanche fracture depths

(D. Issler, A. Burkard and C. Jaccard, FISAR)

The extensive collection of snowfall data and avalanche records of the Davos area — covering five decades and areas from 50–120 km^2 — is used for extracting the statistical distribution of dry slab-avalanche fracture depths under hypothetical conditions of unlimited supply of fresh snow. This function is related to the distribution of mechanical strength of the fresh-snow layers and the underlying weak layers. If the validity of this function extends to other regions as well, it may be multiplied with the respective snowfall distributions of those areas to obtain the actual fracture depth distributions. The long-term goal is to apply this method in refined estimates of the recurrence periods of catastrophic avalanches.

NXD numerical avalanche forecast

(O. Buser, W. Good and M. Roveretto, FISAR)

NXD, a programme for computer-assisted avalanche forecast is spreading widely. Version 2.0 is now available in German, French, Italian and English. Those users who really work with it would not want to do without it any more. The programme was tested in Scotland and will go into use in France in the near future.

Avalanche dynamics

(H. Gubler, M. Hiller and B. Salm, FISAR)

The project to measure flow speeds, flow heights and slope-perpendicular flow speed profiles of artificially released dense flow avalanches using microwave radar is continued. A Doppler radar at 36 GHz is ready for use to measure particle speeds in snowdust clouds. A fixed Doppler radar has been installed in an avalanche track in Austria in collaboration with the Institute für Lawinenkunde, Innsbruck, Austria. Software for easier application of the Swiss guidelines for estimating runout distance, flow speed and flow height based on the Voellmy–Salm model is available for users.

Dynamics of powder-snow avalanches

(F. Hermann, FISAR/VAW, D. Issler, FISAR, S. Keller, VAW, and B. Salm, FISAR)
Powder-snow avalanches are modelled experimentally in a large water tank using small polystyrene particles whose speeds and concentration are recorded by an ultrasonic Doppler apparatus allowing for calculation of local dynamic pressure. Channelled flow has been measured in the track as well as in the runout zone. A series of measurements with unchannelled runout and in a terrain model of an actual powder-snow avalanche track in the Swiss Alps are being carried out. The earlier results are used for testing various theoretical models under development, ranging from quasi one-dimensional approaches to three-dimensional two-phase flows that fully describe local properties and take deposition and erosion of snow into account. Later on, the results of simulations of real powder-snow avalanches will be used to set guidelines for avalanche zoning in Switzerland and to evaluate simplified numerical models that can be applied by users.

Loading and foundation of avalanche defence structures

(S. Margreth, M. Hiller and G. Klausegger, FISAR)
In order to check the design criteria for avalanche defence supporting structures, snow loads on different types of structures (bridges and nets) are measured continuously. Measured stresses are compared with results of finite element calculations. The bearing capacity of anchors and micropiles under artificial loading is measured and analyzed to aid in the improvement of the foundations of avalanche defence structures.

FROZEN GROUND

Monitoring Alpine permafrost evolution

(W. Haeberli, M. Hoelzle, F. Keller, W. Schmid, D. Vonder Mühll, S. Wagner, VAW; M. Monbaron, G. Tenthorey, GGUF; K. Budmiger, B. Krummenacher, GGUB)
Efforts have continued to install and maintain a measurement network for monitoring the long-term evolution of permafrost in the Swiss Alps with regard to on-going and potential future warming trends. Methods applied include aerial photogrammetry of creeping permafrost within selected rock glaciers, temperature and deformation measurements in boreholes, data archiving from geophysical surface soundings and analysis of specially flown small-scale infrared photography. As a consequence of the exceptionally warm late 1980s, near-surface permafrost temperatures seem now to be rising at rates close to 1°C per decade (Murtèl borehole) and rates of thaw settlement have more than doubled since the 1970s (Gruben rock glacier).

Permafrost and glaciers in the Upper Engadin 1850–1990–2050

(M. Hoelzle and W. Haeberli, VAW)
Simple algorithms to parameterize glaciers (thickness, flow reaction and response times, past balances and length changes, bed characteristics, etc.) are developed on the basis of inventory data. In addition, a great number of BTS soundings were made in the investigated region. The BTS measurements are a good representation of the permafrost distribution and permit statistical analysis of large samples of point information. A key is being developed for predicting the distribution of Alpine permafrost as a function of mean annual air temperature and direct solar radiation. The aim of the study is to model the effects on Alpine permafrost and glaciers with various scenarios of potential future warming.

Rock glacier geophysics

(D. Vonder Mühll and W. Haeberli, VAW)
The physical parameters of three active rock glaciers, (Murtèl, Maragl I, Suvretta) in the upper Engadin, Swiss Alps, are investigated using several geophysical methods. Seismic refraction typically shows a three-layer case with a near-surface refractor (3500–4000 m s^{-1}) representing the ice-bearing permafrost underneath a shallow active layer, and bedrock (5000 m s^{-1}) at greater depth. D.C. geo-electrical soundings prove the presence of a layer with several tens to hundreds of kΩm indicating ice-rich permafrost. Gravimetric measurements on rock glacier Murtèl revealed a Bouguer anomaly of about 1.0–1.5 m gal corresponding to an approximately 20 m thick body with a density of 1.0 g cm^{-3}. Radio-echo sounding on rock glacier Murtèl showed weak reflections from internal inhomogeneities. Very low frequency resistivity (VLF-R) measurements were performed on rock glacier Muragl I in order to test the capability of this method in mountain permfrost areas.

Permafrost, hydrology and the glacier–permafrost connection

(E. Gerber, G. Tenthorey and M. Monbaron, GGUF)
Water flow in the rock glacier area of Val de Réchy is being investigated using tracer experiments, precipitation and runoff measurements, as well as geophysical soundings. In the Pas de Lona, a region adjacent to Val de Réchy, the structure and hydrology of glacitectonically deformed permafrost (push-moraines) is being investigated in order to acquire information about the connection between 19th century glaciation and permafrost. Seismic refraction sounding, electrical resistivity soundings and BTS measurements were performed in addition to tracer experiments and hydrochemical analyses of spring water.

Intra- and subpermafrost groundwater in rock glaciers

(D. Wonder Mühll and Ch. Speck, VAW)
Seasonal temperature variations at about 55 m depth within the permafrost of rock glacier Murtél indicate intrapermafrost groundwater flow and are measured in order to investigate effects on the temperature profile. Rock glacier Suvretta dams up the valley river which passes underneath the active rock glacier front. Salt tracer measurements showed that travel time is about 25 minutes for the 170 m wide rock glacier. Water temperature is thereby cooled down by several tenths of a degree.

Pilot permafrost/glacier map of the Upper Engadin

(F. Keller, W. Haeberli, M. Hoelzle, D. Vonder Mühll, VAW; M. Maisch, GGUZ)
The presumed distribution of mountain permafrost was plotted on sheet No. 1257 St. Moritz of the 1 : 25 000 federal topographical map using the application "PERMAKART" of the glaciological information system

KRYO on ARC/INFO. Results of fieldwork since 1970 and surface analyses based on a digital terrain model formed the basis for the computation. A new periglacial coverage containing historical, Holocene and Late Glacial moraines is currently being created and debris flows were systematically mapped from specially flown small-scale infrared aerial photographs. It is planned to combine this information with the already existing inventory of rock glaciers and push moraines of the region.

Fossil rock glaciers in the western Swiss pre-Alps

(Ph. Schoeneich, GGUL)
Fossil rock glaciers and incipient creep features have been recognized at different altitudes and expositions in the western Swiss Alps. Interpretation is made by means of a permafrost distribution model of the VAW. This model enables the classification of the fossil landforms into three generations and the calculation for each group of a "permafrost boundary depression". Dating of the two last generations of rock glaciers is attempted by correlation with late-glacial stages, but remains highly uncertain. There are at least three to four generations of rock glaciers during the late-glacial period.

ICE CORE STUDIES

New core drilling planned in cold firn/ice of the Swiss Alps

(H. Gäggeler, PSI; B. Stauffer, KUP; various members of VAW)
The goal of the planned core-drilling programme on high altitude Swiss glaciers is to investigate correlations between climate and atmospheric composition during the past 1000 years. A first core should allow investigation of the past 200 years with a detailed resolution (seasonal cycles), and second core should cover the past 1000 years with a reduced resolution. Analayses on the ice-cores cover in particular the concentration of CH_4, of reactive components like H_2O_2, H_2CO and of impurities bound to aerosols such as sulphate and nitrate. As a first step, site evaluation is being carried out in the Colle Gnifetti/Monte Rosa area and on other high altitude summits with a workshop taking place on this subject at the VAW in autumn 1992.

Chemical studies on snow-pit samples from Fiescherhorn Plateau and from Jungfraujoch

(M. Schwikowski, U. Baltensperger, H. Gäggeler, PSI; U. Schotterer, KUP)
The seasonal pattern of deposition rates of aerosol-borne chemical components SO_4^{2-}, NO_3^-, NH_4^+, K^+, Na^+, Ca^{2+}, Mg^{2+} was studied at the two nearby locations, Fiescherhorn Plateau (3920 m a.s.l.) and Jungfraujoch (3450 m a.s.l.). Intercalibration of the deposition pattern between both snow pits was achieved by $^{18}O/^{16}O$ measurements. For identical precipitation events similar concentration of the chemical species between both places was found. However, large fluctuations of the concentrations were observed for different meteorological conditions during snowfall.

Ice-core drilling in Greenland

(B. Stauffer, H. Oeschger and J. Schwander, KUP)
A group from the University of Berne is participating in the "Greenland Ice Core Project" (GRIP), an international project under the auspices of the European Science Foundation with eight nations participating. The goal is to drill through the ice sheet to bedrock at Summit in central Greenland (72°35′ N, 37°38′ W) and to analyse the ice core in order to reconstruct the history of climate and earth system processes of the past 200 000 years.

History of atmospheric composition

(J. Schwander, M. Anklin, Th. Blunier and B. Stauffer, KUP)
The CO_2 and CH_4 concentrations in air extracted from ice samples have been measured on a 300 m long ice core from central Greenland, drilled in 1989 within the framework of the project EUROCORE. The age of the gas enclosed in bubbles covers approximately the last 1000 years. The CO_2 results confirm the development of the anthropogenic increase during the past 200 years, found already in ice cores from Antarctica. In the preceding centuries the concentration shows minor variations between 280 ppm and 290 ppm. The anthropogenic increase of the CH_4 is also confirmed but variations before that increase are more pronounced. They range between 690 ppb and 750 ppb. Both measurements have been carried out in collaboration with the Laboratoire de Glaciologie et de Géophysique de l'Environnement at Grenoble. The results from the two laboratories accord well.

New extraction system for gases from ice cores

(A. Fuchs, J. Schwander and B. Stauffer, KUP)
A new system has been constructed and tested which allows the extraction of gases from air bubbles in ice without melting it. The ice sample of up to 20 g is crushed in a sealed container by a milling cutter and the gas escaping from the opened bubbles is flushed with helium to a Propopak column where it is stored until its injection into the gas chromatograph. To avoid any contamination with CH_4 produced by friction in the gear section, a helium-flushed rotary feed-through is used. CH_4 analysis on ice samples of about 10 g from the last 1000 years give precise and reproducible results. It is planned for the future to measure the CO_2 and N_2O concentration on the same sample as well.

Stable isotopes of air constitutions trapped in the bubbles of cold ice

(M. Leuenberger, A. Fuchs and U. Siegenthaler, KUP)
The air trapped in an ice sample is extracted by opening the bubbles with a milling cutter in vacuum and separately collecting CO_2 and the rest of the air, both cryogenically. Stable isotope ratios are measured on CO_2 ($^{13}C/^{12}C$, $^{18}O/^{16}O$), O_2 ($^{18}O/^{16}O$) and N_2 ($^{15}N/^{14}N$) by mass spectrometry. The $^{13}C/^{12}C$ ratios of CO_2 yield information on the cause of the lower Ice Age CO_2 concentration. The $^{18}O/^{16}O$ ratios of O_2 varied approximately in parallel to the isotopic compositions of ocean water and therefore yields information on global ice volume and thus also on sea-level changes. There is a gravitational enrichment of the heavy gas components in the firn before close-off of the air bubbles, which is measured by analysing the isotopic composition of N_2.

Measurements of ^{10}Be and ^{36}Cl on polar ice

(J. Beer, UP EAWAG; H. Oeschger and collaborators, KUP; W. Wölfli and collaborators, IMP)

The measurements of ^{10}Be and ^{36}Cl on polar ice cores have been continued. Within the framework of the GRIP project, a large number of ^{10}Be and ^{36}Cl samples have been collected in the field using a newly developed ion exchange technique. A search for two distinct ^{10}Be peaks which can serve as time markers to synchronise the two hemispheres has been carried out. Two peaks of unknown origin were discovered by Yiou and Raisbeck in the Vostok (Antarctica) core at approximately 35 and 60 Ka BP. Clear evidence was found for the 35 Ka peak in the Byrd (Antarctica) and the Camp Century (Greenland) core but no indication for the 60 Ka peak in any of the two cores.

Measurements of H_2O_2, HCHO, NH_4^+ and Ca^{++} on ice cores

(K. Fuhrer, M. Anklin and A. Neftel, KUP)

Concentration measurements based on a "Continuous Flow Injection Analysis" (CFIA) have been further improved. It is now possible to melt continuously ice strips of a cross-section of 18 mm and to measure in the meltwater simultaneously the H_2O_2, NH_4^+, Ca^{++} and HCHO concentration. Results allow the identification of seasonal cycles and, therefore, the counting of annual layers for the last 13000 years. High peak values of the NH_4^+ concentration are assumed to be caused by plumes from biomass burning events (e.g. large forest fires).

Ice-core drilling in western Mongolia

(U. Schotterer, KUP and K. Frölich, IAEA)

Within the framework of an IAEA technical cooperation programme, shallow boreholes were drilled in a cold glacier on top of Tsast Ula (–18°C at 10 m depth/4200 m a.s.l.; 49° N, 90° E). The goal was to reconstruct the fallout from nuclear bomb testing, the mountain being situated in the vicinity of the Chinese and Russian test sites, as well as to determine climatological parameters relevant to the hydrological cycle. The ice cores cover the time interval of the past 20 years. The mean accumulation rate is 25 cm water equivalent per year and the deuterium excess shows seasonal variations.

SNOW AND ICE CLIMATOLOGY/HYDROLOGY

Energy and mass balance during the melt season at equilibrium line altitude Paakitsoq, Greenland ice sheet (60°35′25.3″ N, 40°17′44.1″ W, 1175 m a.s.l.)

(A. Ohmura and H. Blatter, GGEZ)

A major experimental project is being carried out in order to study the climatology of the ice sheet and its reaction to climatic changes, to investigate the energy and mass fluxes in the snow layer and at the surface, to assess the local meteorological conditions in relation to the synoptic-scale meteorological situation, to provide a parametrization of subgrid phenomena in the surface boundary layer and the planetary boundary layer for numerical climate modelling, and to derive an energy balance related parametrization of the surface boundary conditions for numerical ice-sheet modelling. The objectives of the field experiments are: (1) to measure all components of the energy flux and the mass balance above, at and below the ice surface during the melt season at the average equilibrium line altitude on the Greenland ice sheet in the middle portion of the ice sheet; (2) to sound the structure of the planetary boundary layer and the free atmosphere above the ice sheet; (3) to provide accurate radiation data as a ground truth for the satellite radiometry (with NASA) for mapping short-wave and long-wave incoming radiation and albedo for the entire ice sheet.

Energy–water–mass balance and glacier discharge modelling in the Tien Shan

(E. Kang, H. Lang and A. Ohmura, GGEZ)

The energy, water and mass balances of a Tien Shan glacierized basin are investigated. A glacier melt model is developed by means of parametrized energy fluxes and the standard meteorological elements. The snow/water equivalent is simulated by separation of precipitation form based on the temperature criteria and daily temperature course. The daily net water input to a glacierized basin is calculated during the glacier ablation season and transformed into discharge at the basin outlet by a runoff transformation tank model. Finally, a general Tien Shan glacier melt and discharge model is being developed and tested.

Change of Alpine climate and glacier water resources

(J. Chen and A. Ohmura, GGEZ)

The aim of the work was to understand the changes in Alpine glacier water resources during the period of the 1870s–1970s and the consequent influences on the hydrological characteristics of glacierized basins. It was statistically demonstrated that short-term discharge fluctuations are effectively regulated by changes in climatic elements, while the long-term variations are rather strongly affected by the change in the dimensions of glaciers.

Snow precipitation

(F. Blumer and H. Lang, GGEZ)

Four locations were selected to investigate precipitation intensities in their relation to altitude: two profiles in the Swiss Alps, and two in the Austrian Alps (there in cooperation with the Tirolean Water Power Association). At each profile, four to six recording weighing precipitation gauges were installed at elevations from the valley up to approximately 3000 m a.s.l. At one very exposed location in the Obertoggenburg area near Wildhaus, Switzerland, a second precipitation gauge was installed within a double fence. This measurement set-up will allow a more realistic assessment of the atmospheric precipitation for rain and particularly for snowfall. Without an efficient wind shield like the double fence there is hardly any possibility of obtaining useful data, as deficits can reach 50% and more. Together with the analysis of the atmospheric synoptic processes, the study should lead to a better understanding of precipitation increase with altitude in the Alps.

Water balance of Alpine regions

(L. Braun, H. Müller, GGEZ; M. Aellen, VAW)
Investigations concerning the climate, glacier mass balance and runoff in the Glarnese Alps are undertaken using long series of accumulation and ablation measurements on the Cariden Firn (1914–90). As a first step, homogenisation of precipitation (storage gauge) measurements and the glacier mass balance measurements have been completed. In a second step, a conceptual precipitation-runoff model is applied and the main components of the water balance such as basin precipitation, evaporation, snow accumulation and ablation, glacier mass balance and discharge are simulated, based on data from the standard meteorological network. The long measurement series are then used as an additional basis for the verification of the model.

Discharge forecasts from Alpine regions

(M. Rohrer, U. Steinegger, H. Jensen and H. Lang, GGEZ)
In cooperation with various hydroelectric power companies attempts are made to further develop short- and long-range forecasting of discharge. For this purpose, measurements as well as simulations of snow-water equivalent based on standard meterological variables with high temporal resolution are used.

Snow and glacier hydrology in Nepal

(L. Braun, M. Rohrer, U. Steinegger and G. Kappenberger, GGEZ)
In a joint research project with the Technical Cooperation Agency of Germany, a conceptual runoff model is being applied in various head watersheds in Nepal, and a snow and glacier measuring programme is evaluated. Special emphasis is put on snow accumulation studies at higher elevations.

GLACIAL GEOLOGY/ PALEOGLACIOLOGY

Glacier extent 1850 and glacier changes since the end of the Little Ice Age

(M. Maisch, GGUZ)
An inventory-like documentation of the 1850 glacier advance was completed by the Grisons and adjacent regions of Austria and Italy in order to analyse the former dimensions and the pattern of the glaciological changes since the middle of the last century. Losses in area and volume as well as changes in equilibrium line altitude were determined. The data sets are being used to estimate potential future ice retreat caused by global warming trends. The results show very impressively that the glaciers in the Grisons, and probably also elsewhere in the Alps, would be shrinking and disappearing very quickly. It is also shown how, as soon as the first third of the coming century (ELA scenarios between +100 m to +300 m), only 25% of the present glacier area would be remaining. With an expected temperature rise of about +3°C, only 10% of the present glacier area would be left after the first half of the 21st century, due to significant acceleration in the process of ice wastage. The study outlines the importance of glaciers as climatic indicators and as key parameters to forecast the consequences of atmospheric warming upon the very sensitive glacial and periglacial environments. It is planned to expand the inventory and to include the glaciers in the western parts of the Swiss Alps as well.

Early and middle Holocene glacier fluctuations in the Alps

(C. A. Burga, GGUZ and G. Orombelli, Istituto di Geologia, Milano)
Interaction between glacier fluctuations and vegetation change were investigated by means of pollen analysis in a profile near the actual front of the Rutor Glacier, 2510 m (Aosta Valley, Italy), which provides some information about the early and mid-Holocene glacier extensions. The profile reflects a glycogenic phase during Preboreal–Boreal, a limnic phase at the transition Boreal/Older Atlantic transition, a telmatic-terrestric phase during the Older Atlantic, a glycogenic phase during the Younger Atlantic (moraine), a terrestric phase at the transition of Younger Atlantic/Subboreal (peat), and again a glycogenic phase during the Subboreal (moraine). The peat bog growth began in 6735 BP and ended in 6055 BP. During the Younger Atlantic the peat bog was covered by the glacier. It is planned to do more detailed sediment analyses of several new profiles of the present glacier forefield.

Derivation of precipitation and temperature conditions from late Pleistocene glaciers of the Swiss Alps

(S. Bader, GGUZ)
On the basis of the reconstructed late Pleistocene glaciers, precipitation and temperature of the past are estimated. The geometry of disappeared glaciers is obtained from the analysis of the glacial morphology within the investigated area. Mass balance gradients and equilibrium line altitudes of the reconstructed glaciers were calculated and precipitation and temperature conditions derived. The model is applied to a few Alpine glaciers of the Younger Dryas which can be well reconstructed. The estimated climatic data correspond well with the results of other methodical approaches. On the other hand, calculated equilibrium line altitudes are 100 to 200 m lower than found so far.

The Rhine/Linth Glacier in the Upper Wurm

(O. Keller and E. Kryass, GGUZ)
The Wurm Glaciation of the Alpine foreland has been reconstructed as a result of investigations in the Rhine/Bodan region as well as in the Linth area. The period of maximum ice extent is subdivided into four main periods: (1) the ice advance on to the piedmont basins, (2) the build-up of the foreland glaciation, (3) the maximum stage, and (4) the retreat into the inner Alps. The three main retreat states of the foreland glaciation (Feuerthalen, Stein am Rhein, Konstanz) are now completely mapped. Net balance curves and equilibrium line elevations were modelled.

Glacier history of Liefdefjord (79.5° N, Spitzbergen)

(G. Furrer, GGUZ)
Fossil plants and soils overridden by earlier glacier advances were excavated under moraines. *Salix polaris* seems to have been widespread in former tundra

ecosystems. Humose soil horizons (fAh-horizons) are being radio-carbon dated in view of past glacier and climate fluctuations.

Glacial isostasy and uplift rates in Switzerland

(H. Gudmundson, VAW)
The possible effect of the late Pleistocene deglaciation on recent uplift rates in Switzerland has been estimated. A thick elastic plate overlaying a viscous half space was used as a model of the lithosphere and the asthenosphere. A sensitivity analysis on the uplift rate as a function of the effective elastic thickness (EET) of the lithosphere and the viscosity of the mantle showed that there exists a range of reasonable EET and viscosity values that can give the observed uplifting as determined by repeated measurements of the Swiss first-order levelling net. The possibility must therefore be considered that the recent crustal movements in Switzerland are mainly a result of glacial isostasy.

Submitted by W. Haeberli

Abbreviations used in the text:

ETHZ	Swiss Federal Institute of Technology, Zurich
FISAR	Swiss Federal Institute for Snow and Avalanche Research, Weissfluhjoch-Davos
GK SANW	Glacier Commission, Swiss Academy of Sciences
GGEZ	Institute of Geography, ETHZ
GGUB	Institute of Geography, University of Berne
GGUF	Institute of Geography, University of Fribourg
GGUL	Institute of Geography, University of Lausanne
GGUZ	Institute of Geography, University of Zurich
IAEA	Isotope Hydrology Section, International Atomic Energy Agency, Vienna, Austria
IMP	Institute for Intermediate Energy Physics, ETHZ
KUP	Climate and Environment Project, Physics Institute, University of Berne
PSI	Paul Scherrer Institute, Würenlingen
SI	Institute of Statistics, ETHZ
UP/EAWAG Research	Environmental Physics, Swiss Federal Institute for Water and Water Pollution Control
VAW	Laboratory of Hydraulics, Hydrology and Glaciology, ETHZ

UK

ANTARCTIC GLACIOLOGY

Wilkins Ice Shelf

(D. G. Vaughan, C. S. M. Doake, BAS; D. R. Mantripp, MSSL; J. Sievers, Institut für Angewandte Geodäsie)
A synthesis of remote sensing data over Wilkins Ice Shelf has been completed. The combination of GEOSAT satellite altimetry, Landsat imagery, and airborne radio-echo sounding has revealed an unusual ice shelf regime relying almost exclusively on in situ snowfall. Wilkins Ice Shelf is thus likely to respond very rapidly to changes in both temperature and snowfall rates.

Ice/ocean measurements beneath Ronne Ice Shelf

(A. V. Robinson and K. Makinson, BAS)
A hot-water drill has been used to penetrate 541 m of ice on the flowline of Evans Ice Stream, 200 km from the ice front. Many conductivity/temperature/depth (CTD) profiles were recorded over a period of four days, and several water samples were retrieved. Thermistor cables were frozen into the hole to monitor the temperature of the water column, the ice/ocean interface, and the ice shelf itself. Temperature data are being recorded locally, and the ocean data are also being transmitted to the UK via a satellite link. The water column was about 350 m deep, with a temperature and salinity near the ice shelf base of −2.25°C and 34.58 ppt, and near the sea floor, −1.95°C and 34.70 ppt. Much variability in the water column has been recorded by both the sequence of CTD profiles and by the thermistor cables.

Sub-ice shelf oceanographic processes

(K. W. Nicholls and A. Jenkins, BAS)
A detailed analysis has been completed of oceanographic data and samples obtained beneath Ronne Ice Shelf at a site on the Rutford Ice Stream flowline in 1991. A well-mixed layer of Ice Shelf Water (ISW) immediately below the ice shelf is separated from a deeper layer of modified Western Shelf Water (WSW) by a weak pycnocline. The circulation has been modelled as a simple two layer system in which WSW is transformed into ISW by melting at the ice-shelf base. This picture of water mass transformation beneath the ice shelf is supported by isotopic analyses of water samples. Model results suggest a strong sensitivity to the temperatures of the WSW.

Radar absorption in polar ice sheets

(K. W. Nicholls, H. F. J. Corr, J. C. Moore, A. Jenkins, BAS; P. Huybrechts, AWI)
A model relating the electrical properties of ice both to its soluble impurity content and to its temperature has been used in a study of the radar absorption properties of polar ice sheets. Specific cases include the interpretation of radar echo strengths above a sub-glacial lake near Vostok, Antarctica, to infer the presence of a basal layer of stagnant ice; and the use of radar absorption measurements from the southern end of George VI Ice Shelf, Antarctica, to predict the concentration of soluble impurities in the ice column there. Maps of total radar absorption have been produced for the Antarctic and Greenland ice sheets.

Contribution of Antarctic Peninsula ice to sea-level change

(E. M. Morris, D. A. Peel, R. C. A. Hindmarsh, D. G. Vaughan, W. Connolley and R. M. Frolich, BAS)

A team from BAS has contributed to the European Community project on Climate Change, Sea Level Rise and Associated Impacts in Europe by investigating the effect of climate warming on ice in the Antarctic Peninsula region. Work so far has established an improved estimate for the present mass balance of Antarctica and has refined methods for estimating mass balance changes in the future. The Robin relation between precipitation and temperature has been shown to apply over most of the Antarctic Peninsula where the mean annual temperature is less than −11°C. In the warmer areas, potential ablation has been estimated initially by analogy with glaciated areas in other parts of the world. However, in the 1992/93 field season, mass and energy budget studies will begin on Uranus Glacier near Fossil Bluff.

Radio-echo sounding database

(D. G. Vaughan, BAS)

BAS and SPRI have now combined their digitized airborne radio-echo sounding data. The resulting database is held at BAS and is managed by Vaughan. The data covers all campaigns by BAS and the SPRI/TUD/NSF consortium. Vaughan will be happy to meet requests by researchers for small amounts of data. It is hoped that larger requests will form the basis of collaborative projects.

MODELLING

Theoretical studies of marine ice sheets

(R. C. A. Hindmarsh, BAS)

Two types of marine ice sheets have been studied: (i) where the basal traction at the grounding line shows an abrupt change, and the sheet–shelf transition may be represented through jump conditions; and (ii) where the basal traction over the sheet–stream–shelf transition shows a smooth change. Progress has been made in conceptualising the flow in terms of rheological layers, each characterised by a Stokes number and with the basal resistance characterised by a slowly varying basal traction number. This permits systematic simplification of the mechanics, showing that several earlier and apparently different models are (asymptotically) equivalent and correct under certain conditions.

Modelling of Rutford Ice Stream, Antarctica

(R. M. Frolich, BAS)

The dynamics of Rutford Ice Stream have been investigated using control methods to infer, from observations made at the ice surface, conditions at the unobserved ice stream base and side walls. These results are guiding seismic and radio-echo sounding field studies of the ice stream. The remote sensing fieldwork will allow existing models to be calibrated and lead to the testing of competing theories of how ice streams are able to flow much faster than the surrounding ice sheet.

Numerical modelling of the Svalbard–Barents Sea ice sheet

(M. J. Siegert, SPRI)

A time-dependent ice-sheet model is being used to determine the response of the Svalbard–Barents Sea ice sheet during the last glaciation to various climatic and dynamic inputs. The results are compared against the existing palaeoceanographic and geological records in an attempt to find the most likely glacial scenario in terms of the date of the glacial onset, the maximum ice-sheet extent and dynamics, and the timing of deglaciation. The behaviour of the ice sheet in the presence of a deforming bed is also being examined. An early Cenozoic glacial run is planned to test the possibility of massive ice-sheet induced bedrock erosion that may have helped to cause the present Barents Sea bedrock elevation to be below sea-level.

Numerical modelling of the last Scandinavian ice sheet

(N. Arnold, M. Tulley, M. Sharp; GUC)

Work to date has focused on development of ice-sheet models which allow investigation of the influence of glacier hydrology on the response of the last Scandinavian ice sheet to environmental forcing, and of the erosional impact of the ice sheet. A one-dimensional version of the model (Arnold and Sharp, 1992, *J. Quatern. Sci.*, **7**, 109–124), which incorporated consideration of the likely configuration of the subglacial drainage system, has now been generalised to two dimensions, and will be used to investigate the evolution of the pattern of subglacial water flow throughout the last climatic cycle. A glacial erosion model has also been developed, and will be used to investigate the spatio-temporal pattern of erosion beneath the ice sheet over a glacial cycle, together with the influence of bed erosion on the response of the ice sheet to external forcing.

Modelling the mass balance of north-west Spitsbergen glaciers and their response to climate change

(K. M. Fleming, J. A. Dowdeswell, SPRI; J. Oerlemans, University of Utrecht)

Spitsbergen is particularly sensitive to climate change due to its position at the northern extremity of the strong poleward transfer of heat through the Norwegian Sea. An energy balance model is used to calculate mass balance and equilibrium line altitudes on two north-west Spitsbergen glaciers, both of which presently have negative mass balances. The energy balance model takes meteorological data (temperature, precipitation, humidity and cloudiness), ice-mass area distribution with altitude, and solar radiation as inputs. Glacier surface albedo is generated internally. Mean daily meteorological data from a nearby weather station, adjusted for altitude, are used to model modern mass balance. Average net balance modelled for 1980–89 is −0.35 m water equivalent for Broggerbreen and −0.28 m for Lovenbreen. This compares with mean observed values of −0.47 and −0.39 m, respectively. Calculated equilibrium-line altitudes for the two glaciers vary by < 13% from observed values. Sensitivity tests on glacier response to greenhouse warming predict a net balance of $-0.7\,\mathrm{m\,a^{-1}}$ per degree of temperature rise relative to the present, and a rise in equilibrium line of 100 m per degree. Modelling Little Ice Age conditions in Spitsbergen suggests that a 0.5°C cooling or a precipitation increase of 23% would result in a zero net mass balance for Broggerbreen, and that further cooling would result in an increase in net balance of $0.35\,\mathrm{m\,a^{-1}}$ per degree.

Seasonal and spatial patterns in the surface energy balance of valley glaciers

(I. C. Willis, M. J. Sharp, B. W. Brock, GUC)

In September 1992, a three-year programme was initiated to investigate how temporal and spatial variations in glacier surface conditions (particularly albedo and surface roughness) influence the net radiation and turbulent flux components of the energy balance. An automatic weather station has been set up in front of the Haut Glacier d'Arolla, Valais, Switzerland, to run for three years. Additionally, an extensive glacier-wide survey of surface albedo and roughness was undertaken and these measurements have been used to produce maps of late-summer albedo and roughness variations across the glacier. Maps based on measurements to be made over the next two years will enable parameterisations to be developed for albedo and surface roughness in terms of the seasonal evolution of parameters such as accumulated melt, dust cover, snow depth and water content, ice structure and crystal size. The weather station data and glacier surface parameterisations will then be used to structure and crystal size. The weather station data and glacier surface parameterisations will then be used to predict glacier melt using a previously developed distributed energy balance model.

SURGE-TYPE GLACIERS

Structure and dynamics of a quiescent-phase surge-type glacier in Spitsbergen

(R. Hodgkins, SPRI)

In summer 1992 field investigations were conducted at a Svalbard surge-type glacier in mid-quiescence. These included repetitive surveying to determine horizontal and vertical ice velocity and strain, glacier long profiles and ablation, continuous monitoring of proglacial stream discharge and suspended sediment concentration, and mapping of glacier structure. A further field season will take place in 1993. The aim of this work is to characterize the quiescent-phase development of the glacier in contrast with temperate examples.

Tectonic processes in Svalbard surge-type glaciers: evidence from structural glaciology

(R. Hodgkins and J. A. Dowdeswell, SPRI)

Distinctive ice structures and tectonic processes are associated with the rapid down-glacier transfer of mass during a surge. Previous work has shown that deformation takes the form of a propagating strain wave, in which longitudinal compression is progressively replaced by longitudinal extension. Aerial photograph time series of Svalbard surge-type glaciers in the active phase are used to obtain tectonic information. The orientation of crevasses formed during rapid flow is used to indicate the directions of principal strain, and therefore tectonic regime. Tectonic profiles constructed by this method are in good agreement with observational evidence from Variegated Glacier, Alaska. This method is applied to a number of Svalbard glaciers in order to investigate their tectonic behaviour. The palaeotectonic regime of a quiescent-phase surge-type glacier in Svalbard is also considered on the basis of structural mapping in the field. Although Svalbard glaciers possess distinctive thermal and hydraulic regimes and mass balance gradients, the propagating strain wave tectonic model of glacier surges generally appears to be applicable to the examples analyzed here. Some extra consideration is required of cases where there is advance of the glacier terminus, although this can be accommodated within the same model. However, rapid advance of Svalbard tidewater glacier termini during the active phase requires modification of the model, and is contrasted with the steady, cyclic advance of temperate tidewater glaciers. A descriptive model of the temporal development of tectonic zones in a tidewater surge-type glacier, in which the active phase is divided into two stages, is outlined.

GLACIER HYDROLOGY

Water storage, drainage evolution and water quality in Alpine glacial environments

(M. Sharp, I. Willis, B. Hubbard, M. Nielsen, G. Brown, P. Nienow, GUC; M. Tranter, Department of Geography, University of Bristol; C. Smart, Department of Geography, University of Western Ontario; J. M. Bonvin, Grande Dixene S.A., Sion)

A three year programme designed to investigate the links between the seasonal evolution of glacier drainage systems, the temporal pattern of englacial water storage and the nature of subglacial weathering environments was initiated at the Haut Glacier d'Arolla, Switzerland in the summer of 1992. The programme involves (i) hot water drilling a dense network of boreholes in an area affected by seasonal conduit growth to monitor the effects of this process on subglacial piezometry, and on the temperature and quality of water entering boreholes from below, (ii) measurement of electrical conductivity profiles in boreholes to document the sources of waters responsible for changes in borehole water levels, (iii) sampling of borehole waters for detailed chemical analysis (major cations, anions, pH, alkalinity and dissolved oxygen) and comparison with the chemistry of bulk meltwaters leaving the glacier portal and of supraglacial waters as sampled throughout a full melt season, (iv) borehole and moulin dye-tracer experiments to characterise different elements of the subglacial drainage system and their evolution over time, (v) a study of glacier water balance over a full annual cycle, including an attempt to disaggregate supraglacial and englacial storage elements, and (vi) detailed monitoring of the quantity/quality characteristics of bulk runoff. A network of 22 boreholes was drilled in 1992, and has been instrumented for the 1992–93 winter. Seven of these holes connected to major low-pressure drainage axis, the position of which had been accurately predicted from modelling of the form of the subglacial hydraulic potential surface on the basis of ice thickness measurements made by radio-echo sounding. These holes showed significant diurnal and longer term fluctuations in water level, changes which indicated some lateral shifting of the major drainage channel. Conductivity profiling proved an effective means of determining whether holes were fed from above (by dilute supraglacial waters) or below (by solute-rich basal waters), and also made it possible to identify well-defined englacial inputs. Chemical analysis of waters collected in 1992 will be carried out over the 1992–3 winter, along with analyses of all snowfall events that occur at Arolla during that winter.

Spatially-distributed water balance of Small River Glacier, British Columbia

(M. Sharp, I. Willis, B. Hubbard, M. Nielsen, S. Lane, GUC; C. Smart, Department of Geography, University of Western Ontario)

The accumulation and ablation areas of Small River Glacier, British Columbia, have discrete drainage systems. The accumulation area drains through a karst aquifer, while the ablation area drains over predominantly impermeable shale bedrock at the glacier bed. This unique drainage configuration permits separate study of summer water storage processes in the two parts of the glacier. Water inputs are determined using measured rainfall, and melt calculated using a spatially distributed model of the glacier surface energy balance driven by data on solar radiation, air temperature, relative humidity and wind-speed collected a two sites within the catchment. The model is applied to a digital terrain model of the glacier catchment constructed from ground survey measurements and analyses of terrestrial oblique stereo-photogrammetry. Performance of the model is evaluated by comparison of outputs with bi-weekly ablation and snowpack depth measurements made at a network of 24 stakes distributed along a transect up the glacier. Water outputs are determined by gauging of the major streams draining the glacier and the major karst springs. Drainage catchments for each water source are determined by dye tracer methods. The results permit calculation of the hourly pattern of water storage change in each of the sub-catchments throughout the six week study period.

Solute provenance and transport pathways in the Small River Glacier catchment, B.C.

(G. H. Brown, GUC; C. C. Smart, University of Western Ontario)

A preliminary study of Alpine chemoglacial weathering conditions and solute provenance on carbonate bedrock was undertaken in the summer of 1992. Sampling was conducted at the Small River Glacier, British Columbia, where two discrete drainage systems co-exist. The glacier tongue, underlain predominantly by an impermeable shale lithology, drains to a proglacial stream. In contrast, water inputs to the accumulation area re-routed through a karst aquifer and discharged some distance down-valley from springs. Sampling of waters for major cations, anions, pH, alkalinity, and dissolved oxygen was conducted to establish short-term (diurnal) solute-discharge relations at the major outflows from the two drainage systems, in addition to twice daily sampling of the proglacial stream during July, and a spatial survey of water quality characteristics throughout the catchment.

GLACIER GEOCHEMISTRY

Heavy metals in snow

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

Samples collected around Halley Station have shown that the station may affect the concentrations of some metals, including lead, up to a distance of 10 km. This imposes limits for the location of other studies of metals in snow, and indeed in aerosol. Samples have also been analysed from a snow pit covering two years' accumulation on Dolleman Island, Antarctic Peninsula. Lead appears to peak in the autumn/winter period, when crustal and marine elements also show maxima.

Halley snowfall

(E. W. Wolff and R. Mulvaney, BAS)

A programme to collect the snow surface daily at Halley has been continued, and over two years' samples will soon be available. The earlier samples have now been analysed, and the data will be compared with daily aerosol collections and with records of meteorological conditions.

Ice core analysis

(D. A. Peel, G. F. J. Coulson, E. C. Pasteur, R. Mulvaney, BAS; C. Chenery, NERC Isotope Geosciences Laboratory)

Analytical work on the Dolleman Island ice core, which was drilled in 1986, is almost finished. High-resolution oxygen isotope analysis has now been carried out along the whole 133 m core, and parallel analyses for deuterium are underway. A provisional date of 1651 AD has been assigned to the bottom of the core. Decadal averages of the Dolleman Island isotopic record have been compared with a range of other data. An apparently anomalously warm period in the period 1820–80 AD during the final stages of the Little Ice Age and evidence for rapid increases during the past two decades are evident at Dolleman Island. The sectioning and sub-sampling of the 104 m Dyer Plateau ice core, collected in 1989, has been completed. In comparison with the Dolleman Island core, much lower concentrations of soluble ions are found, reflecting the greater altitude of the Dyer Plateau site, and the increased distance from open sea water.

Greenland Ice Core Project

(K. Makinson, J. C. Moore, D. A. Peel and E. W. Wolff, BAS)

GRIP is a multi-national project, carried out by eight European countries under the auspices of the European Science Foundation (ESF) to drill an ice core to bedrock at Summit in central Greenland. As the UK scientific contribution, the BAS dielectric profiler (DEP) has been used to obtain the dielectric properties of the core at 2 cm resolution all the way to bedrock. A new high-resolution instrument has also been used at resolutions better than 2 mm on many sections of core, which allows annual layers to be identified. Work is underway to link the profiles with chemical data.

SATELLITE REMOTE SENSING

Remote sensing of Rutford Ice Stream

(A. M. Smith, H. F. J. Corr and C. S. M. Doake, BAS)

Seismic and radar soundings have been undertaken both downstream and upstream of the grounding line on Rutford Ice Stream. On the floating portion at the mouth of the ice stream, seismically determined sea-bed depths showed that there was a deepened area close to the Ellsworth Mountain side, reaching depths of 2000 m below sea level. Radio-echo polarisation studies were carried out at several sites to examine the development of ice crystal fabric in a shear zone. Upstream from the grounding line, single fold seismic reflection lines totalling 14 km were obtained. Shallow refraction lines were obtained in different areas with surface strain-rate fields ranging from overall compression to overall extension to investigate firnification processes. High resolution radar sounding was also carried out along the seismic lines and diffraction patterns from bottom reflectors were measured near a subglacial rise to investigate the sliding of the ice as it flowed up a basal hill.

ERS-1 SAR data for glaciological research

(G. J. Marshall, SPRI)
Investigations are continuing into the capability of ERS-1 C-bank SAR data to provide significant information for glaciological research. Several multi-temporal scenes of Nordenskiold Land, Spitsbergen, are being studied in conjunction with ground-truth measurements obtained on the glacier Ayerbreen during the summer of 1992. Parameters sampled in the field included both small-scale roughness, using close-range photogrammetry, and larger scale roughness of the order of several wavelengths. These data, together with information on snow liquid water content, density, temperature, and grain-size are being used to model changes in radar backscatter as the melt season progresses. In addition, the transient margins of the wet snow and ice facies on Ayerbreen were monitored to determine whether the SAR can identify these features and therefore provide an input for regional mass-balance studies. Further fieldwork will be undertaken in spring 1993, at the onset of the melt season.

Glaciological investigations of Franz Josef Land, Russian High Arctic

(J. A. Dowdeswell, M. R. Gorman, SPRI;
Yu. Ya. Macheret, A. Glazovsky, M. Moskalevsky, . Sinkevich, C. V. Smirnov, IGRAN)
Satellite imagery from Landsat (MSS, TM), ERS-1 synthetic aperture radar, and Russian KATE-200 instruments is being used to investigate several aspects of the glaciology of the archipelago of Franz Josef Land. The area of the islands that is ice covered has been mapped accurately from geometrically rectified Landsat TM images using ground-control points. The major ice caps of the islands have been subdivided into drainage basins, based on apparent shadowing on Landsat images. The production of tabular icebergs (up to 2.3 km long) from several ice caps has been recorded, as well as the relatively rapid retreat of several tidewater glacier termini. Synthetic aperture radar imagery is being used to define snow and ice facies and the spatial variation in these zones through the year. This remote-sensing work is a preliminary to airborne radio-echo sounding of the major ice masses in the archipelago, to be undertaken in spring 1994.

ERS-1 Synthetic Aperture Radar (SAR) studies of Austfonna, Nordaustlandet, Svalbard

(W. G. Rees, J. A. Dowdeswell, A. Diament, SPRI)
A times series of ERS-1 SAR imagery has been obtained for the Austfonna ice cap (8200 km^2), eastern Svalbard. These scenes cover winter, and the period of major melting from June through to September. Digital analysis of backscatter values show systematic changes associated with the progress of the melt season, linked to up-glacier migration of the snow-line and related facies. The development of a dense network of supraglacial streams and the failure of bridges over crevasses also affects the backscatter properties of bare ice surfaces low on the ice caps. The interpretation of SAR data from Nordaustlandet is assisted by the availability of existing datasets on, for example, ice-surface topography, the nature of the snow stratigraphy, and the position of the snow-line.

ERS-1 altimeter studies of ice sheets and ice shelves

(J. L. Bamber, J. Morley, J. K. Ridley, D. Mantripp, D. Wingham, J. Proud, MSSL)
ERS-1 altimeter data are being used to map, in detail, the topography and features of the Antarctic and Greenland ice sheets, and several ice shelves. A number of specific studies have been initiated. The data have been used to map the surface expression of the sub-glacial lake near Vostok station. This study is being extended to cover all detectable lakes. A collaborative project to map the Filchner–Ronne Ice Shelf (FRIS) using altimeter data is also underway. Waveform migration techniques are being employed to investigate areas of undulating topography and new methods for measuring mass balance are being developed. Two field campaigns on the FRIS were conducted in the 1991/92 field season with the objective of validating ERS-1 altimeter and Along Track Scanning Radiometer measurements of surface elevation, temperature and backscatter coefficient. Analysis of the field data and numerical modelling of the radar scattering properties of the firn are continuing.

Satellite investigations of sea ice

(S. Laxon, MSSL)
Work on sea-ice mapping at MSSL continues with comparisons of Geosat Radar Altimeter and SSM/I mapping of total ice extent. AVHRR imagery is being used to interpret differences. The performance of the ERS-1 radar altimeter over sea ice has also been assessed. Early data showed some problems in tracking over sea ice but this has since been improved following studies by MSSL for ESA. The ERS-1 altimeter fast delivery data have also been used on several occasions to provide operational ice maps in support of scientific cruises in the Southern Ocean. Data from the Topex-Poseidon radar altimeter has also shown a capability for ice-extent mapping, although observations are limited to latitudes below 66 degrees. Future work will involve investigation of ERS-1 radar altimeter waveform data over sea ice and will also look at data from the Along Track Scanning Radiometer (ATSR).

GLACIAL GEOLOGY

The origin of the supraglacial sediment system: a comparison between a surge and non-surge type subpolar glacier, Svalbard

(S. J. Wilson, SPRI)
The aim of the 1992 field season was to describe the spatial pattern of the supraglacial landform/sediment assemblages, at surge and non-surge type glaciers. The aims were achieved by field and laboratory analysis of moraine ridges, clast characteristics and in-situ geotechnical tests. These results will be linked to field and laboratory analysis of basal ice characteristics, which include the physical description of ice facies, debris contained in the facies and isotopic evolution. The analysis will determine the origin of the basal ice and subsequent formation of the supraglacial system. The results will assist in the construction of a conceptual model, which will be applied to other Svalbard subpolar surge type glaciers, and deposits in the Pleistocene record. Future analysis of aerial photographs is required to test the general applicability of the model.

Dynamic controls on moraine formation

(N. Spedding, A. J. Dugmore, Department of Geography, University of Edinburgh; M. P. Kirkbride, Department of Geography, University of Dundee)

The aim is to determine the dynamic controls on moraine formation, initially by testing the hypothesis that it is the degree of continentality, thorough its influence on the intensity of glacier activity, which determines the size, form and composition of moraines. Fieldwork in Iceland will taken advantage of the marked north–south climatic gradient across the island, together with the presence of identifiable, isochronous tephra layers within the glaciers. Further applications of tephrochronology in glaciology and glacial geomorphology are being developed for the rapid assessment of glacier flow, and as a means of bracketing the age of moraines. This is part of a wider programme of tephra research conducted in collaboration with G. Larsen of the Science Institute, University of Iceland, Reykjavik.

Iceberg scouring in Scoresby Sund and on the East Greenland continental shelf

(J. A. Dowdeswell, SPRI; H. Villinger, AWI; R. J. Whittington, UCW; P. Marienfeld, AWI)

Modern and relict scours produced by iceberg keels have been reported from a number of high latitude continental shelves in the Northern Hemisphere and Antarctica, but observations are largely absent from the East Greenland shelf. About 18 $km^3 a^{-1}$ of icebergs are calved into the Scoresby Sund fjord system, East Greenland. These icebergs have submarine keels with drafts up to 550 m. Modern iceberg contacts with the sea floor are inferred from calculated keel depths and stationary icebergs identified on sequential Landsat imagery. Acoustic profiles (Parasound, 3.5 kHz) of the sea floor show that scouring is a significant process in water depths < 550 m. Iceberg scouring intensity varies inversely with water depth. The most intense scouring occurs at depths of < 300-400 m. Iceberg scours were observed on over 25 000 km^2 of the East Greenland shelf, at 69–72° N and 75° N. Scours are being actively produced on the modern shelf, but relict scours probably dating back to the Late Weichselian are also present. The rate of iceberg production from Greenland Ice Sheet outlet glaciers, and iceberg drift tracks on the shelf, suggests that iceberg scouring is important over a significant proportion of the 500 000 km^2 area above the shelf break around Greenland.

The origin of massive diamicton facies by iceberg rafting and scouring, Scoresby Sund, East Greenland

(J. A. Dowdeswell, SPRI; R. J. Whittington, UCW; P. Marienfeld, AWI.)

Almost 90% of 39 m of core material recovered from Scoresby Sund and the adjacent East Greenland shelf is massive diamicton, interpreted to be formed predominantly by the release of iceberg-rafted debris and reworking by iceberg scouring. There is also likely to be a contribution from suspension settling of fines derived from glacifluvial sources. Model calculations suggest that the radiocarbon-derived Holocene sedimentation rate of 0.1–0.3 m/1000 a in Scoresby Sund can be accounted for largely by iceberg rafting of debris. Intensive iceberg scouring, which reworks sea-floor sediments, is observed on acoustic records from over 30 000 km^2 of the Scoresby Sund fjord system and the adjacent East Greenland shelf (69–72° N and 75° N). The relatively extensive modern occurrence of massive diamicton, formed by iceberg rafting and scouring, together with suspension settling of fines, suggests that it may also be a significant facies in the glacier-influenced geological record. The occurrence of the massive diamicton facies described above in the geological record may also be an indicator of the former presence of fast-flowing ice-sheet outlet glaciers.

Submitted by J. A. Dowdeswell

Abbreviations used in the text:

AWI: Alfred-Wegener-Institut, Bremerhaven
BAS: British Antarctic Survey, Cambridge
GUC: Department of Geography, University of Cambridge
IGRAN: Institute of Geology, Russian Academy of Sciences
SPRI: Scott Polar Research Institute, University of Cambridge
UCW: University College of Wales, Aberystwyth

USA - ALASKA

Abbreviations used in the text:
UAF: University of Alaska, Fairbanks, Alaska
USGS: U.S. Geological Survey
CRREL: U.S. Army Cold Regions Research and Engineering Laboratory
ADGGS: Alaska Division of Geological and Geophysical Surveys
JPL: Jet Propulsion Laboratory, Pasadena, California
USDA: U.S. Department of Agriculture

ALPINE GLACIERS

Benchmark monitoring of Gulkana Glacier

(R. S. March, USGS, Fairbanks, Alaska)

Long-term glacier/climate monitoring, begun in 1966, continues at Gulkana Glacier with regular measurements of air temperature, precipitation, glacier mass balance, glacier surface altitude, glacier flow, and stream discharge. Photogrammetric remapping of the Gulkana Glacier basin was begun in 1992. The original USGS map was made in 1954. In preparation for remapping the basin, survey net monuments were re-surveyed using a GPS and marked with paneling. The glacier surface altitude was surveyed at about 80 points along longitudinal and cross profiles as independent checks on the accuracy of the new map. The surface altitude survey duplicated similar surveys from 1985 and 1973 and will be used to determine the glacier volume change between those dates and 1992. The air photography window opened on 23 July but, unfortunately, poor weather prohibited acquisition of the mapping photos through 17 August, when new snow covered the entire glacier and all but one control point. The next opportunity to acquire the mapping photography will be the summer of 1993.

Knik Glacier and glacier dammed lake outbursts from Lake George

(R. S. March, USGS, Fairbanks, Alaska)
The 48 kilometer long Knik Glacier dammed the Knik River Gorge annually from 1918 to 1966. Outbursts from Lake George, which formed above the ice dam, were some or the largest floods in Alaskan history (up to $10\,200\,m^3\,s^{-1}$). The possibility of renewed outburst flooding is of significant economic concern due to construction of housing and roads in the flood plain. From 1979 through 1992 (except 1984 and 1991) annual glacier surface profiles and terminus position measurements have been made at Knik Glacier. Measurements in 1992 indicate that the terminus continues to retreat at a rate of $8\,m\,a^{-1}$ and the lower half of the ablation zone continues to thin at a rate of $1\,m\,a^{-1}$ suggesting a decrease in the potential for renewed outburst floods. However, the upper half of the ablation zone has changed little and the accumulation zone continues to thicken by about $0.4\,m\,a^{-1}$ indicating that outbursts continue to be a long-term threat.

Volcano-glacier interactions on Mount Wrangell

(C. Benson and G. Bender, Geophysical Institute, UAF, R. Motyka, ADGGS, Juneau, Alaska, and A. Follett, AeroMap U.S., Anchorage, Alaska)
Changes in the volume of ice and snow in the North Crater on the rim of the summit caldera of Mount Wrangell, Alaska are being measured by precision surveying and photogrammetry. Our measurement at the summit began in 1961 and the first vertical aerial photographs were taken in 1957; in 1992 we obtained our 20th annual set of vertical aerial photos. Detailed cross-sections at 20 m intervals across the crater allow us to determine ice volume changes. These are being interpreted in terms of possible mechanisms controlling the volcanic heat flux. Our results indicate that the Great Alaska Earthquake of 1964 initiated an order of magnitude increase in the heat flux at the summit.

Drift Glacier, Alaska: Alaska Volcano Observatory

(D. Trabant, USGS, Fairbanks, Alaska)
The Alaska Volcano Observatory has been supporting a study of the processes that resulted in the conversion of snow and ice into debris and flood flows during the 1989–90 eruptions of Redoubt Volcano and during the recent eruptions of Crater Peak on the flank of Mount Spurr. Both volcanoes are across Cook Inlet from Anchorage, Alaska. The eruptions of Redoubt Volcano removed between 112 and 121 $\times\ 10^6\,m^3$ of perennial snow and ice, principally from a single glacier. The piedmont lobe of that glacier, which drains the summit crater, is now beheaded, but continues to respond to a kinematic wave initiated by the reconnection of the glacier following the 1965–68 eruptions. On Redoubt Volcano, the debris and flood flows were initiated by mechanical entrainment of snow and ice by rapidly moving hot volcanic material. Less energetic flows of hot volcanic debris on the glaciers on Mount Spurr have resulted in smaller mud, debris, and flood flows thus far in the eruptive sequence.

Malaspina and Bering glaciers, Alaska

(D. Trabant, USGS, Fairbanks, Alaska)
A digital low frequency monopulse ice radar system is being used on Malaspina and Bering glaciers to investigate the relation between airborne and satellite SAR image patterns and glacier ice thickness. On both Bering and Malaspina glaciers ice surface roughness features, which influence SAR image brightness, have led to identification of large scale topographic features in the glacier bed.

Black Rapids Glacier, Alaska — monitoring

(T. A. Heinrichs and L. R. Mayo, USGS, Fairbanks, Alaska, and K. Echelmeyer and W. D. Harrison, Geophysical Institute, UAF)
A report summarizing more than 20 years of observations of mass balance, ice velocity, and thickness changes on Black Rapids Glacier is nearing completion. The monitoring program was begun in 1970 and as many as ten sites have been under observation. The ice speed has displayed unexpected fluctuations for a surge-type glacier. While the ice speed at Variegated Glacier steadily increased during the 10 year period preceding its surges, on Black Rapids Glacier at the equilibrium line, the annual speed has fluctuated more than 40% about the mean velocity. Annual speed monotonically increased from $46\,m\,a^{-1}$ in 1978/79 to $72\,m\,a^{-1}$ in 1986/87. The following year the trend reversed, and for the next four years, the annual speed steadily decreased to a low of $54\,m\,a^{-1}$ in 1990/91. Most recent observations for 1991/92 show a slight speed increase to $56\,m\,a^{-1}$. Looped moraine patterns indicate that today the glacier is in approximately the same configuration as it was prior to its most recent surge in 1936. Monitoring efforts continue at a reduced level — three sites are currently being observed.

Black Rapids Glacier, Alaska — SAR reflectors

(R. Fatland, JPL, Pasadena, California, T. A. Heinrichs , USGS, Fairbanks, Alaska, and C. S. Lingle, Geophysical Institute, UAF)
Three trihedral corner cube reflectors were deployed in the Black Rapids Glacier basin in an attempt to determine ice speed using the ERS-1 Synthetic Aperture Radar (SAR) satellite. In September of 1992, two reflectors were placed on the glacier surface and a third on bedrock near the glacier margin. Their positions were surveyed and, when re-surveyed in the spring of 1993, their velocities will be known to within a few percent. This information will be used as "ground truth" for the SAR-derived velocity observations.

Taku Glacier studies

(R. J. Motyka, ADGGS, Juneau, Alaska, D. Trabant, USGS, Fairbanks, Alaska, and J. Beget, UAF)
Taku Glacier, a valley glacier located 32 km north-northeast of Juneau, has advanced 7.25 km since 1890 in contrast to neighboring glaciers which have all retreated.

Continued advance of the Taku Glacier threatens closure of the Taku River which could result in the subsequent formation of a huge lake behind the ice dam. Our investigations have focused on understanding the current dynamic state of the Taku Glacier and documenting its Holocene advances and retreats in order to assess the potential for future damming of the Taku River. The Holocene record shows that the Taku Glacier dammed the Taku River at least three times in the past 3000 years, most recently around 1750 AD. We believe the Taku Glacier to be a tidewater-type glacier and that its current advance is linked to the periodic rapid retreat and gradual advance cycle documented at other Alaskan tidewater glaciers. The high accumulation area to total area ratio (0.86) and extensive tide flats which presently isolate the terminus from deep tidewater ensure the Taku Glacier will continue to advance. From 1979 to 1989, the glacier advanced at an average rate of 15 to 30 m a^{-1}, but it has shown little or no advance during the past three years. Our future work will focus on obtaining bedrock profiles near the equilibrium line using radio-echo sounding and seismic techniques. In addition, we hope to measure surface elevations in the upper accumulation zone to determine whether the upper glacier has thickened since 1950; the ice has not thickened in the zone immediately above the equilibrium line during the past 40 years.

Airborne profiling of surface elevation of valley glaciers

(K. Echelmeyer, W. D. Harrison and J. Mitchell, Geophysical Institute, UAF)

We have developed, tested and utilized a compact, lightweight laser/GPS profiling system for use in a small fixed-wing aircraft. This profiling system is used to determine the volume changes of valley glaciers in Alaska and elsewhere by measuring profiles of surface elevation along a glacier that can be compared with existing maps or future profiles. Data are collected about once per meter along the surface, allowing a nearly continuous profile to be determined. The system presently has an accuracy of about 0.5 m, we hope to improve this to about 0.2 m in the future.

The depth of Ruth Glacier, Denali National Park, Alaska

(K. Echelmeyer, Geophysical Institute, UAF and T. Clarke, Geophysics, Univ. Wisconsin, Madison)

Seismic reflection techniques have been used to determine the thickness of ice in the Great Gorge of Ruth Glacier on the south side of Mt. McKinley. The glacier is 1800 m deep at this location, and it lies in a 2 km wide valley with sheer granite walls up to about 2000 m high along its sides. This makes it the deepest gorge in North America. Ice speeds are on the order of 1 m per day, and thus the flux of ice through the gorge is quite large.

Geophysical investigation of basal processes on Black Rapids Glacier, Alaska

(K. Echelmeyer, W. D. Harrison, O. Cochran, M. Nolan, Geophysical Institute, UAF, and C. F. Raymond, Geophysics Program, University of Washington, Seattle, Washington)

Black Rapids is a surge-type glacier which shows an annual spring speed up of nearly 200% at some locations. We are studying the mechanisms of this change in speed by geophysical imaging of the glacier bed using high-resolution seismic and ice radar methods. At the same time we are monitoring the hydrologic discharges of the glacier in order to determine the coupling between bed conditions, the glacier hydraulic system and glacier speed.

McCall Glacier, Alaska as an indicator of climate change in the Arctic

(K. Echelmeyer and C. S. Benson, Geophysical Institute, UAF)

McCall Glacier is one of the most northerly glaciers in Alaska, and one that was the subject of intensive studies during IGY and the early 1970s. The present program seeks to compare the present geometry of this glacier with that observed during these early studies. Measurements include surface elevation and velocity, mass balance, terminus position and local meteorological variables. Changes in volume will be interpreted in terms of climatic change in Arctic Alaska.

SAR investigations of glaciers in northwestern North America

(C. S. Lingle, K. Ahlnaes, and W. D. Harrison, Geophysical Institute, UAF)

Synthetic aperture radar data from ERS-1 (the first European Earth Remote Sensing Satellite) is under investigation as a tool in the studies of mountain glaciers, particularly in regional mass balance studies. Winter imagery clearly shows the positions of late summer snowlines, or possibly equilibrium lines, on glaciers on the interior sides of the Alaska Range and the St. Elias Mountains.

ANTARCTIC GLACIERS

The role of the margins in ice stream flow

(W. D. Harrison and K. Echelmeyer, Geophysical Institute, UAF)

The mechanisms of ice stream flow are not well understood and in this project we are attempting to determine the role of the marginal shear zones in the overall force balance of an active ice stream. Measurements of ice temperature at depth and velocity across the highly crevassed shear margin of Ice Stream B are being combined with modeling of the velocity, stress and temperature fields within the ice. Preliminary results show that the margins can provide a significant portion of the total resistive drag required to balance the overall driving stress, and that viscous heating in the marginal zones can be large.

Satellite radar altimetry and ice sheet dynamics

(C. S. Lingle and Li-her Lee, Geophysical Institute, UAF, and U. C. Herzfeld, Scripps Institution of Oceanography, University of California, San Diego)

Satellite radar altimeter data from the Geosat Exact Repeat Mission (1986–1989) are being used to derive high-resolution maps of the lower Lambert Glacier and Amery Ice Shelf, East Antarctica, and to measure seasonal mean changes in elevation on the lower Lambert Glacier in and near the grounding zone. Preliminary results have shown that kriging can be employed to invert the altimetry in this topographically complex region into digital terrain models defined on 3 km grids, and suggest that seasonal mean changes in elevation, and perhaps multi-year mean changes, will be measurable using the method of orbit crossover analysis.

SEA ICE

Inter-relationships between sea ice properties, structure and synthetic aperture radar signatures during the summer to winter transition in the Beaufort–Chukchi Sea

(M. O. Jeffries, S. Li, W. F. Weeks and K. Schwartz, Geophysical Institute, UAF, and R. Shuchman and R. Onstott, Environmental Research Institute of Michigan (ERIM), Ann Arbor, Michigan)
The objectives of this research are to improve our knowledge and understanding of (1) the internal structure and development of Arctic pack ice, (2) the physical properties of warm Arctic sea ice and how they compare with warm Antarctic sea ice, and (3) the physical and structural controls on SAR backscatter from Arctic sea ice as it undergoes the transition from warm to cold conditions. The study began in August–September 1992 aboard the U.S. Coast Guard icebreaker USCGC *Polar Star* operating in the northern Chukchi Sea and the western Beaufort Sea. Ice core temperature, salinity and brine volume data were obtained and additional cores were returned to Fairbanks for structural–stratigraphic analysis. In situ backscatter data (so) were obtained with a C-band (l = 53 mm) scatterometer mounted on the ship. Ice property and structure data, and in situ backscatter variations will be correlated with backscatter derived from ERS-1 and JERS-1 SAR images acquired at the Alaska SAR Facility. The study will continue in 1993 and 1994 with further cruises aboard U.S. Coast Guard icebreakers.

Simulation of the profile properties of first-year sea ice

(R. Wade and W. F. Weeks, Geophysical Institute, UAF)
The properties of first year sea ice are highly variable, both in profile and time. The major factor controlling this variability is the brine volume which in turn is controlled by salinity and temperature profiles. Studies are currently underway to evaluate and to extend the applicability of the salinity profile model developed earlier by Cox and Weeks. The initial model treated only the case where the temperature profile in the ice was linear. This constraint has now been removed by coupling the brine incorporation and drainage aspects of the model to a finite element ice growth model. The newer version of the model is in Fortran and is designed to run on a workstation, a change that should make it available to a broader user group. Efforts to understand the exact effects of the different components of the model are currently underway. Because of internal feedbacks, this is not proving to be simple. Our ultimate goal is to apply this model using data extracted from both SAR imagery and the Unidata meteorological model output in order to provide an improved assessment of the gross thermodynamics of pack ice.

Application of SAR imagery to an analysis of the thermodynamics of pack ice

(R. Wade and W. F. Weeks, Geophysical Institute, UAF)
Studies of SAR imagery have shown good discrimination between first-year and multi-year sea ice. Discrimination between the various thickness of first-year ice is more difficult. This is unfortunate in that the majority of the heat and mass transfer between the ocean and the atmosphere occurs through open water and thin first-year ice. This project examines the variations in the radar backscatter from refrozen leads to explore the relations between backscatter and ice thickness. The observations suggest that there is a decrease in the backscatter with an increase in ice thickness between 0–50 cm. The decrease is believed to be associated with changes in the dielectric properties of the upper layer of sea ice. It is caused primarily by a reduction in the near-surface brine volume due to the combined effects of brine drainage and cooling surface temperatures during initial ice growth. If these trends can be generalized via the ice growth model described in the previous project, the SAR observations will be combined with the modeling estimates to study ice–ocean–atmosphere interactions in the Beaufort and Chukchi seas.

SAR detection and characterization of ice islands

(M. O. Jeffries, Geophysical Institute, UAF)
The objective of this study is to assess the capability of the ERS-1 and JERS-1 synthetic aperture radars (SAR) to detect ice islands, the tabular icebergs that calve from ice shelves located on the northern coast of Ellesmere island in the Canadian Arctic. The targets for this study are the ice islands that broke off the Ward Hunt Ice Shelf in 1982–83, including Hobson's Choice ice island. A number of ERS-1 SAR scenes of the ice shelves and the ice islands, acquired at the Alaska SAR Facility in 1991 and 1992, are currently being examined.

Physical properties and structural–stratigraphic characteristics of summer sea ice in the Pacific sector of the Southern Ocean

(M. O. Jeffries, W. F. Weeks, A. Danielson, K. Morris, Geophysical Institute, UAF, and R. Shaw, Department of Physics, Brigham Young University, Provo, Utah)
We are trying to document variations in the physical properties and structural–stratigraphic characteristics of pack ice and fast ice in the Ross, Amundsen and Bellingshausen seas in order to identify the processes and conditions governing sea ice development. Ice cores were obtained during icebreaker cruises in 1990–91 and 1991–92 for analysis of ice temperature, salinity, crystal structure and stratigraphic variability, and stable isotopic composition. Samples have also been sent to other investigators for analysis of sea ice microbial communities and nutrients. Together with the results of research by other investigators, primarily in the Weddell Sea, the results of our work add to the growing body of evidence that Antarctic sea ice development differs considerably from sea ice development in the Arctic.

LAKE AND RIVER ICE

Icing blisters on the Alaskan North Slope

(E. F. Chacho, Jr, CRREL, Fort Wainwright, Alaska, and S. A. Arcone and A. J. Delaney, CRREL, Hanover, New Hampshire)

Detailed studies on icing blisters on the Sagavanirktok River are continuing as part of a study on winter water supply on the North Slope of Alaska. Current emphasis includes detection by remote sensing techniques and studies on the growth mechanics of icing blisters. SAR imagery is being investigated as a tool to detect and map the location of icing blisters throughout the winter. Ground truth for SAR images was done by conducting short-pulse radar surveys on the ground during mid-winter and late-winter overflights. Icing blister growth is currently being monitored by periodic site surveys. Pressure transducers have been installed to relate blister growth to changes in water pressure, possibly as a function of air temperature. Short pulse radar surveys are being utilized to map the extent of talik formations which may influence icing blister occurrences and growth rate.

Regional climate change and physical–structural factors affecting SAR signatures of lake ice

(M. O. Jeffries and W. F. Weeks, Geophysical Institute, UAF, H. Wakabayashi, Earth Observation Centre/ NASDA, Saitama, Japan, D. K. Hall, NASA, Goddard Space Flight Centre, Greenbelt, Maryland, and K. M. Peterson, Department of Biological Sciences, University of Alaska, Anchorage, Alaska)

The objective of this combined field, remote sensing and modeling investigation of lake ice growth and decay is to improve the understanding of the ice properties responsible for spatial and temporal variations in lake ice synthetic aperture radar (SAR) signatures. Successful completion of this work will enable SAR to be used more effectively in managing water resources on the Alaska North Slope and in utilizing lake ice SAR characteristics and variations as indicators of regional climate variability and environmental change. Field investigations include ice core studies of the characteristics of ice on shallow tundra lakes at Barrow, Alaska. Radar backscatter data (so) are being derived from ERS-1 and JERS-1 SAR data received at the Alaska SAR Facility.

SNOW

Snow precipitation in the Arctic

(C. Benson, Geophysical Institute, UAF, and G. Clagett, USDA Soil Conservation Service, Anchorage, Alaska)

Precipitation records for snow always underestimate the quantity, especially when snowfall is accompanied by strong winds. On Alaska's Arctic Slope, records from the two stations, Barrow and Barter Island (about 500 km apart) have been analyzed to determine sources of error, such as long strings of "traces" in the record (which add up to zero). The standard unshielded rain-gauge used at the stations have been compared with gauges shielded by the Wyoming wind shield. Snow measured on the tundra has been compared with the gauge records. It appears that unshielded gauge records, and thus the official climatological records for this region, are too low by a factor 3 or more.

Shock wave propagation studies in snow

(J. B. Johnson, D. J. Solie and S. A. Barrett, CRREL, Fort Wainwright, Alaska)

For the past several years we have been conducting a study to understand the physical processes involved in shock wave propagation and attenuation in snow. We have analyzed shock wave measurements in snow from gas-gun tests conducted at Los Alamos National Laboratory in New Mexico. From shock stress and arrival time data and finite element (FE) modeling techniques we have determined pressure-volume (P-V) loading and unloading paths for dry snow (100–500 kg m^3) for pressures ranging from 5–40 MPa. A series of field experiments using plane wave explosives were conducted in spring, 1992 to verify these results, and to extend the loading curves by an order of magnitude in pressure. We have also used F.E codes (PRONTO-2D, PUFF) to model snow compaction. We are now extending the study to compaction of snow in general by a re-analysis of existing data for snow compaction in all pressure ranges.

Snow water equivalent of Kuparuk River basin

(R. Rovansek, University of Alaska, ORE Water Research Center, Fairbanks, Alaska)

As part of a effort to model the hydrologic processes in the Kuparuk River basin, I have developed equations to estimate the average water equivalent of a snowpack and the variance of this estimate using data obtained by double sampling. Double sampling refers to sampling the snowpack in two ways: sampling the depth of the snowpack at a number of points, and sampling both depth and water equivalent at a smaller number of points. The system takes advantage of the benefits of each sampling method. Sampling depth is quick, but provides only a rough estimate of water equivalent. Sampling water equivalent gives an accurate estimate but is time consuming. By combining the two measurements it is possible to obtain estimates of average snowpack water equivalent with lower estimated variance. Research continues to predict the optimal ratios of depth to water equivalent measurements to use under various field conditions.

Fractionation of stable isotopes during the formation of depth hoar

(C. Benson, Geophysical Institute, UAF, and I. Friedman and J. Gleason, USGS, Denver, Colorado)

Changes in the stable isotopes (deuterium and oxygen-18) that accompany the formation of depth hoar in the sub-Arctic snow have been studied in interior Alaska where large temperature gradients exist across the snowpack. Water vapor moves from the soil into the overlying snow during the long (150–200 days) cold winter. The extent of this exchange can be measured by drying of the soil, and by the change in isotopic content of the snow. The snow also undergoes isotopic fractionation during depth hoar formation in settings where soil moisture is prevented from moving upward into the snow. By using both oxygen and hydrogen isotopes we are learning about heat and mass transfer processes in the snow.

Development of a thermal classification of seasonal snow covers

(M. Sturm and J. Holmgren, CRREL, Fort Wainwright, Alaska)

Since 1989 we have run up to 9 instrument sites along a north–south transect across Alaska. Throughout the winter at each site, we have recorded in situ snow temperature at 30 locations, heat flow at the snow/ground interface, and local meteorology. Snow stratigraphy, texture and spatial variability have been measured monthly in trench excavations. From these data we have calculated seasonal averages of thermal parameters such as mean snow/ground interface temperature and vertical temperature gradient. Discrimination analysis suggests that the thermal parameters can be used to classify the different climatic types of snow. We are now trying to assemble data from other locations to test the classification system.

Small-scale spatial variability of snow covers

(M. Sturm and J. Holmgren, CRREL, Fort Wainwright, Alaska, Carl Benson, Geophysical Institute, UAF)

We have been studying the small-scale variability of the snow cover (distances < 100 m) in three distinctly different types of snow. In tundra regions, we have made measurements of stratigraphic variability due to the micro-topography of tundra hummocks and tussocks. Temperature measurements indicate large variations in basal temperature (up to 20°C) due to this topography. The flux of wind-blown snow on the tundra has been measured in carefully selected, naturally occurring drift traps, such as river banks. In the taiga, we have been investigating the uneven distribution caused by trees. At one location, the snow surrounding small, medium and large conifers was instrumented and the thermal regime monitored for an entire winter. In the maritime regions, we have been examining spatial variability resulting from heterogeneous water infiltration and freezing of percolation columns.

USDA Soil Conservation Service Alaska snow surveys

(G. Clagett and R. McClure, USDA Soil Conservation Service (SCS), Anchorage, Alaska)

A network of approximately 200 stations state-wide report monthly snow depth and water equivalent values. These are maintained by the USDA-SCS and other agencies and individuals in a cooperative program. The state-wide system also includes 23 snow pillows, which give daily snow water equivalent records, 46 precipitation gauges and 11 Wyoming shielded precipitation gauges. Monthly reports of snow depth and water equivalent are issued, as well as an annual summary.

ICE CORING AND LOGISTICS

Polar Ice Coring Office (PICO)

(Submitted by J. J. Kelley, Director/PICO, UAF)

The Polar Ice Coring Office (PICO), located at the University of Alaska Fairbanks for the Division of Polar Programs, National Science Foundation, provides technical (drilling, coring) and logistics services for glaciological research worldwide.

Greenland Ice Sheet Program (GISP-2): PICO provides drilling and logistical support to this major multi-disciplinary program. Coring at GISP-2 in the 1992 season finished about two thirds of the way through the ice. It is expected that the project will be completed during summer 1993. The electromechanical drill operates in a fluid-filled hole (butyl acetate). Once near the ice–bedrock interface, the drill will be fitted with a rock coring section in hopes of obtaining a unique sample of this interface.

Guliya Ice Cap: During the 1992 summer an international team led by L. Thompson of the Byrd Polar Research Center drilled several holes to a maximum depth of 308 meters on the Guliya Ice Cap on the Tibetan Plateau in SW China. High altitude (6200 m), remoteness and long logistics lines presented interesting challenges for core retrieval and its return in a frozen state to The Ohio State University. Standard PICO drill systems, designed for use in remote areas, were used for core retrieval. Both electromechanical and electrothermal drills were required because of unique coring requirements. Preliminary observations suggest the core record may be 400 000 years old, covering four ice ages. This project is part of a continuing investigation of low latitude–high altitude paleoclimate reconstruction using ice cores which began in 1983 with solar powered drilling of the Quelccaya Ice Cap in Peru.

Amanda Project: During the 91-92 Austral summer PICO drilled several hot water holes at the South Pole to test the feasibility of placing photomultiplier tubes (PMTs) deep within the ice to act as neutrino detectors. The Antarctic Muon and Neutrino Detector Array (AMANDA) project plans to use the ice as a medium for detecting neutrinos by suspending 200 m strings of PMTs to a depth of 1100 m where clean, bubble free ice exists. Two holes approximately 850 m deep and 45 cm diameter were drilled using hot water. PMTs were lowered in the holes to check survivability of the freezeback process and confirm ice clarity. The hot water drill had a heat input of 1 MW. A standard recirculating hot water drilling technique was used. The drill was instrumented to provide information on tilt, nozzle temperature, hole depth and other parameters necessary to provide straight, large-diameter holes. The tests were successful enough to suggest proceeding to stage II which requires the placement of nine PMT strings during the 1993–94 and 1994–95 seasons.

Submitted by Matthew Sturm

ANNUAL GENERAL MEETING 1992

MINUTES OF THE ANNUAL GENERAL MEETING OF THE INTERNATIONAL GLACIOLOGICAL SOCIETY

17 September 1992 in Nagaoka, Japan

The President, Dr G. K. C. Clarke, was in the Chair. 70 members from 12 countries were present.

1. The Minutes of the 1991 Annual General Meeting, published in *ICE* 98, p. 24–25, were approved and signed by the President.

2. The President gave his report for 1991–92:

Welcome to the Annual General Meeting of the International Glaciological Society. It is a wise strategy to begin meetings with good news and today's good news is that Louis Lliboutry has been selected as the next recipient of the Seligman Crystal. Lliboutry is a giant of scientific glaciology and I am proud that the Society has chosen to honour his long and distinguished career. As is our custom, the award will be presented at the next IGS symposium, to be held in Rovaniemi, Finland in April 1993.

The main theme of the past year has been that of stabilizing the Society following the many changes we faced in 1991. These changes included the acquisition of new deskstop publishing hardware and software, a new look for the Society's publications, the move to a new office location in Cambridge, U.K. and substantial turnover of office staff. Council met three times in 1992: once at Boulder and twice at Nagaoka. The Treasurer's report presented at Boulder warned the Society that the costly reorganizations of 1991 had weakened the financial base of the Society. It is our conviction that these added expenditures could be explained by unique circumstances, but we chose, nevertheless, to interpret the Treasurer's report as an early warning and to take appropriate steps. In response to the Treasurer's warning, Council agreed to raise membership dues and library subscription charges and to adopt a new policy on page charges for the *Journal of Glaciology*. I shall discuss our new policy on page charges separately because it is a complex and contentious issue.

The appearance of the *Journal of Glaciology* and *Annals of Glaciology* has been substantially improved, in particular in the presentation of mathematics. These general improvements have been made possible by changing our publishing hardware and software. We are pleased with these changes but are less pleased with our success at reducing the interval between receipt of manuscripts and final publication of the *Journal*. Delays that result from problems with our scientific editors and with in-house handling of manuscripts is being addressed by our Chief Editor and our Secretary General. But a second and major source of delay has caused us great concern: we have a manuscript backlog that must be cleared before acceptably fast publication times can be achieved. This leads me to the issue of page charges. Many of you may not realize that the length of the *Journal of Glaciology* is determined by financial rather than scientific considerations. For example, the approved length for 1992 was 384 pages and this number was agreed to in August 1991 — long before we had any idea of how many manuscripts we might receive or accept for publication in 1992. With the aim of reducing the publication backlog and establishing a system that will allow more flexibility in planning future issues of the *Journal*, Council has approved the following policy: "Manuscripts submitted for publication in the *Journal of Glaciology* will be subjected to a uniform editorial process that aims to be speedy and fair. Acceptance or rejection of articles is based upon their perceived merit. Following acceptance for publication in the *Journal*, paid manuscripts will be published without additional delay; unpaid manuscripts will be published at the fastest rate that the Society can afford." There is no intention to delay publication of manuscripts as some form of punishment to non-paying authors; we simply must gain greater control of the financial management of the *Journal*. We foresee that the result of this new policy will be to eliminate the manuscript backlog and to speed the publication of both paid and unpaid submissions.

Next year the Society will maintain its present high level of activity. A Symposium on Applied Ice and Snow Research will be held in Rovaniemi, Finland from 18–23 April and a Workshop on Glacier Hydrology is scheduled for Cambridge, England from 8–10 September in parallel with the SCAR Fifth International Symposium on Antarctic Glaciology (VISAG). A highlight of both the Workshop and Symposium will be the Soirée Richardson to celebrate Hilda Richardson's forty years of service to the Society. Hilda will retire as Secretary General at the end of 1993 and we are beginning the search for her successor. We hope to identify the new Secretary General early in 1993.

Lastly, I would like to thank Hilda Richardson, David Rootes, Sally Stonehouse, Linda Gorman, Ray Adie, Evelyn Dowdeswell and Sylva Gethin for their contributions at IGS Headquarters, and our Scientific Editors, Officers and Members of Council, members of the Society's various committees and the many others who have publicly or privately contributed to the smooth operation of the Society.

3. The Treasurer, Dr J. A. Heap, submitted a report with the audited accounts for 1991. He apologised for his absence from the meeting. The President highlighted some of the items and suggested that questions about details on the accounts be addressed to the Secretary General after the meeting.

The Treasurer in his report pointed out that the deficit on the 1991 accounts was mainly caused by reorganization and the need to publish more pages in the *Journal of Glaciology* in an attempt to keep up with the increasing number of high-quality contributions. It was against this background that the Council approved in May 1992 a slightly larger than normal increase in members' dues and in sales price to libraries, and decided to take a different approach to page charges, as described by the President in his report.

The Treasurer concluded: "While it is a universally appreciated truism that a piece of research is not complete until its results have been published, it is less readily appreciated that fulfilment of that truism costs money. Funding agencies, please note."

K. Hutter proposed and D. McClung seconded that the audited accounts for 1991 should be adopted. This was agreed unanimously.

4. Election of auditors for the 1992 accounts.
R. Braithwaite proposed and L. Makkonen seconded that Messrs Peters, Elworthy and Moore of Cambridge be elected auditors for the 1992 accounts. This was carried unanimously.

5. Election to the Council 1992–95. 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.

Treasurer:	J. A. Heap
Elective Members:	A. Glazovskiy
	L. Makkonen
	T. Nakamura
	K. Steffen

The President thanked those members who had served on the Council 1989–92 and were now retiring.

6. Motion to adjourn was proposed by R. Hooke, seconded by D. Collins and agreed unanimously.

. . . .

After the conclusion of the formal business of the meeting, an informal discussion took place on matters such as the Council nomination system and the new page charge system.

IGS SYMPOSIUM ON SNOW AND SNOW-RELATED PROBLEMS

Nagaoka, Japan, 14–18 September 1992
and
POST-SYMPOSIUM TOURS TO ECHIGO AND KUROBE CANYON

172 participants enjoyed a busy and interesting week in Nagaoka, Niigata Prefecture — a location that normally has to cope with very heavy snowfalls each winter. The invitation to IGS to hold a symposium in Nagaoka on snow problems came from the Mayor, who ensured that there was ample and generous support for the local organization.

A full programme of plenary and poster sessions was complemented by interesting and lively social events, including a special fireworks display one evening, in this city famous for its spectacular pyrotechnics.

After the symposium, two tours took place, one a two-day visit to the Echigo area, and one lasting four days to the Kurobe Canyon, Munodon Plateau and Kyoto. It was thanks to the Kansai Electric Power Company that we were privileged to visit the Kurobe Dam and Power Plant, using their private routes and visiting areas not open to the public. Our journey from Nagaoka to Kyoto used about 20 different changes of transport: coach, mountain railways, power company railway, 200 m high elevator, bus, cablecar, main railways. In Kyoto, we saw many of the beautiful buildings of this ancient capital of Japan.

the new conference centre, where the IGS symposium was held

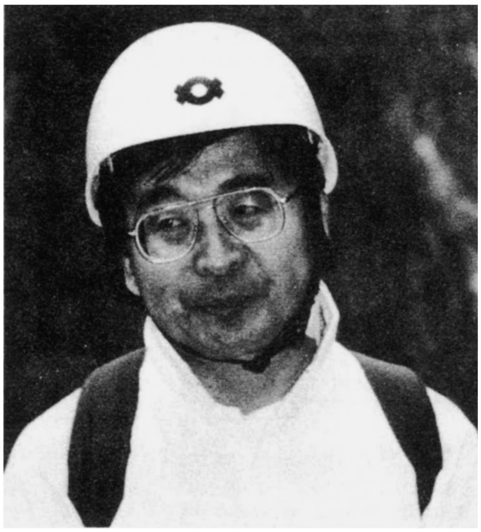
There was plenty of help at the Registration desk

Tom Nakamura
Secretary General President
The Local Comittee Chairman, Tsutomu Nakamura, welcomed participants at the opening ceremony

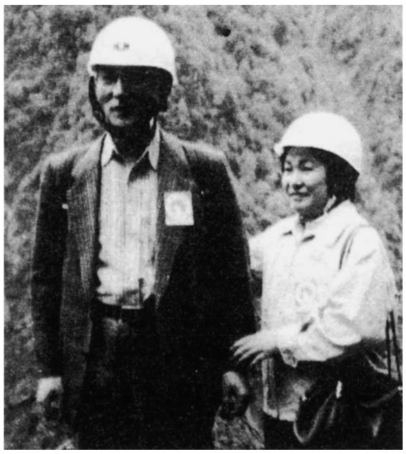
McKittrick, Brown, Richardson, Eiken

The tour also included the Kurobe Dam (see cover photograph)

IGS participants, wearing the Power Company's security badge and "hard hats", were allowed on their private routes — and into the power plant — before re-joining the public route, on the top of the dam



Norio Hayakawa
(Vice-Chairman Local Committee)



Kou and Sachiko Kusunoki

INTERNATIONAL WORKSHOP ON GLACIER HYDROLOGY

8–10 September 1993
Jesus College Cambridge UK
ORGANIZATION: D.N. Collins (Chairman), H. Bjornsson, A. Fountain, E.M. Morris

An international workshop on Glacier Hydrology will be held in parallel with the Fifth International Symposium on Antarctic Glaciology (VISAG). The Workshop will provide a forum for discussion of new developements in glacier hydrology. Field investigations, methods and results, modelling and the coupling of basal hydrological systems with glacier flow form the underlying themes of the meeting. There will be a poster display throughout the Workshop. Final date for registration: 30 June 1993.

SOIREE RICHARDSON

On Thursday afternoon (9 September) VISAG and Workshop sessions will end early and there will be a special session (Soirée Richardson) from 1600–1800 to celebrate the career of Hilda Richardson, who is retiring as Secretary General of the International Glaciological Society. A banquet will be held in honour of Hilda Richardson in College Hall.

An IGS Council meeting will be held on Monday 6 September during the evening and the IGS Annual General Meeting will take place on Friday morning.

JOURNAL OF GLACIOLOGY

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

C H DAVIS AND R K MOORE
A combined surface and volume scattering model for ice-sheet radar altimetry

C H DAVIS AND H J ZWALLY
Geographic and seasonal variations in the surface properties of the ice sheets by satellite radar altimetry

J J CLAGUE AND S G EVANS
Historic retreat of Grand Pacific and Melbern glaciers, St Elias Mountains: an analogue for decay in the Cordilleran ice sheet at the end of the Pleistocene?

G KITE
Measuring glacier outflows using a computerized conductivity system

S ANANDAKRISHNAN AND C R BENTLEY
Microearthquakes beneath Ice Streams B and C, West Antarctica: observations and implications

R LeB HOOKE AND V A POHJOLA
Hydrology of a segment of a glacier situated in an over-deepening, Storglaciären, Sweden

U H FISCHER AND G K C CLARKE
Ploughing of subglacial sediment

R B ALLEY
In search of ice-stream sticky spots

W D HARRISON AND K A ECHELMEYER
Short period observations of speed, strain and seismicity on Ice Stream B, Antarctica

V G KONOVALOV AND A S SHCHETINNICOV
Evolution of glaciation in the Pamiro-Alai and its effect on river runoff

R E GAGNON, C TULK AND H KIEFTE
Internal melt figures in ice by rapid adiabatic compression

B B NAROD AND G K C CLARKE
Miniature high-power impulse transmitter for radio-echo sounding

QIN DAHE, J R PETIT, J JOUZEL AND M STIEVENARD
Distribution of stable isotopes in surface snow along the route of the 1990 International Trans-Antarctica Expedition

C J MERRY AND I M WHILLANS
Ice-flow features on Ice Stream B, Antarctica, revealed by SPOT HRV imagery

J L FASTOOK AND M PRENTICE
A finite-element model of Antarctica: sensitivity test for meteorological mass balance relationship

R BINDSCHADLER, P L VORNBERGER AND S SHABTAIE
The detailed net mass balance of the ice plain on Ice Stream B, Antarctica: a geographic information system approach

A M D GEMMELL
Thermoluminescence in suspended sediment of glacier meltwater streams

A HALL AND K WESTON
The interaction between an ice sheet and its atmospheric boundary layer

E ISAKSSON AND W KARLEN
Spatial and temporal patterns in snow accumulation, western Dronning Maud Land, Antarctica

L H BURCKLE
Is there direct evidence for late Quaternary collapse of the West Antarctic ice sheet?

P P DUNPHY AND J E DIBB
^{137}Cs gamma-ray detection at Summit, Greenland

J WARBURTON AND C R FENN
Unusual flood events from an alpine glacier: observations and deductions on generating mechanisms

P G KNIGHT, D E SUGDEN AND C D MINTY
Ice flow around large obstacles as indicated by basal ice exposed at the margin of the Greenland ice sheet

I M WHILLANS, M JACKSON AND Y-H TSENG
Velocity pattern in a transect across Ice Stream B, Antarctica

I M WHILLANS AND C J VAN DER VEEN
New and improved determinations of velocity of Ice streams B and C, West Antarctica

R BINDSCHADLER
Siple Coast Project research of Crary Ice Rise and the mouths of Ice Streams B and C: review and new perspectives

S A ATRE AND C R BENTLEY
Laterally varying basal conditions under Ice Streams B and C, West Antarctica

R RETZLAFF, N LORD AND C R BENTLEY
Airborne radar studies: Ice Streams A, B and C, West Antarctica

R RETZLAFF AND C R BENTLEY
Timing of stagnation of Ice Stream C, West Antarctica, from short-pulse radar studies of buried surface crevasses

L STEHN
Fracture toughness and crack growth of brackish ice using chevron notched specimens
L A LLIBOUTRY
Monolithologic erosion of hard beds by temperate glaciers
J B JAMIESON AND C D JOHNSTON
Rutschblock precision, technique variations and limitations
J A RICHTER-MENGE, K J CLAFFEY AND M R WALSH
Endcapping procedure for cored ice samples used in tension tests
V A SQUIRE, W H ROBINSON, M MEYLAN AND T G HASKELL
Observations of flexural waves in the Erebus Glacier Tongue and nearby sea ice
J A RICHTER-MENGE AND K F JONES
The tensile strength of first-year sea ice
W D HARRISON, K A ECHELMEYER, E F CHACO, C F RAYMOND AND R J BENEDICT
The 1987–88 surge of West Fork Glacier, Susitna Basin, Alaska
V A POHJOLA
TV-video observations of englacial voids in Stoglaciären, Sweden
D M McCLUNG AND J TWEEDY
Numerical avalanche prediction: Kootenay Pass, British Columbia
S J DeFRANCO AND J P DEMPSEY
Crack propagation and fracture resistance in saline ice
J KLEMAN AND I BORGSTROM
Glacial landforms indicative of a partly frozen bed
B LEFAUCONNIER, J O HAGEN, J F PINGLOT AND M POURCHET
Mass balance estimates on the glacier complex Kongsvegen and Sveabreen, Spitsbergen, Svalbard, using radioactive layers
T LAUMANN AND N REEH
Sensitivity to climate change of the mass balance of glaciers in southern Norway

ANNALS OF GLACIOLOGY

The following papers will be published in Volume 17, *Proceedings of the Symposium on Remote Sensing of Snow and Ice*, held at Boulder, CO, 17–22 May 1992.

R KOELEMEIJER, H OERLEMANS AND S TJEMKES
Surface reflectance of Hintereisferner, Austria, from Landsat 5 TM imagery
S HASTENRATH
Toward the satellite monitoring of glacier changes on Mount Kenya
W G REES AND I I LIN
Texture-based classification of cloud and ice-cap surface features
J A DOWDESWELL, M R GORMAN, Yu Ya MACHERET, M Yu MOSKALEVSKY AND J O HAGEN
Digital comparison of high resolution Sojuzkarta KFA-1000 imagery of ice masses with Landsat and SPOT data
G J MARSHALL, W G REES AND J A DOWDESWELL
Limitations imposed by cloud cover on multi-temporal visible band satellite data sets from polar regions
G CASASSA AND H H BRECHER
Relief and decay of flow stripes on Byrd Glacier, Antarctica
R W JACOBEL AND R BINDSCHADLER
Radar studies at the mouths of ice streams D and E, Antarctica
M FREZZOTTI
Glaciological study in Terra Nova Bay, Antarctica, inferred from remote sensing analysis
J-G WINTHER
Studies of snow surface characteristics by Landsat TM in Dronning Maud Land, Antarctica
M KENNETT, T LAUMANN AND C LUND
Helicopter-borne radio-echo sounding of Svartisen, Norway
S FUJITA AND S MAE
Relation between ice sheet internal radio-echo reflections and ice fabric at Mizuho Station, Antarctica
S FUJITA, S MAE AND T MATSUOKA
Dielectric anisotropy in ice Ih at 9.7 GHz
K SEKO, T FURUKAWA, F NISHIO AND O WATANABE
Undulating topography on the Antarctic ice sheet revealed by NOAA AVHRR images
C SERGENT, E POUGATCH, M SUDUL AND B BOURDELLES
Experimental investigation of optical snow properties
C R DUGUAY
Modelling the radiation budget of alpine snow-fields with remotely sensed data: model formulation and validation
A W NOLIN, J DOZIER AND L A K MERTES
Mapping alpine snow using a spectral mixture modeling technique
JIANCHENG SHI, R E DAVIS AND J DOZIER
Stereological determination of dry snow parameters for discrete-scatterer microwave modeling
JIANCHENG SHI AND J DOZIER
Measurements of snow- and glacier-covered area with single polarization SAR
M STURM, T C GRENFELL AND D K PEROVICH
Passive microwave measurements of tundra and taiga snow covers in Alaska, U.S.A.
R E DAVIS, A W NOLIN, R JORDAN AND J DOZIER
Towards predicting temporal changes of the spectral signature of snow in visible and near-infrared wavelengths
P GLOERSEN, W J CAMPBELL, D J CAVALIERI, J C COMISO, C L PARKINSON AND H J ZWALLY
Satellite passive microwave observations and analysis of Arctic and Antarctic sea ice, 1978–1987
U C HERZFELD, CS LINGLE AND L-H LEE
Geostatistical evaluation of satellite radar altimetry for high-resolution mapping of Lambert Glacier, Antarctica
D K HALL, J L FOSTER, J R IRONS AND P W DABNEY
Airborne bidirectional radiances of snow-covered surfaces in Montana, U.S.A.
E G JOSBERGER, W J CAMPBELL, P GLOERSEN, A T C CHANG AND A RANGO
Snow conditions and hydrology of the upper Colorado River basin from satellite passive microwave observations
M C SERREZE, J A MASLANIK, G R SCHARFEN, R G BARRY AND D A ROBINSON
Interannual variations in snow melt over Arctic sea ice and relationships to atmospheric forcings
A WANKIEWICZ
Multi-temporal microwave satellite observation of snowpacks
S SURDYK AND M FILY
Comparison of the passive microwave spectral signature of the Antarctic ice sheet with ground traverse data
B BOURDELLES AND M FILY
Snow grain-size determination from Landsat imagery over Terre Adélie, Antarctica

P SKVARCA
Fast recession of the northern Larsen Ice Shelf monitored by space images
F PATTYN AND H DECLEIR
Satellite monitoring of ice and snow conditions in the Sør Rondane Mountains, Antarctica
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Snow and ice applications of AVHRR in polar regions: report of a workshop held in Boulder, Colorado, 20 May 1992

Future meetings (of other organizations)

Scientific Committee on Antarctic Research

FIFTH INTERNATIONAL SYMPOSIUM ON ANTARCTIC GLACIOLOGY (VISAG)

Cambridge, UK, 5 –10 September 1993

Co-sponsored by
International Glaciological Society (IGS)
International Commission on Snow and Ice (ICSI)
British Antarctic Survey (BAS)

LOCAL ORGANISING COMMITTEE: E. M. Morris (Chairman)
D. J. Drewry, E. W. Wolff, A. Jenkins, A. E. Hall

INFORMATION ABOUT THE CONFERENCE MAY BE OBTAINED FROM:
Mrs A. Hall, British Antarctic Survey, Madingley Road, Cambridge CB3 0ET, UK
Tel: +44 223 61188 Fax: +44 223 62616 EMAIL: U_EWW@UK.AC.NERC-BAS.VAXC

This is the fifth symposium in a series of successful meetings previously held in Helsinki (1960), Hanover (1968), Columbus (1981) and Bremerhaven (1987). Since the 4th Symposium, Antarctica and its ice sheet have assumed an increasing scientific and public prominence. The meeting will provide an opportunity for a comprehensive overview of the many new developments in Antarctic glaciology and their relevance to global concerns.

PROGRAMME

Registration will take place at Jesus College on the evening of Sunday 5 September and on Monday 6 September. Oral sessions will take place in the College, between on Monday morning and Friday afternoon. There will be poster sessions, which are expected to form an important part of the Symposium. A detailed programme will be sent out later to all registered participants.

There will be no sessions on Wednesday afternoon (8 September). Participants will be able to visit the British Antarctic Survey and the Scott Polar Research Institute or explore Cambridge. There will also be a meeting of the International Transantarctic Scientific Traverse (ITASE) during the afternoon (convenor Professor Paul Mayewski).

Glaciological Diary

** IGS Symposia
* Co-sponsored by IGS

1993

26 June-1 July
4th Canadian Marine Geotechnical Conference, St John's, Newfoundland, Canada (C-CORE, Memorial University of Newfoundland, St John's, NF, Canada A1B 3X5)

5-9 July
6th International Conference on Permafrost, Beijing, China (Cheng Guodong, Lanzhou Institute of Glaciology and Geocryology, Academia Sinica, Lanzhou 730000, China)

5-11 September
* Fifth International Symposium on Antarctic Glaciology, Cambridge, U.K. (E.M. Morris, Head, Ice and Climate Division, British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET, U.K.)

8-10 September
** International Workshop on Glacier Hydrology, Cambridge, U.K. (Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, U.K.)

12-19 September
International Symposium on Seasonal and Long Term Fluctuations of Nival and Glacial Processes in Mountains, Tashkent, Republic of Uzbekistan (Dr V.G. Konovalov, Central Asian Research Hydrometeorological Institute, SANIGMI, Republic of Uzbekistan 700052, Tashkent, 72 Observatorskaya str.)

17-21 September
European Research Conference: Ice sheet–Climate Interactions, Aghia Pelaghia, Crete, Greece (Dr Josip Hendekovic, European Science Foundation, 1 quai Lezay-Marnésia, 67080 Strasbourg Cedex, France)

1994

3-8 July
Bi-Polar Information Initiatives: the Needs of Polar Research. 15th Polar Libraries Colloquy, Cambridge, U.K. (William Mills, Scott Polar Research Institute, Cambridge CB2 1ER, U.K.)

7-12 August
** International Symposium on the Role of the Cryosphere in Global Change, Columbus, Ohio, USA (Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, U.K.)

1995

20-25 August
** International Symposium on Glacial Erosion and Sedimentation, Reykjavík, Iceland (Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, U.K.)

News

INTERNATIONAL COMMISSION ON SNOW AND ICE

In August 1991 during the General Assembly of the International Union of Geodesy and Geophysics a new Bureau of ICSI was constituted. M. Kuhn (Austria) was elected President, supported by C. Bentley (USA), E. Morris (UK) and G. Young (Canada) as Vice Presidents and by B. Salm (Switzerland) as Secretary-Treasurer.

Much of the work of the Commission is undertaken through its four Divisions: on Seasonal Snow Cover and Avalanches (Chair: E. Brun, France); on Glaciers and Ice Sheets (Chair: A. Glazovsky, Russia); on River, Lake and Sea Ice (Chair: S. Ackley, USA); and on Ice as a Material (Chair: J. Klinger, France). It is largely through working groups, constituted for four year periods, that ICSI promotes basic scientific investigations. Currently working groups are active on: Glacier Mass Balance Measurements (Chair: M. Kuhn); Snow Ecology (Chair: G. Jones, Canada); and Snow Atmosphere Chemical Exchange (Co-Chairs: R. Bales, USA and A. Neftel, Switzerland). A working group on Sea Ice Classification has also been created and a working group on Extraterrestrial Ice has been jointly created with the International Permafrost Association.

Recently ICSI has co-sponsored or collaborated in the following symposia and workshops: Symposium on Glaciers–Ocean–Atmosphere Interactions (St Petersburg, 1991); Symposium on Snow and Ice Chemistry (Sapporo, 1991); Symposium on Snow, Hydrology and Forests in High Alpine Areas (Vienna, 1991); Symposium on Snow and Glacier Hydrology (Kathmandu, 1992); Workshop on Glacier Contribution to Sea Level (Copenhagen, 1992). ICSI will co-sponsor several symposia in the near future including: Symposia on Snow Cover and its Interactions with Climate and Ecosystems; Processes of Mass and Energy Exchange between the Atmosphere and Polar Surface; Workshop on the Role of Snow and Ice in the Water Cycle in High Mountainous Areas (Yokohama, 1993); Symposium on Seasonal and Long-term Fluctuations of Nival and Glacial Processes in Mountains of Different Scales of Analysis (Tashkent, 1993).

The World Glacier Monitoring Service, of which the ICSI Bureau is the directorial board, is in process of publishing the sixth volume in the series on Glacier Fluctuations, its second Glacier Mass Balances Bulletin and and Earthwatch environmental brochure with UNEP on Glaciers and the Environment.

ICSI continues to collaborate with, and be supported by, UNESCO's Division of Water Sciences. ICSI coordinates and implements snow and ice related projects within the International Hydrological Programme (specifically through organizing the activities related to IHP Projects H-4, H-4-2, and H-5-6 on High Mountain Hydrology) and is currently particularly active in promoting glaciological activities in Central Asia. The *World Atlas on Snow and Ice Resources*, edited by V. Kotlyakov, past President of ICSI, is close to being completed and a technical document on Methods of Calculation and Mapping of Snow and Ice Resources (with insufficient initial information) will soon be completed.

There is a continuing need for the promotion of coordination of glaciological concerns in many regions of the world. ICSI is currently promoting such activities between Arctic countries, between countries in Central Asia, and in South America. Its work with the Scientific Committee on Antarctic Research (SCAR) and with the International Geosphere–Biosphere Programme (IGBP) is very active.

The ICSI Bureau is conscious of its duties to identify future research needs in glaciology. The impacts of climate change on and through snow and ice are recognized as of particular importance. The promotion of snow ecology through the establishment of a new Working Group demonstrates ICSI's acceptance of this subject as important to global change. ICSI will encourage cooperation between scientists in these and other areas of interest to glaciologists.

Gordon J. Young

INTERNATIONAL ANTARCTIC CENTRE

The International Centre for Antarctic Information and Research (ICAIR) at Canterbury (New Zealand) is now spaciously housed in the new International Antarctic Centre. A manager has been appointed, and a computer network with geographic information system and image-processing facilities is being installed.

ICAIR is an independent, non-profit organisation under the auspices of the Royal Society of New Zealand. One of its objectives is the servicing of scientific and environmental information needs, as indicated in the Madrid Protocol on Environmental Protection of the Antarctic, through the application of appropriate information technology. The ICAIR mission is:

To develop and operate a Centre of acknowledged international leadership in the collection, coordination, utilisation and dissemination of scientific and environmental digital information on Antarctica and the Southern Ocean;
to facilitate the exchange and analysis of data related to Antarctica's role in global processes;
to contribute to the development of soundly based principles for environmental management and planning in Antarctica;
to foster research using the information and resources of the Centre.

Immediate objectives are to develop a spatially referenced environmental database for the Ross Sea region of Antarctica that will serve as a useful baseline against which to monitor and assess change, but it is hoped in the longer term to extend these to other areas of the continent. The Director, Dr Steven Smith, anticipates that global change researchers in New Zealand and elsewhere will take advantage of the data bases for their own work (via Internet links). ICAIR's emphasis at present lies in the development of an Antarctic science directory system for New Zealand, the US and Italy whose Antarctic programmes are already making use of the facilities. ICAR is also involved in the development of computer data bases to assist in the logistical aspects of moving science teams to and from the ice. And while in Christchurch, they may tap into ICAIR's resources.

For further information about ICAIR contact: Dr Steven Smith, Manager, ICAIR, P.O. Box 14 199, Christchurch, New Zealand. Tel: (+64-3) 358 4450, Fax: (+64-3) 358 4489, E-mail: ssmith@icair.iac.org.nz.

OBITUARIES

William J. Campbell (1930–92)
Dr William J. Campbell, an international expert on polar ice, died on 20 November 1992 at this home in Gig Harbor, Washington, USA, at the age of 62. He had suffered a heart attack.

At the time of his death, Bill was chief of the United States Geological Survey's Ice and Climate Project, based on the campus of the University of Puget Sound in Tacoma, Washington. The group, under his leadership, contributed much to the interpretation of microwave remote sensing of the cryosphere. He helped develop international and interagency experiments in remote sensing of ice in the polar regions, and was a member and director of some of the major projects in that subject.

Born in Brooklyn, where he attended the Technical High School, he graduated in physics at the University of Alaska. He then spent a year at the Scott Polar Research Institute, Cambridge, on a Fulbright Scholarship. As a graduate student he studied ice physics on a floating ice island in the Arctic Ocean, and took part in expeditions to Antarctica in 1962 and 1964. He received his doctorate in atmospheric physics and oceanography in 1964 from the University of Washington.

He then joined the U.S. Geological Survey as a member of a team studying sea ice and glacier dynamics. In 1969 he became chief of the Survey's Ice Dynamics Research Project. He became actively involved in the protection and preservation of the environment, and gave many stimulating lectures in that field.

He wrote and was a co-author of over 130 research papers and received many prestigious awards. An energetic and enthusiastic person, he was a first-class teacher and a generous friend, as his many colleagues all over the world can testify. He is survived by his wife, Nelly, who is also a physicist, their two sons and his younger brother.

Richard P. Goldthwait (1911–92)
Richard P. Goldthwait died of a stroke on 7 July 1992, while collecting water samples near his summer home in Wolfeboro, New Hampshire. He was 81 years of age.

Professor Goldthwait was born in Hanover, New Hampshire, on 6 June 1911. He received an AB (1933) in Geology from Dartmouth College, and an MS (1937) and PhD (1939) in Geology from Harvard University. From 1939 to 1943 he was an Instructor and Assistant Professor of Geology at Brown University. Dr Goldthwait moved to Ohio in 1944 to serve in the U.S. Army Air Force as a Materials Engineer at Wright Field. He joined the faculty of The Ohio State University as Associate Professor in 1946 in the Department of Geology and served as Professor from 1948 until his retirement in 1977. He was Chairman of the Department of Geology (1965–69) and Acting Dean of the College of Mathematics and Physical Sciences (1972).

In 1960, he founded the Institute of Polar Studies and became its first Director (1960–65). Throughout his later life, he remained an active and important member of the now Byrd Polar Research Center and frequently visited the Center to renew old acquaintances and to meet the newest generation of young scientists. Most recently, he participated in the rededication of the Goldthwait Polar Library and helped to celebrate the opening of this new facility that will serve as a continuing reminder of his legacy to polar research.

He was a member and fellow of numerous national and international scientific organizations. He was President of the Ohio Academy of Science (1958–59), a Governor of the Arctic Institute of North America (1960–66) and on the Council of the International Glaciological Society (1970–73).

In his youth, he worked as a field assistant for his father, an eminent geologist at Dartmouth College, and began in 1935 his own research on glacial geology and glaciology. In 1936 he published the results of the first successful seismic sounding through glacier ice. Much of his career was devoted to understanding the glacial history of Ohio and he was one of the first to use carbon-14 dating in this task. He published more than 30 papers and reports, many co-authored with his students, on the glacial geology of Ohio. These have been of immense practical value in resource development, waste disposal, and land-use planning. Concepts and models for deglaciation and glacial morphological features benefitted from his research on glaciers and glacial landscapes in Antarctica, Greenland, Baffin Island, Alaska and New Zealand. He published more that 100 papers and reports and edited or authored five books. His understanding of past and present glaciers continued to grow even in retirement. As a Professor Emeritus, he continued to do field research, publish papers, edit books, organize sessions at professional meetings, and give advice to young scientists, other professionals and students.

His many awards and honors include the Antarctic Medal from the U.S. Congress (1968), the Outstanding Quaternary Scientist Award of the Geological Society of America (1981), the first Distinguished Career Award from the Geological Society of America (1986) and the Mather Medal from the Ohio Geological Survey (1989). Mount Goldthwait in Antarctica is named for him.

He influenced the lives of many with courses, popular lectures (some on radio), publications and his service to the university, the community and the state. His wisdom, foresight, high standards and enthusiasm in research and education will not be forgotten.

(Ken Jezek)

James H. Zumberge (1924–92)

James H. Zumburge died in Pasedena, California. He was 68 years old. The cause of death was a brain tumour, from which he had been suffering for more than a year.

Dr Zumberge was appointed president of the University of Southern California in 1980 and retired last year after leading the university to new academic and financial stability. He was also a renowned geologist who led several polar expeditions. Two Antarctic sites, Cape Zumberge and the Zumberge Coast, bear his name.

He was a native of Minneaopolis, earned bachelor's and doctoral degrees in geology at the University of Minnesota and then taught geology for a time. He was president of Grand Valley State College in Michigan, dean of the College of Earth Sciences at the University of Arizona, chancellor at the Lincoln campus of the University of Nebraska and president of Southern Methodist University.

When Dr Zumberge was appointed President of U.S.C., the university was reeling from academic scandals, mostly involving its athletic programme. When he retired on 31 March 1991, he said he hoped he had helped the university become "known for being more than just a place that consistently fields a strong football team".

His retirement was also preceded by a $641 million "Campaign for U.S.C.", one of the largest fund-raising efforts in the history of higher education.

The tumour that proved fatal was diagnosed shortly after he left the university.

It was his involvement in the International Geophysical Year as a glaciologist that led to his research on the deformation of ice and the formation of crevasses, work that continues today. His interest in Antarctic glaciology and his articulate support for research in all scientific disciplines on that continent led to his appointment as Chairman of the Polar Research Board, as U.S. SCAR Representative, and President of the Scientific Committee on Antarctic Research.

Jim was a musician of international reputation, at least among the SCAR nations. He played piano in almost all of the original 12 SCAR nations, and his skills with the accordion resulted in the importing of an accordion to Antarctica so that he might lead the songs at the Beardmore Camp Symposium in the mid 1980s. He was the originator of the famous SCAR Marching Song, a song that is now about 80 verses long.

Jim was a family-oriented man — he loved to have his family and extended family with him. He lived a full and rewarding life, and received many honorary degrees and medals that recognized his contributions to science. He gave himself to society, and looked forward to the future with eager anticipation. He was supported throughout by his family: his wife Marilyn, his three sons and his daughter.

APPOINTMENTS

Dr John A. Heap (Treasurer of I.G.S. for many years) took up his appointment as Director of the Scott Polar Research Institute on 1 December 1992.

John received his MA in Geography at the University of Edinburgh. In 1953 he was the leader of the University of Edinburgh's first-ever undergraduate-initiated expedition, to the Lyngen Peninsula in Norway. He then moved to Cambridge, where he spent seven years conducting sea-ice research for the Falkland Islands Dependencies Survey (later the British Antarctic Survey). His resultant thesis, " Sea ice distribution in Antarctica between longitudes 7° and 92° west from 1898–1962", was submitted for a PhD at SPRI; he was awarded his doctorate in 1962.

After two years as a research associate at the University of Michigan, he returned to Britain and was appointed Deputy Head of the Polar Regions Section of the Foreign Office, later renamed the Foreign and Commonwealth Office (FCO). In 1975 he succeeded Dr Brian B. Roberts as Head of the Polar Regions Section, a position that he held until his retirement in 1992. As Head of the Polar Regions Section, he was a member or the leader of UK delegations to all meetings of the Antarctic Treaty. He was also responsible for the FCO policy relating to the Antarctic Treaty system, and specifically for the convention on the Conservation for the Regulation of Antarctic Mineral Resource Activities, the Convention for the Conservation of Antarctic Seals, and the Protocol on Environmental Protection to the Antarctic Treaty.

In 1991 he was made a Commander of the Order of St Michael and St George (CMG) for his services at the FCO. At SPRI, he succeeded Acting Director Dr Peter Friend, who had held the post for a short period following its relinquishment by Dr Peter Wadhams on his appointment as Reader in Polar Studies. Members will be interested to know that the offices of the Secretary General and the Treasurer are now vertically juxtaposed — instead of 55 miles apart!

New members

J. M. N. T. (Nico) Gray, University of East Anglia, Norwich NR4 7TJ, U.K.
Francis M. Jones, 3549 West 28 Avenue, Vancouver, British Columbia V6S 1S1, Canada
Mirco Meneghel, Department of Geography, Universita degli Studi di Padova, via del Santo, 26, I-35123 Padova, Italy
D. Scott Munro, Department of Geography, University of Toronto, Erindale Campus, Mississauga, Ontario L5L 1C6, Canada
Elisabeth Schlosser, Institute of Meteorology and Geophysics, Innrain 52, A-6020 Innsbruck, Austria
Thomas Schneider, Blodstensvägen 36, S-752 44 Uppsala, Sweden
Wolfgang Schöner, Corneliusgasse 16/6, A-2380 Perchtoldsdorf, Austria
Nicholas Spedding, Department of Geography, University of Edinburgh, Drummond Street Edinburgh EH8 9XP, U.K.
Dan Weinstein, 3 Ridgley Terrace, Jamestown, NY 14701, U.S.A.

INTERNATIONAL GLACIOLOGICAL SOCIETY

Lensfield Road, Cambridge CB2 1ER, England

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INTERNATIONAL GLACIOLOGICAL SOCIETY

Lensfield Road, Cambridge CB2 1ER, England

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Membership is open to all individuals who have scientific, practical or general interest in any aspect of snow and ice study. 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: H. Richardson (Secretary General)
Assisted by D.M. Rootes and S. Stonehouse

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