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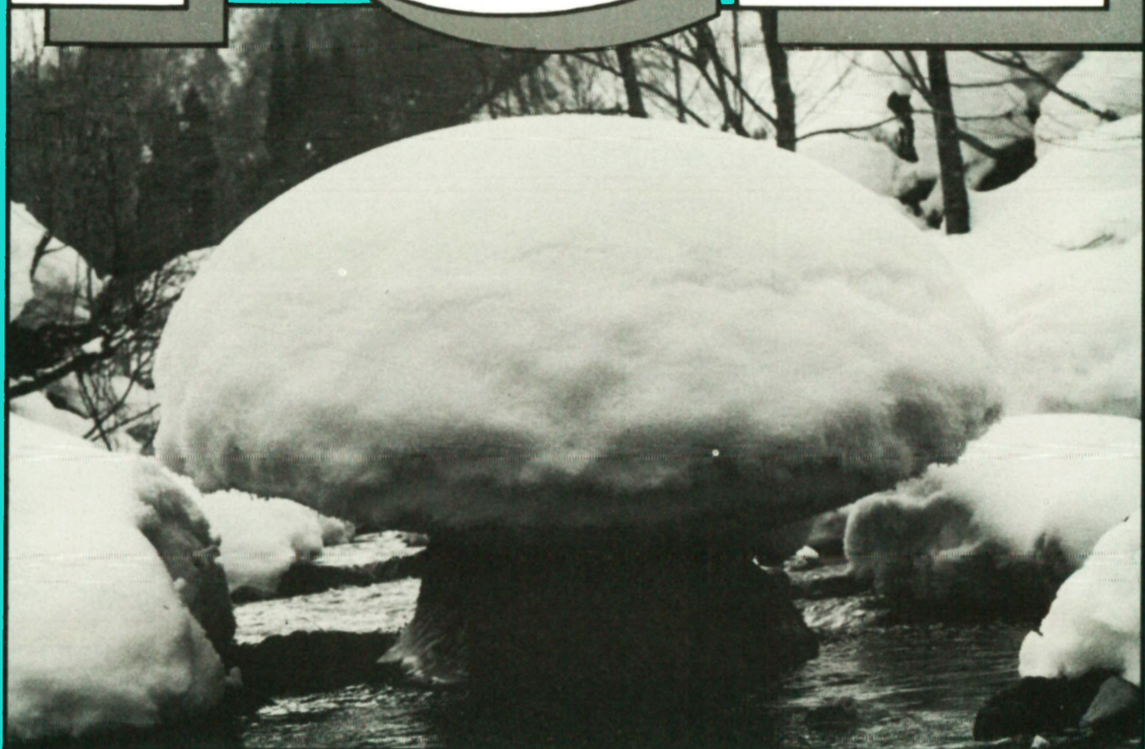

NEWS BULLETIN OF THE INTERNATIONAL GLACIOLOGICAL SOCIETY

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CONTENTS

COVER PICTURE:
Snow mushroom, from *Snow in Japan — a thing of beauty* (photograph and book by Kihei Takahashi).

Recent work

FINLAND

Baltic Sea ice climatology

(J. Haapala, A. Herlevi, M. Leppäranta, T. Saloranta, Z. Zhanhai, Dept. Geophysics, Univ. Helsinki (GEOP/HELS))

The variability of ice seasons in the Baltic Sea is quite large. In the last 100 years the maximum annual ice coverage has ranged from 12 to 100% of the total sea area and the length of the ice season has ranged from three to seven months. The maximum annual thickness of undeformed ice has been 50–120 cm. A seasonal coupled ice–ocean model has been constructed for climatological forecasting for future ice conditions in the region based on various possible scenarios for future atmospheric climate conditions. The model development is to continue to 1999. The main features under investigation are ice melting, snow cover on ice, and wintertime convection. A particular 1D thermodynamics model will be developed for process studies and for examining parameterization schemes. This modelling work is a part of BALTEX which belongs to GEWEX.

In the field of sea-ice morphology and dynamics, both experimental and theoretical basic research is undertaken. The morphology part is highly concentrated in the observation and analysis of ice-thickness distributions. The observation programme is largely based on airborne systems; electromagnetic and thermal infrared. The dynamics research is focused on the role of various possible ice rheologies, the ice–ocean dynamic coupling problem, and the downscaling of ice mechanics from the geophysical scale to the ice-engineering scale.

Gulf of Finland and Gulf of Bothnia

(J. Launiainen, M. Simila, T. Manninen, H. Gronvall, B. Cheng, FIMR)

The Finnish Institute of Marine Research continued annual ice expeditions with the RV *Aranda* in the Gulfs of Finland and Bothnia to study sea-ice geometrics and roughness and obtain ground-truth data for satellite image classification. A method has been developed for automatic sea-ice mapping using radar satellite images. The operational FIMR dynamic sea-ice model was coupled with the high-resolution atmospheric model HIRLAM (Finnish Met. Institute) and a thermodynamic module was developed for the ice model.

Baltic air–sea–ice study: BALTEX

(J. Launiainen, Finnish Inst. Marine Res. (FIMR); B. Brummer, Met. Inst., Univ. Hamburg; B. Hakansson, A. Omstedt, Swedish Met. Hydrol. Inst.; R. Roth, Inst. Met. Climatol., Univ. Hannover; A.-S. Smedman, Met. Inst., Univ. Uppsala; T. Vihma, GEOP/HELS)

The Baltic Air–Sea–Ice Study, a BALTEX (BALTEX-BASIS) field experiment, will be carried out in March 1998 in the Gulf of Bothnia, in cooperation with five institutions in Finland, Sweden, and Germany. A pilot experiment will be arranged in March 1997. BALTEX-BASIS aims at an improved understanding and modelling of the energy and water cycles during winter conditions. The field experiment will collect data, particularly on: (1) exchange of heat, moisture and momentum between the air, ice and sea; (2) structure of atmospheric and oceanic boundary layers and their interaction with the exchange processes; (3) ice motion and atmospheric and oceanic forcing on it; and (4) the interaction between dynamic and thermodynamic processes in the air, sea and ice. Research vessels, aircraft, helicopters, meteorological masts and soundings, buoys, thermistor chains, and instruments on and below the ice will be used.

Power requirements for vessels in ice in the Baltic

(K. Riska, M. Wilhelmsson, Ship Laboratory, Helsinki Univ. Technology (HUT/SL))

The requirements placed on merchant-vessel propulsive power in different ice conditions are beng studied. The project concentrates on ship resistance in navigation channels and formulating the power requirements for different ice classes. The accuracy of earlier calculation methods for estimating resistance have not been satisfactory. Therefore, both full-scale and model tests have been conducted to determine a more accurate method for calculating the resistance of a ship in a navigation channel. A methodology for studying the resistance of ships in brash-ice channels in the model ice basin has also been developed.

Winter shipping

(P. Koskinen, State Technical Res. Center VTT (VTT))

A new method for dimensioning ship machinery against ice loads was performed in 1991–95. Models for calculating the loads that a marine screw propeller experiences during ice/propeller interaction are being developed. The interaction process and various contact geometry and interactions types have been described. The former is described with a simulation model which calculates the ice-block/propeller contact geometry at each time step. The load balance between the blade and the block is based on a contact load model and a model of hydrodynamic disturbance loads caused by the presence of an ice block. This load balance affects the relative velocity between the ice block and propeller and accordingly the contact conditions for the next time step. The models were verified against full-scale events. A set of parameter variations were studied with the simulation model. Finally the results of the parameter runs were condensed by regression analysis to simple load-calculation formulas. The input parameters for these formulas were limited to those considered the most essential.

The ice-going capability and restrictions imposed on small vessels travelling in the ice of the Baltic Sea were surveyed in 1994–95. A large data set was obtained by interviewing ship operators about their experiences navigating through ice. All the main types of small vessels are represented: patrol boats, cutters, fairway supply vessels, coastal service ships, oil recovery vessels, cargo/supply ships and tugs. Interviews were conducted using a questionnaire covering the topics of: vessel operation in different ice conditions; the main operational restrictions which apply; critical operation conditions; dimensioning of structures; and ice damage. Visits were made to 13 small vessels and answers obtained from the operators of 28 vessels. During six of the visits, test runs were made in the vessels being visited. Published research work on full-scale and model-scale tests of small vessels in ice conditions were collected. Tests conducted were found in the main to be performance tests in level ice, measurements of hull ice load, or measurements of propulsion machinery ice load. Ice test data from 14 small vessels have been described.

Ship ice loads in the Baltic

(P. Kujala, HUT/SL)
Probabilistic models have been developed for ice loads in specific ice conditions and for long-term ice loads encountered by shell structures of ships in the Baltic Sea. The models developed give results for the development of design codes for ice-strengthened ships. The developed methods have been verified by extensive full-scale measurements on board IB *Sisu*, MS *Arcturus* and MS *Kemira*. A database of damage statistics has been gathered and analyzed to evaluate the extreme ice-load levels for ships.

Ice environment and hull loading along the NSR

(M. Lensu, S. Heale, K. Riska, P. Kujala, HUT/SL)
To combine ice conditions for ship transit and hull damage calculations, ice conditions have been described in terms of thickness, floe size, leads and ridging. The assumed or observed composition of the ice cover, together with ship parameters, are used as input in a ship-transit simulation model for distributions of transit times, speed and power consumption. The ice-cover parameters are also used in a statistical model of hull-damage probability. These two tools are used for trafficability analyses along the Northern Sea Route and elsewhere. The first phase of the program was part of the International Northern Sea Route Programme (INSROP).

Arctic96

(A. Blanco, GEOP/HELS)
The Department of Geophysics took part in Arctic96, an international expedition to the Eurasian central Arctic Ocean in the summer 1996, on the IB *Oden*. A study of sea-ice thickness and melting was carried out successfully, although little melting was observed. This consisted of field measurements of spectral solar shortwave radiation in the ice and snow, dielectric properties of sea ice, and ice thickness measurements by ground-penetrating (short-pulse) radar. The results will help in understanding the role of the solar radiation in sea-ice melting and in the remote sensing of sea-ice thickness using the electromagnetic method.

Sea-ice dielectric measurements and radar

(J. C. Moore, Arctic Centre, Univ. of Lapland (AC/LAP))
The low-frequency EM properties of sea ice from the Baltic, Greenland Sea and Arctic Ocean have been measured between 20 Hz and 1 MHz with an LCR bridge. The data, at frequencies of several kHz, have been used for information on the conductivity of sea ice for modelling the AEM measurements of sea-ice thickness. Radar sounding, with modified antennas, successfully penetrated cold, multi-year sea ice in the Greenland Sea up to 6 m thick, but seems problematic for the thinner, warm ice encountered during Arctic96. This work is done in cooperation with the University of Oulu, University Courses on Svalbard, and University of Helsinki.

Electromagnetic and laser profiling of sea ice

(M. Lensu, HUT/SL)
A fixed-wing aircraft, mounted with an electromagnetic, ice-thickness sounder and a laser surface profiler, was used to map ice cover in different sea areas and the data analyzed for thickness and ice-ridge distributions. Analysis packages have been developed and the results used to construct theoretical models for thickness and ridging statistics. This work is being done in co-operation with the University of Helsinki and the Geological Survey of Finland.

Design ice forces in multi-year ice

(K. Riska, HUT/SL)
The maximum bow ice force in a head-on collision with a large ice feature has been analyzed. In Canadian ice regulations, this force is part of the definition of all other ice-loading quantities, such as hull load area factors and local pressures.The head-on collision has been treated both analytically and numerically. The analytical model employs Laplace transform methods, and makes some linearisations of the problem. The analytical solution is valid for infinite and non-infinite ice, and takes the hull girder response into account. It is corroborated by a numerical model which solves essentially the same equations in a time-step manner. The solution provides the time-history of vessel motions, ice forces, bending moments, and shear forces in the hull girder. It can be applied directly to the design of ice-going ships. This study is a joint project with Claude Daley (Memorial University of Newfoundland).

Ice dynamics and air–ice–ocean heat exchange, Weddell Sea, Antarctica

(J. Launiainen, J. Uotila, FIMR; T. Vihma, GEOP/HELS)
A project on the ice dynamics and air–ice–ocean heat exchange in the Weddell Sea has been carried out as a part of the Finnish Antarctic Research Program. During 1994–1995 results from the previous Weddell Sea experiments (1990, 1992) were analyzed. The analyses were mostly based on Argos buoy data and considered particularly wind forcing on Weddell Sea ice motion as well as the heat and moisture exchange at the air–ice and air–lead interfaces. Modelling studies on the subgrid parameterization of surface fluxes over a fractured ice cover were made. Some 10 reports are published and all the marine meteorological data sets have been delivered to over 20 institutions and data banks abroad. A new field experiment in the Weddell Sea was carried out in January–February, 1996. Seven buoys were deployed on ice floes to detect ice drift and measure the meteorological surface layer variables. The atmospheric boundary layer was studied by radiosonde soundings, and the surface properties by radiation and turbulence measurements on the ice.

Local ice-cover deformation and mesoscale ice dynamics

(K. Riska, J. Tuhkuri, M. Lensu, HUT/SL)
This joint European project is describing and modelling the processes involved in local ice-cover deformation and incorporating them into the governing equations of mesoscale ice dynamics. Ridge-formation mechanics and ice-floe field deformation are studied experimentally in a model basin and computationally, using the discrete-element model. These physical and numerical experiments

are used to construct analytical models for local deformation processes. The research includes field experiments. The project is funded by the European Commission through the MAST III programme. The participants are the Helsinki University of Technology, Nansen Environmental and Remote Sensing Center, Scott Polar Research Institute, University of Helsinki, and University of Iceland.

Morphological evolution of sea-ice cover

(M. Lensu, HUT/SL)

A unified theory for the evolution of sea-ice morphology is being developed. The evolution is described in terms of differential equations for the distributions pertaining to the morphological variables (ice thickness, floe size, ridges, leads). These equations can then be coupled with dynamic equations to models capable of predicting the morphological evolution.

Compression of circular ice floes

(M. Hopkins, J. Tuhkuri, E. Hansen, M. Lensu, HUT/SL)

The three-dimensional deformation of ice fields made up of thin floes is central to the processes of ice-jam formation in northern rivers, pressure-ridge formation in northern seas, and the dynamics of ice fields in Antarctic marginal seas. Model experiments have been performed in which a floating layer of circular ice floes, confined in a rectangular domain, were uniaxially compressed. The forces exerted by the ice against the moving boundary were measured. Geometrically and dimensionally identical computer simulations have been performed and the calculated forces compared with forces measured in the experiments.

Ice/structure interaction

(K. Riska, S. Wang, HUT/SL)

The failure and breaking pattern of level ice against a conical offshore structure has been simulated. It is assumed that a vertical force breaks the ice cover into successive circular segments. Formation of the segments changes the geometry of the contact area between the structure and the ice cover. The ice pile-up and ride-up phenomena have been of special interest.

Modelling of brittle ice fragmentation

(J. Tuhkuri, HUT/SL)

The brittle failure of ice, and the contact between ice and a structure, have been studied. In laboratory experiments, a block of ice was crushed continuously against a structure, and a sequential flaking process leading to a wedge-shaped failure surface, was observed. It was suggested that flakes were formed through the growth of macro cracks. The growth of these cracks was analyzed and a flaking model formulated using linear, elastic fracture mechanics and the boundary-element method. Through edge flaking a solid can maintain a wedge shape and even evolve into it. Characteristic to the process is that the flakes form in cascades.

Ship in compressive ice

(K. Riska, P. Kujala, L.T. Kosomaa, HUT/SL)

Compressive ice increases considerably the ice loads and the ice resistance of a ship. This problem has been studied experimentally in a model basin and theoretically. Both a uniform, level ice cover and a broken ice field have been used. The research has clarified the additional ship resistance due to ice pressure and thus the susceptibility of ships to getting stuck in ice. It clarified the physical processes present when the ice is pressing at ship sides with a ship stopped in compressive ice. This study is in cooperation with the Institute for Problems in Mechanics of the Russian Academy of Sciences.

Ship trafficability in ice

(K. Riska, HUT/SL)

The passage of a vessel across an ice-covered route has been simulated to determine a ship's suitability for transiting a route of various ice conditions. Transit times and energy consumption on different routes or under different ice conditions are studied. The ice conditions included are those of open water, channel ice, level ice, and pack ice. Ship's speed and energy expenditure calculations are based on ice resistance formulae, developed mainly for the Baltic.

Marine screw propeller ice contact forces

(B. Veitch, HUT/SL)

A model has been developed that simulates the processes that occur when a marine screw propeller and a submerged ice body come into contact. The time simulation predicts the ice contact forces acting on a propeller blade and the motion response of ice. The equations of ice-body motion are a system of six, nonlinear, ordinary differential equations for rigid-body motion. A propeller–ice contact model, based primarily on laboratory ice-cutting experiments, has been developed. An inference, drawn from the experiments, is that contact during ice cutting is concentrated near the propeller blade's leading edge. The model can be used to improve propeller-blade and propulsion-system design.

Icing

(L. Makkonen, M. Marjaniemi, VTT)

Studies on prediction and control of icing, and on estimation methods of accreted ice loads for structural design, continue at VTT. Projects deal with icing problems on towers, suspension bridges, marine structures and wind turbines. Research includes climatological analysis, numerical modelling, physical small-scale modelling and measurements in the field. Ice-detection technology and meteorological measurements under icing conditions are also tested and atmospheric ice-load measurements developed.

Radar sounding of glaciers

(John C. Moore, AC/LAP)

A Ramac GPR operating at 50 MHz and 400 MHz has been used to examine winter snow depths on Brøggerbreen, Lovénbreeen, and Kongsvegen (Svalbard), Hardangerjøkulen (Norway), and on Storglaciären (Sweden). The 400 MHz radar has been compared with a SIR2 radar operated by NVE and NP and results compared with manual sounding and dielectric analyses of shallow ice cores.

50 MHz sounding on the polythermal glaciers shows interesting structure due to internal reflections from ice–water interfaces within the glaciers. Penetration depths are sufficient that the bed of the glacier can be seen easily up to about 300 m. Future development of focused antennas will increase penetration depths. Field work next spring will concentrate on detailed surveys of the hydrological system of some glaciers on Svalbard. This work is in

cooperation with the University of Oulu, Norwegian Polar Institute, Norwegian Water and Energy Resources, and University of Stockholm.

Time-series analysis of GRIP core

(J. Moore, M. Pichl, AC/LAP)

The continuous, 2 cm resolution, dielectric data from the GRIP ice core from Summit, Greenland is being analyzed, particular in the decadal to millennial period range. The data will be used in correlation with analyses of salinity and sea-ice anomalies in the Atlantic Ocean (ACROSS project).

Snow and ice education

(M. Leppäranta, GEOP/HELS; J. C. Moore, AC/LAP)

Since 1994 post-graduate international snow and ice courses have been arranged in the Department of Geophysics, University of Helsinki. In 1994 an extensive 2 week course "Physics of ice-covered seas" was organized together with the IAPSO Sea Ice Commission, in 1995 there was a field and classroom multi-disciplinary Snow School, and in 1996 a Glacier Field Course at Tarfala, Sweden. In 1997 the Snow School and the Glacier Field Course will be re-run.

Snow fun

In the winter 1996 the world's largest snow castle was built in Kemi, northern Finland. A lot of popular and cultural activities were arranged in the castle. A new one will be built in 1997.

Theoretical work and field tests have been done at VTT, together with sports authorities and communities, to improve outdoor skating and skiing conditions. These studies include means of extending the winter sports season by artificial ice and snow-making and ice and snow protection.

Submitted by Matti Leppäranta

NEW ZEALAND

Glacier monitoring programme

(T. J. Chinn, Inst. Geol. Nuclear Sciences Ltd)

A programme to estimate the mass-balance changes of some 48 selected glaciers of New Zealand's Southern Alps has been continued using the end of summer position of the snow-line (ELA) as a surrogate for annual mass balance. The positions of the ELAs were obtained by oblique aerial photographs taken from a hand-held camera in a small fixed-wing aircraft.The flights, timed for the elusive last day of fine weather before the first snowfall of winter, have often encountered cloud before the survey was completed. However, the 1996 flight was the third year in succession when all of the index glaciers were covered. Results of the 1996 survey indicate that the trend to highly positive balances of recent years may be reversing with 5 of the 48 glaciers showing negative balances.

GPR profiles and lake surveys at Southern Alps glaciers

(Ian Owens, David Nobes, Wendy Lawson, Dept. Geography, Univ. Canterbury)

Ground-penetrating radar (GPR) profiles on four glaciers in the Southern Alps (Tasman, Hooker, Franz Josef (upper) and Mueller Glaciers) have elucidated the depth and internal structure of these glaciers at the profile locations, as well as some uses of GPR in research on temperate valley glaciers. Depth data indicate that glaciers on the leeward side of the major north–south divide continue to respond to changes in climate by decreasing in thickness. Internal reflectors and diffractors observed at all profiles are interpreted as large-scale structural and/or hydrological features. In particular, it seems likely that large diffractors observed in profiles of the lower part of the Tasman Glacier are englacial channels of the order of 1–2 m in diameter, that are probably approximately bed-parallel. During this work, GPR has been used successfully on heavily debris-covered ice (debris layer approximately 0.5–1.0 m thick) in the lower ablation areas of the Tasman and Hooker Glaciers. Control experiments conducted in the upper accumulation area of the Franz Josef Glacier suggest that the orientation of buried (sub-snow) crevasses, with respect to the antennae, affects the nature of the signal, and that for the best basal reflection, antennae should be located pendicular to crevasse orientation. Surveying (using GPS) of proglacial lakes at the Hooker and Tasman Glaciers indicates that these lakes are expanding rapidly. The lake at the Hooker Glacier, for example, doubled in surface area between 1986 and 1996.

Submitted by T. J. Chinn

USA - ALASKA

GLACIERS

Geophysical investigations, Black Rapids Glacier

(M. Nolan, O. Cochran, K. Echelmeyer, W. Harrison, GI-UAF; T. Gades, C. Raymond, GEOPHYS-UW)

Black Rapids Glacier is a surge-type glacier in the central Alaska Range. Its last surge (1936–37) was the first "galloping glacier" to attract wide public attention. Recently we have monitored surface geometry and velocity, vertical strain, passive seismicity and hydrologic properties of the glacier stream. Active seismic and ice radar methods were used to investigate both the spatial and temporal nature of the glacier bed. Large variations in speed occur in the spring and summer, especially when marginal lakes drain. We attempted to illuminate changes in basal properties during these speed-ups using geophysical methods. Seismic reflections indicate extensive regions of the bed temporarily become "seismically transparent", and that water storage occurs. Analysis of the seismic data also suggests the presence of a till layer beneath the glacier. Studies of the terminal stream indicate significant changes in the basal hydraulic system during the glacier speed-ups, and that the character of this hydraulic system changes through the summer.

Drilling program, Black Rapids Glacier

(W. Harrison, M. Truffer, D. Pomraning, M. Nolan, K. Echelmeyer, GI-UAF)

In April 1996, seven holes were drilled to the bed of Black Rapids Glacier across a transverse profile and were 350 to 650 m deep; four were instrumented for water-level measurement. Only one of the holes connected to the basal hydraulic system at the time of drilling, but data indicate the other holes connected shortly thereafter. All holes show similar patterns of complex but low water pressures in summer, with temporary events of higher pressure approaching or exceeding overburden. Some of these events are correlated with increased glacier seismicity and motion. The morphology of the bed will be investigated by wireline drilling in 1997. We will attempt to obtain relatively undisturbed cores of the basal ice and underlying material. Based on earlier seismic investigations, we expect to encounter a thick layer of water-saturated till over bedrock. Experiments on the rheology of the basal material in these cores will be made.

Marginal shear zone of Ice Stream B, West Antarctica

(W. Harrison, K. Echelmeyer, GI-UAF)

The role of the shear margins in ice stream flow has been investigated by making ice temperature and surface velocity measurements in the margin of Ice Stream B. Analyses of the deformational warming and shear strain rates indicate the margins provide a large part of the total drag on the ice stream, with marginal shear stresses as high as 2 bars. These measurements provide two independent means of determining the migration rate of the margin into the ice sheet. In one, the migration of the transverse velocity profile is measured. In the other method, the downward rate of propagation of low temperatures caused by the ponding of winter air in marginal crevasses is determined. Both sets of measurements indicate the marginal zone is migrating outward into the ice sheet at a rate of about 10 m per year.

Airborne laser profiling of mountain glaciers

(K. Echelmeyer, W. D. Harrison, J. DeMallie, B. Rabus, L. Sombardier, GI-UAF)

An airborne profiling system for measuring elevation changes on glaciers has been developed and tested. It consists of a laser ranger for measuring distance to the glacier, a gyroscope for determining the pointing direction of the laser and kinematic GPS for determining aircraft position. The system is lightweight, compact, and relatively inexpensive. It is mounted in a small aircraft capable of making low altitude flights along curving mountain glaciers. The overall accuracy of the system is about 0.3 m. To date we have profiled approximately 65 glaciers in Alaska, Canada and Washington. The glaciers were chosen to span different climatic zones, and different types and sizes. Changes in surface elevation and volume are determined by comparison of these profiles with existing maps. The accuracy of the calculations is limited by the map accuracy, which is often poor in remote regions or where the surface was ill-defined in the mapping photographs. Preliminary estimates show that a majority of the glaciers have undergone a decrease in surface elevation since the 1950s, though some have thickened. Repeat profiles have been made on some of the glaciers after an interval of a few years to determine short-term mass balance. Two projects, described below, are using these profile data for specific investigations.

Volume change of the nine IGY glaciers

(J. Sapiano, GI-UAF)

A set of nine glaciers in Alaska and Washington was mapped in detail as part of the International Geophysical Year (IGY, 1957–58). These are the most complete glacier maps of this era in North America, and the glacier locations span many of the climatic zones of Alaska, plus the Pacific Northwest maritime climate. We have flown laser elevation profiles along each of them. GPS measurements have been made at recovered IGY control points to tie each of the earlier maps into an absolute coordinate system. Elevation change along each flight path has been determined. A program for determining the volume change of the glaciers from the profiles of elevation change was developed. The volume changes show substantial thinning on many, but not all, of the glaciers. However, the termini of almost all of them have retreated.

Glaciological research, McCall Glacier

(B. Rabus, K. Echelmeyer, GI-UAF)

McCall Glacier, a polythermal valley glacier, has the only long-term glaciological record in northern Alaska. Previous studies in 1957/58 and 1969/72 concentrated on mass balance and meteorology. In 1993, we resumed measurements of annual mass balance and meteorological parameters, made a detailed map of ice thickness, and measured volume and terminus changes since the 1970s. Volume changes since the 1950s were also measured on ten other glaciers in the vicinity. Our data show a regional trend of strongly increasing mass wastage that is well represented in the mass balance of McCall Glacier. A simple two-parameter degree day/accumulation model adequately predicts the mass balance of McCall Glacier using as input radiosonde data from Inuvik, Canada, 400 km to the northeast. However data from Barrow, Alaska, about 500 km to the northwest, give incorrect results, suggesting a large spatial variation in climate in northern Alaska. Modeling the flow of McCall Glacier from ice thickness and surface slope reveals significant year-round sliding in the lower ablation area. We also observe a seasonal increase in sliding underneath most parts of the glacier. The spatial and temporal distribution of sliding reflects the polythermal ice temperature distribution and the extremely short but vigorous melt season on McCall Glacier.

Glacier changes on the Harding Icefield

(Gudfinna Adalgeirsdóttir, GI-UAF)

Harding Icefield is an 1800 km^2 icefield on the Kenai Peninsula of southcentral Alaska. There are 23 named outlet glaciers draining it, some of which terminate in tidewater. The icefield and 14 of the largest glaciers were mapped with an airborne laser profiler. Elevation changes since 1950 are being estimated by comparing profile results with U.S. Geological Survey topographic maps. The upper firn-covered part of the icefield had poor definition in the original mapping photography, and the maps may have significant errors there. One goal of the project is to compare the changes of glaciers terminating in tidewater with those terminating on land. Repeat profiles on a few of the glaciers have shown some thinning (negative mass balance) between 1994 and 1996.

1994–95 surge of Variegated Glacier

(W. Harrison, K. Echelmeyer, GI-UAF; C. Raymond, GEOPHYS-UW)

A surge of Variegated Glacier was observed during summer 1995. It probably started in autumn 1994, and it ended in June 1995. The previous surge was in 1982–93, making a recurrence interval of 12 or 13 years, several years less than the average interval this century. The surge front did not propagate as far down glacier as in previous surges. A large flood occurred at the termination of the surge. Airborne elevation profiles along the glacier, made in 1995 and 1996, will allow determination of changes in elevation near the end of the surge for comparison with elevations measured during the previous surge.

Glacier monitoring, Denali National Park and Preserve

(P. Brease, J. Roush, NPS-DENALI)

The long-term glacier program at Denali National Park and Preserve will characterize potential threats to park visitors and facilities, monitor effects on water resources, and provide an understanding of mass-balance trends and their relation to regional and global climatic conditions. Glacier monitoring started in 1991, when index sites for measuring mass balance, flow, and surface elevation were installed on Kahiltna and Traleika Glaciers. Measurements are made twice annually, in late May and late August, by L. Mayo (USGS retired) in cooperation with NPS personnel. The termini of Middle and West Fork Toklat Glaciers, Polychrome and Polychrome West Glaciers, Cantwell, Cul-de-Sac, and Tatina Glaciers were surveyed in 1994 and 1995. Longitudinal profiles, using both GPS surveying and airborne laser profiling of several glaciers, including Kahiltna, Ruth, Muldrow, Toklat and Polychrome Glaciers was done by K. Echelmeyer and W. Harrison (GI-UAF). Flow of the Muldrow Glacier has been measured periodically since the installation of a single surface target near McGonagall Pass by Bradford Washburn in 1976. Flow rates have averaged $45\,m\,a^{-1}$ during the last 20 years. Targets established further down glacier in 1995 have shown movement ranging from $28\,m\,a^{-1}$ near Anderson Pass, to $3\,m\,a^{-1}$ near the terminus. Additional measurements of Muldrow Glacier's surge potential are ongoing in cooperation with P. Jay Fleisher (SUNY, Oneonta). A program is being developed for long-term monitoring of glacier area and mass balance on a park-wide scale. Long-term monitoring will rely primarily on remote sensing with some ground observations.

Surface velocities from ERS-1 SAR imagery, Malaspina Glacier

(V. A. Voronina*, C. S. Lingle, GI-UAF [*now at Colorado Center for Astrodyn. Res., Univ. Colorado (CCAR)])

The piedmont lobe of Malaspina Glacier is characterized by immense folded moraines which form striking patterns in satellite images and air photographs. The moraines may be expressions of periodic surging superimposed on a flow regime characterized by longitudinal compression and transverse extension, as suggested by A. Post for the Bering piedmont lobe, where smaller folded moraines occur that appear otherwise to be analogous. Surface velocities on Malaspina Glacier have been measured using 29 June 1992 and 14 June 1993 SAR images from a 35 day exact repeat orbit. Cross-correlation of sequential satellite images was employed to calculate velocity. Three of the resulting velocities were compared (in an approximate sense) to velocities measured earlier in nearby locations by R. Krimmel and M. Meier over a 10 year period, by comparing ERTS imagery acquired in 1972 to a mosaic of Malaspina Glacier compiled by A. Post using aerial photographs acquired in 1962. Agreement was found to be within 4–20%.

Surface elevation changes from satellite radar altimetry, East Antarctic ice sheet

(C. S. Lingle, D. N. Covey, V. A. Voronina,* GI-UAF [*now at CCAR])

Antarctic ice-sheet altimetry from the first half of the ERS-1 mission (1991–93), the Geosat Exact Repeat Mission (1986–89), the Geosat Geodetic Mission (1985–86), and Seasat (1978) have now been re-processed with JGM-2 orbits and improved retracking by the ice-sheet altimetry group at NASA Goddard Space Flight Center and STX. Measurements of multi-year regional mean changes in surface elevation are being carried out on the East Antarctic ice sheet north of 72° S, which is within the orbital coverage of Geosat and Seasat as well as ERS-1, using the method of orbit crossover analysis.

Time-dependent numerical model of Antarctic ice sheet

(E. N. Troshina, C. S. Lingle, GI-UAF)

The radar altimeters on ERS-1 and ERS-2, in orbit since 1991, have resulted in substantially improved digital elevation models of the Antarctic ice sheet to 81.5½ S. Within the next several years, the altimetry time series may be long enough to yield preliminary measurements of regional mean changes in surface elevation. A time-dependent numerical model of the ice sheet is under development, to interpret the measured changes in terms of longer-term changes in flow and accumulation. In its present form, the model is vertically integrated and solves the equation of mass continuity on a 20 km staggered grid in a map plane. The constitutive equation is Glen's flow law with $n = 3$. Motion is assumed to occur by shear-strain rates parallel to the geoid. An alternating-direction, implicit finite-difference method, with a 1 year time step, is employed to solve the model equations, which have been extended to include a basal sliding relationship appropriate for 'soft bed' sliding. The model has been applied to the Antarctic ice sheet, digitized from the SPRI Antarctic Map Folio with the present mass balance. A set of 5000 model-year test runs has shown the sensitivity of the ice-sheet to basal sliding.

Bagley Icefield during the 1993–94 Bering Glacier surge

(D. R. Fatland, GI-ASF-UAF) Differential satellite radar interferometry has been employed to separate the surface motion and topographic signals in interferograms synthesized from SAR images acquired over Bagley Icefield before and during the recent surge of Bering Glacier. The preliminary results show West Bagley Icefield, previously thought not to participate significantly in the periodic surges of Bering Glacier, experienced significant acceleration during the 1993–94 surge.

Benchmark monitoring of Gulkana and Wolverine Glaciers

(R. March, D. Trabant, B. Kennedy, USGS-Fairbanks)
Long-term glacier/climate monitoring, begun in 1966, continues at Gulkana and Wolverine Glaciers with continuous measurements of air temperature and precipitation, and seasonal measurements of glacier mass balance, surface altitude and flow. Additionally, continuous stream discharge below the glacier during open-water conditions, continuous wind speed, and annual terminus position are being measured at Gulkana Glacier. Photogrammetric remapping of the Gulkana Glacier basin, begun in 1992, is nearing completion. A digital terrain model has been compiled and will be turned into a 5 m contour interval topographic map after assessment of its accuracy by comparison with surveyed glacier-surface altitudes at about 70 points along longitudinal and cross profiles of the glacier. It is anticipated that the new map will lead to a significant improvement in the determination of the glacier's area altitude distribution and its change with time, which in turn will lead to a recalculation of the glacier's long-term balance history.

Drift Glacier, Alaska Volcano Observatory

(D. Trabant, USGS-Fairbanks)
The Alaska Volcano Observatory has supported an investigation of the volume of perennial snow and ice, and its distribution in both aspect and altitude, on Redoubt Volcano, Alaska. The glacier volume assessment was performed using three-dimensional volume modeling supported by a geographic information system. The model was developed and tested along a 2.5 km reach of Drift Glacier, removed by the 1989–90 eruption. A "measured" volume for the control reach was determined from before-and-after eruption maps produced from large-scale vertical aerial photography. The glacier-bed–surface model was controlled by third-order polynomial fits to the valley walls exposed above the glacier surface. The modeled volume was larger than the "measured" volume of the control reach by about 1%. Glacier volume estimation for the entire massif was not as good, due to a reduced number of polynomial cross sections and less well-controlled estimates in areas where there were limited or no confining valley walls. The total volume of perennial snow and glacier ice on Redoubt Volcano was estimated to be 4.09 km^3 $\pm$ 20%.

Volcano–glacier interaction, Mt Wrangell

(C. S. Benson, GI-UAF, T. Follett, AeroMap U.S.)
Volcano-glacier interactions on Mt Wrangell are being studied by measuring variations in the ice volume within the North Crater on the rim of the Summit Caldera at 4000 m altitude. These measurements are now being done by precision photogrammetry. Our aerial photography record spans nearly 4 decades with annual coverage since 1972. Observations on the surface date back to the High Altitude Cosmic Ray Studies in 1953–54, so they have allowed us to observe changes following the Great Alaskan Earthquake of 1964 in Prince William Sound.

SAR Imagery to detect glacier facies, Wrangell Mountains

(C. S. Benson, C. S. Lingle, K. Ahlnäs, GI-UAF)
Mt Wrangell was selected as an Alaskan research site in 1961 partly because it appeared to be a good place to find the full span of glacier facies. Detailed measurements at the summit showed that indeed the dry snow facies was present; Mt Wrangell is a "vest pocket" example of the assemblage of glacier facies which covers a huge area in Greenland. Since SAR imagery penetrates the surface and can locate facies boundaries not visible at the surface (dry snow line and wet snow line), we have looked for these boundaries on SAR imagery of Alaska. The boundaries show, to the extent that the facies boundaries on Mt Wrangell appear even on a map showing all of Alaska. A detailed study of SAR imagery over the Wrangell Mountains is now being made.

Fireweed rock glacier, Wrangell Mountains

(E. F. Elconin, Anchorage; E. R. LaChapelle, McCarthy)
A late-summer flood in 1993 caused the entire snout of the compound Fireweed rock glacier to calve. Geomorphological studies of it and its environs began immediately afterwards. Composition and structure of the full transverse cross section exposure were documented and mapped in the summer of 1994. These revealed that Fireweed rock glacier is composed of a debris-covered ice mélange. The rock–ice mass is built by steady-state accumulation of polygenetic ice and talus at the bases of cirque headwalls and subsequently moves down-slope by glacier-like flow. Maximum flow rate of the trunk rock glacier, measured from 1994 to 1996, exceeded 3.80 m a^{-1}. A plan is being developed to perform two-dimensional flow measurements and a geophysical survey.

Bank and channel erosion of a glacial river

(E. Chacho, J. Zufelt, J. Wuebben, USA CRREL)
The Tanana River is a large, glacial-fed, braided river in interior Alaska. Channel migration and bank erosion have adversely impacted a 100 km stretch of the Richardson Highway. This study will identify potential future erosion sites in the vicinity of the highway and evaluate possible methods of bank protection. The patterns of channel migration and bank erosion will be determined through analysis of aerial photos, site surveys and the design and construction records of past erosion control projects.

Hydrologic hazards from Kennicott Glacier, Wrangell Mountains

(R. L. Rickman, USGS Anchorage; D. S. Rosenkrans, NPS-Wrangell)
The Kennicott Glacier dams several side valleys where unstable, ice-dammed lakes form, the largest of which is Hidden Creek Lake. It drains annually, producing floods that threaten a cable crossing of the West Fork of the Kennicott River, soon to be the site of a bridge, and an increasingly popular Park destination for summer tourists. Studies were undertaken to better understand and predict floods from Hidden Creek Lake. Precursors to outburst floods include a gradual rise in river stage 4–6 days prior to floods, the onset of Hidden Creek Lake drainage with ice calving into the lake becoming evident, and a noticeable clean ice "bathtub" ring. The peak discharge during one outburst flood is estimated at 1400 $m^3 sec^{-1}$. The Kennicott Glacier has been down-wasting and retreating since 1860, accompanied by considerable change in the location and configuration of outwash channels. For example, the East Fork of the Kennicott River has nearly been abandoned as an outwash channel, with the outflow now carried by the West Fork. Future changes could increase the potential impact of outburst floods.

SEA ICE

Evaluation of Radarsat geophysical processor system

(K. C. Partington, GI-ASF-UAF, with JPL and UW)
The Radarsat Geophysical Processor System (RGPS), designed and developed by University of Washington and Jet Propulsion Laboratory, is being evaluated prior to delivery to Alaska SAR Facility for operations (1997). Radarsat Scansar B data will be recorded over the Arctic Ocean, giving complete coverage every 6 days. The system is designed to generate information on ice motion, ice age, ice thickness and data or melt and freeze-up, with the fundamental product being a Lagrangian database. The RGPS products will be widely available and interested parties are encouraged to contact the ASF for further information.

Sea-ice modeling

(A. Lynch, J. Walsh, G. Weller, GI-UAF)
The Arctic Region Climate System Model (ARCSyM) has been developed to simulate coupled interactions among the atmosphere, sea ice, ocean and land surface of the western Arctic. The atmospheric formulation is based upon the NCAR regional climate model RegCM2, and includes the CCM2 radiation scheme and the Biosphere–Atmosphere Transfer Scheme (BATS).

The dynamic–thermodynamic sea-ice model includes the Hibler–Flato cavitating fluid formulation and the Parkinson–Washington thermodynamic scheme and is linked to a swamp ocean. Simulations have been performed at a range of horizontal resolutions, from 7 km to 63 km, and experiments at the coarser resolutions have addressed the model sensitivity to sea-ice dynamics (rarely done in global climate models).

Simulations at finer resolutions have addressed the formation of the St Lawrence Island polynya (SLIP) in the Bering Sea. Observations of the polynya have previously been limited to large-scale, low-resolution imagery or costly field expeditions that are highly dependent on season and cloud conditions, although SAR imagery has improved the situation in recent years. Modeling a SLIP event (the opening and closing of the polynya) has been a difficult task due to the relatively small size of the polynya leading to the requirement for a regional-scale coupled atmosphere/sea ice model. With the development of ARCSyM, simulation of the SLIP has been achieved. SAR data were used to validate the model simulations successfully.

Summer sea-ice properties, structure and SAR signatures, Beaufort/Chukchi Seas

(M. O. Jeffries, S. Li, K. Schwartz, W. F. Weeks, GI-UAF)
To improve our knowledge and understanding of (1) the development of Arctic pack-ice floes, (2) the physical and structural properties of warm Arctic sea ice, and (3) the physical and structural controls on SAR backscatter from summer sea ice, field investigations were completed aboard the USCGC *Polar Star* in August and September 1992 and 1993. ERS-1 SAR data have been acquired from the ASF. A simple model has been developed to determine ice-floe melt-pond fractions from SAR backscatter variability.

Sea-ice development and SAR signatures, Pacific sector of the Southern Ocean

(M. O. Jeffries, S. Li, K. Morris, W. F. Weeks, GI-UAF; A. P. Worby, Antarctic CRC, Univ. Tasmania (CRC); R. Jana, Instituto Chileno Antartico; T. S. Chuah, Univ. Kansas)
Field investigations, including snow-cover characterization, ice-core analysis of structure and stable isotopic composition, measurements of snow and ice thickness, and in situ radar scatterometer measurements were completed aboard the R/V *Nathaniel B. Palmer* in August and September 1993 in the Bellingshausen and Amundsen Seas, and in September and October 1994 in the Amundsen and Ross Seas. ERS-1 SAR data, originally recorded in August and September 1993 and in January–March 1994 at the German Antarctic Receiving Station at O'Higgins Base, have been acquired from the German Processing and Archiving Facility for comparison to field data.

Snow in Antarctic sea-ice development and ocean–atmosphere energy exchange

(M. O. Jeffries, K. Morris, GI-UAF; M. Sturm, CRREL-Alaska; R. Massom, CRC; R. Jana. Instituto Chileno Antartico)
Field investigations, including extensive characterization of the snow cover, its temperature and properties, the ice and its stable isotopic composition, and measurements of snow and ice thickness, were made during cruises aboard the R/V *Nathaniel B. Palmer* in May and June 1995 in the Ross Sea between the ice edge and the Ross Ice Shelf, and in August and September 1995 in the northern Ross Sea and the Amundsen and Bellingshausen Seas. General descriptions of the snow and ice in these sectors have been produced, and a one-dimensional model of ice growth, snow accumulation, seawater flooding and snow-ice formation is being developed.

East Siberian river-ice and sea-ice processes

(M. O. Jeffries, S. Li, K. Morris, W. F. Weeks, GI-UAF)
Lake- and river-ice processes in the Kolyma, Indigirka and Anadyr river basins, and ea-ice processes in the Gulf of Anadyr and the East Siberian Sea, are being investigated as they relate to the role of lake, river and sea ice in the storage and transport of pollution and contaminants. ERS-1 SAR data from the Alaska SAR Facility are being used to document the large-scale patterns of ice growth and decay, to derive ice motion vectors in the East Siberian Sea, and for interferometric analysis of river- and landfast sea-ice processes.

Climate sensitivity of thaw lakes on the Alaskan North Slope

(M. O. Jeffries, T. Zhang, W. Zhou, GI-UAF; G. E. Liston, Dept. of Atmospheric Science, CSU)
ERS-1 SAR images from the Alaska SAR Facility have been used to identify which lakes on the Alaskan North Slope and the Kolyma Lowlands, Russian Far East, freeze completely to the bottom each winter, and when they do so. A one-dimensional numerical model is used to determine the ice thickness, and thus the maximum water depth, at the time each lake freezes completely. This method is used to determine the bathymetry of individual lakes, and to determine the water-depth distribution and

water availability in a population of lakes. The lake-ice growth model is coupled to a two-dimensional permafrost model to simulate the effects of ice growth and the complete freezing of lakes on the soil thermal regime below and adjacent to the lakes. The soil thermal regimes associated with different lake-basin shapes and sizes are simulated, and sensitivity tests are run in order to assess some of the potential impacts of climate change.

Radarsat and the Antarctic coastal polynya pilot study

(M. O. Jeffries, GI-UAF; V. Lytle, R. Massom, K. Michael, CRC)
The all-weather, all-season, high-resolution and enhanced wide-swath capability of the RADARSAT SAR will be used to investigate in detail the dynamics and thermodynamics of an East Antarctic coastal polynya. This will include: (1) characterizing and monitoring sea ice type and open water distributions in the vicinity of the polynya; (2) monitoring the sea-ice motion field, and estimating rates of ice production as they affect heat and brine fluxes; and (3) conducting time-series analysis to examine possible seasonal and inter-annual variability in polynya dynamics and thermodynamics. A field experiment is planned for August 1998 using the RSV *Aurora Australis* and other vessels.

SNOW

CRREL Research Report 70: Greenland snow stratigraphy

(C. S. Benson, GI-UAF)
Research Report 70 (RR70) has been reprinted because it is still in demand and referred to, but was out-of-print and largely unavailable. Also, since the report first appeared, several ice cores have penetrated to the bottom of the ice sheet along the traverses covered in the report: (a) the U.S. GISP-2 Core (72°34′ N, 38°28′ W) and the nearby European GRIP Core (72°34′ N, 37°37′ W) done in 1990–1993, near Station 4-325 (72°28′ N, 40°20′ W) of RR70, and (b) the 1966 Camp Century core (77°10′ N, 61°08′ W) near Station 2-20 (77°13′ N, 61°01′ W) of RR70. The report contains data which demonstrate lateral continuity of strata (at 10 and 25 mile intervals) extending several hundred miles, both north and south from these core sites. Some corrections have been made, plus an up-dating of the ***glacier facies concept*** with a new diagram of "the assemblage of glacier facies".

Diagenetic changes in the snow pack, interior Alaska

(C. S. Benson, R. Brenner, GI-UAF)
These experiments to investigate diagenetic changes in the snow pack of interior Alaska, caused by strong and persistent temperature gradients in the snow, have been underway for over three decades and the benefit of a long series of observations is apparent. The research has included the measurement of stable isotopes (H/D and O^{18}/O^{16}) to track the movement of water vapor, within the snow, and into the snow from the underlying soil. The formation of depth hoar is especially pronounced in this snow and has been observed to be accompanied by a reduction in the electrical conductance of the derived melt water. Experiments to investigate the chemical changes responsible for the reduction in ions in the snow are currently underway.

Passive microwave investigations of seasonal snow cover

(C. S. Benson, GI-UAF; D. K. Hall, NASA-Goddard)
Alaska's seasonal snow cover and its interaction with vegetation types across all of Alaska is being examined on passive microwave imagery. A persistent anomalous minimum in brightness temperature has been observed just north of the Brooks Range. Several ideas are being pursued to explain this. Vegetation plays a major role in controlling the brightness temperature independently of the snow cover.

Snow distribution studies on the North Slope

(M. Sturm, J. Holmgren, CRREL-Alaska; G. Liston, Dept. of Atmospheric Sciences, CSU, C. Benson, M. Koenig, GI-UAF)
The distribution and character of snow on the North Slope of Alaska is being studied through field measurements and modeling. The work is part of a larger program (LAII) to determine the response of the Arctic ecosystem to climate change. Between 1995 and 1996, we made four over-snow traverses of the Kuparuk Basin (each > 200 km long) where we made extensive measurements of the distribution of snow depth and other snow properties. In addition to traditional methods, a vehicle-mounted FM-CW radar was successfully used to collect over 250 000 measurements of snow depth. These measurements form the basis of a distribution map. From it we have determined regional trends in snow depth, snow water equivalent, and the percentage of the snow pack consisting of depth hoar. The map is also being used to check two models which allow us to distribute snow over the landscape from more limited input. One model is physically based. Using measured wind speed, temperature and precipitation, it "evolves" a snow cover over the winter. The second model is based on relationships between the snow and landscape. It has been checked against end-of-winter aerial photography and appears to provide a way of deriving maps of snow distribution from limited topographic data.

Experimental and numerical studies on snow mechanics

(J. Johnson, S. Barrett, CRREL-Alaska)
CRREL is trying to improve its ability to use snow mechanics to solve engineering problems at high (shock waves) and intermediate (vehicle mobility) strain rates. The effort involves studies to understand the parameters that determine snow's deformational response to load, the development of methods to measure those parameters, and the development of methods to accurately calculate solutions to engineering problems. CRREL's extensive data set for the response of snow to shock loading is being used to calculated the performance of explosives in snow in collaboration with the Sandia National Laboratories. Experimental and numerical studies are being conducted to determine the role of micro-structure on snow compaction. The interaction between the individual ice grains that make up the snow are modeled and then related to the macro-scale behavior of the snow. The model, in conjunction with experiments, is used to obtain information about the influence of particle shape, bonding, deformation and movement that can then be used to develop macro-scale constitutive models. Studies are also being conducted to develop better instruments for

measuring snow loads and snow properties related to snow mechanical response to load. A new generation snow load sensor is being developed as a possible replacement for the National Resource Conservation Service's snow pillow, and a collaborative study with M. Schneebeli (Swiss Federal Institute for Snow and Avalanche Research) is in progress to develop a new snow penetrometer.

Land surface treatments in a regional climate model of the Arctic

(A. Lynch, J. Tilley, G. Weller, GI-UAF; W. Chapman, J. Walsh, Univ. of Illinois, D. McGinnis, Univ. of Colorado-Boulder)

In this modeling work we are focusing on interactions and feedbacks between the atmosphere and underlying land surface of the Arctic to improve our understanding of the role of the Arctic in global change. The land-surface area switches from snow-covered to bare ground rapidly, impacting the climate both hydrologically and radiatively. The land area is also underlain by permafrost, believed to represent a large net carbon store and thus a potential source of greenhouse gases. General circulation models predict amplified warming over land areas in the Arctic. This amplification could be due in part to inadequate representations of atmosphere-surface feedbacks in GCM models. We have conducted 1-D test simulations of three leading land-surface packages, BATS, LSM, and CLASS, using field data from several sites on the North Slope, and additional tests using data from Barrow are currently underway. Preliminary results indicate that the spring transition, with accompanying snow melt, is not only a large driving force in the surface hydrology, but the primary driver contributing to local perturbations in climate. Initial comparisons also tend to suggest that the LSM package, with the largest number of soil layers, represents processes in the active layer and permafrost to the greatest degree of accuracy and provides somewhat more realistic feedbacks to the atmosphere than the other packages, however, additional tests are needed to confirm these findings. Continuing work, including detailed principal-component analysis of the results, is underway.

Abbreviations used in this report:

CRREL-Alaska U.S. Army Cold Regions Research and Engineering Laboratory-Alaska
CSU Colorado State University
GEOPHYS-UW Geophysics Program, University of Washington, Seattle, WA
GI-UAF Geophysical Institute-University of Alaska Fairbanks, AK
GI-ASF-UAF Geophysical Institute-Alaska SAR Facility-University of Alaska Fairbanks, AK
JPL Jet Propulsion Laboratory, Pasadena, CA
NPS-Denali U.S. National Park Service, Denali National Park and Preserve
NPS-Wrangell U.S. National Park Service, Wrangell-St Elias National Park and Preserve
UAF University of Alaska Fairbanks, AK
USGS-Fairbanks U.S. Geological Survey-Water Resources Division, Fairbanks, AK
UW University of Washington, Seattle, WA

Submitted by Matthew Sturm

UZBEKISTAN

Investigations of glaciers in the SANIGMI during the last decade

The end of the 1990s marks more than one hundred years of continuing investigations of central Asian glaciers by scientists and collaborators of the Central Asian Research Hydrometeorological Institute (SANIGMI), Hydrometservice of Uzbekistan, and its predecessors. The main developmental stages are described in the monograph "Essays on the development of central Asian hydrometeorology". Investigations by the Department of Glaciology this decade have determined the main directions for glaciological work by the Uzbekistan Hydrometservice at least till the year 2000. These include studies by V. G. Konovalov on mathematical modelling, computation and forecasting of the main characteristics (ablation, accumulation, runoff) of the long-term hydrological regime of central Asian glaciers. SANIGMI specialists have participated in numerous glacier field studies jointly with collaborators from the Uzbekistan, Kazakhstan, Kirgizstan and Tadjikistan Hydrometeorological Services, providing quality control for the hydromet-services of the central Asian Republics, and scientific and methodological leadership.

Influence of Pamir–Alai and Caucasus glaciers on river runoff

For the first time since the catalogue of USSR glaciers was compiled, changes in the size of Pamir–Alai glaciers from 1957 to 1980 have been determined (V. G. Konovalov, A. S. Schetinnikov, A. A. Akbarov, V. Sh. Tsomaya). Using air- and space photos, it has been revealed that glaciers of the Gissaro-Alai and Pamirs have shrunk in area by 15.8% and 10.8% and in volume by 16.6% and 12.4% from the 1957 values of 2183 km^2 and 105 km^3 (Gissaro-Alai) and 7362 km^2 and 534 km^3 (Pamirs). Glacier loss was confirmed also by the prevailing negative annual mass balances in several experimental basins (glaciers Abramov, Golubin, Karabatkak and others).

Data collected included: long-term maximum altitude of the snow line; dates of the beginning, end and duration of bare ice melting at the termini of glaciers; monthly and seasonal volumes of total melting; and glacier runoff. It has been calculated that the total glacier melt and glacier runoff within the Pamirs declined from 1.170 km^3 to 0.335 km^3 from 1957 to 1980. For Gissaro-Alai glaciers the estimates are 0.783 km^3 and 0.169 km^3. It is interesting there has been no reduction in the total runoff of the Vakhsh and Pyange rivers, which might be explained by greater winter–spring precipitation and summer air temperatures.

Forecasting glacier runoff

The main conclusion reached in forecasting total July–September runoff is that, for river basins where the area of glaciers is not less than 3%, the snow- and ice-melt components should be determined separately. Forecasting formulae were determined for the main river basins of the Pamirs and the methods used successfully by the Uzbekistan and Tadjikistan hydrometeorological services, who are also successfully using the same approach for monthly hydrological forecasts. At present, the regional model of total glacier melt and runoff is being used in automated hydrological forecasts for the Amudarya river basin (V.G. Konovalov).

F. I. Pertziger has developed methods for forecasting seasonal, monthly and daily discharges of river basins located at the northern slope of the Alai range. These methods are based on data from the Abramov Glacier and a hydrograph simulated by the isochrone model.

Glacier hydrological components, central Asia and Caucasus

A guidebook has been prepared on determining glacier statistical parameters and forecasting glacier runoff, with updated methods for estimating generalized values of glacier morphometric characteristics. These results were an IHP contribution to the USSR Section of Glaciology (V. G. Konovalov, V. Sh. Tsomaya).

Glaciological data base

A major project has been the development of a data base on central Asian glaciers. As part of this A. S. Schetinnikov compiled a map on the contemporary glaciation of Uzbekistan and a catalogue of surging glaciers in the Pamirs and Gissaro-Alai, highly valued by the glaciologists of the Geography Institute in Moscow. Work on updating the data base continues and includes computer routines to provide specified information to users, statistical processing of data, and the production of reports.

At present the data bank "Glaciers" includes the following: (a) General information about all central Asian glaciers for 1957, and only on the Pamiro-Alai territory for 1980, (b) Data on glaciers in the experimental basins: Abramov, Tuyuksu, Aktru, Djankuat, etc., c) Data from the "Catalog of surging glaciers within the Pamirs and Gissaro-Alai areas". The principal participants were A. S. Schetinnikov, A. V. Yakovlev, V. M. Avruchevsky and L. I. Likhacheva. Also related is the work by F. I. Pertziger on the Abramov Glacier reference book. A data base for the 1966–1996 period is planned with additional software support.

Inylchek river runoff and outburst of Mertzbacher Lake

This project has established: monthly values of glacier runoff for May–October; a new method of determining the lake volume and outburst hydrograph; and a way of forecasting the outburst date. The results of this work were used by the "HydroProject" Institute for projects in the Sarydjaz river basin (V.G. Konovalov).

Snow-line survey

Since 1986, for hundreds of glaciers of the Pamirs, Gissaro-Alai and Tien-Shan, estimates have been made of the maximum altitude of the snow line. Annual determinations were made by plane and helicopter during the nineties. These were supplemented in some basins by remote-sensing measurements of the glacier mass balance using an automated stake designed by V. G. Konovalov.

Guidebook on mountain glacier measurements

In 1994, the Guidebook on Mountain Glacier Measurements, approved by Russian and Uzbekistan hydromet-services, was published. It was prepared under the direction of V. G. Konovalov with assistance from F. I. Pertziger, G. M. Kamnyansky, A. S. Merkushkin, G. E. Glazyrin (Tashkent Univ.), and D. G. Tsvetkov (Inst. Geography, Moscow). It established the organization and conduct of glaciological field studies, methods of measurements, standardized data registration and reports. Use of the guidebook is mandatory for the scientific organizations and hydrographic departments of the CIS hydromet-services, responsible for field measurements on mountain glaciers.

Dynamics and mass balance of central Asian glaciers

A method of computing a long-term series of annual mass balances and the other parameters for central Asia glaciers, based on standard hydrometeorological information has been developed (V. G. Konovalov), as well as one for the multidimensional extrapolation of 10 day precipitation and air-temperature values as a function of geographical coordinates and altitude above sea level (V. G. Konovalov and L. M. Karandaeva). Data on the hydrological regime of glaciers in the 45 main watersheds of the Vakhsh and Pyandge river basins have been compiled (V. G. Konovalov and L. M. Karandaeva). A reference book on the morphology of glaciation of the Pamiro-Alai river basins has been published and contains data on glacier area, distribution of ice and moraine areas by altitude, and the characteristic parameters of the glacier groups (A. S. Schetinnikov). From 1984–1994, 11 volumes of the Proceedings of SANIGMI series on the "Glaciology of mountain areas" were published containing results from most of the work described.

Abramov Glacier

For 30 years a number of annual and seasonal studies have been carried out from the SANIGMI field base at the Abramov Glacier, upstream of the Koksu river, a third-order tributary of the Amudarya river which flows into the Aral Sea. The glacier is 9.4 km long, has an area of 24.4 km^2, a volume of 2.8 km^3, a thickness range from several meters at the terminus to 180–200 m in the middle, a mean width of 750–800 m with a maximum of 5 km, and an altitudinal range from 4600 to 3600 m a.s.l. There are more than 14 glaciers in the basin of Koksu river having a total area of 9 km^2.

Abramov Glacier was first visited by botanist S. P. Korjinsky in 1895. From then until the 1970s short geological and glaciological observations were made there. In 1966, the staff of the SANIGMI glaciological expedition built houses, well-equipped laboratories and other buildings as a base for the study of the regime of contemporary glaciation of central Asia that was part of the International Hydrological Decade programme. The base has electrical energy, hot and cold water, central heating, and regular radio communication with Tashkent. Snow scooters and tractors are used within the glacier basin. Access is by helicopter which can deliver about one ton of cargo to 3840 m a.s.l. in one flight. All along, the activity of this base and its staff, as well as the success of many scientific and operational programs, are dependent on the timely transportation of materials, food stuffs and equipment. 40 tons of diesel fuel, petrol and oil are delivered annually to the glacier by helicopter.

Climate conditions here are typical for the high alpine zone of the Pamiro-Alai mountains. Annual precipitation ranges from 500–1000 mm, winter lasts from October to May, and summer mean monthly air temperature is not more than 3°C. Atmospheric pressure is 58–65% of that at sea level. Solar radiation in summer approaches 712.3–754.2 MJ m^2, close to the maximum possible. Since 1966, Abramov Glacier has been included in most major international and national programmes and projects.

Observational data have been used to estimate the long-term hydrological regime and mass balance of the Pamiro-Alai, where there are 11 500 glaciers with a total area of 7500 km^2 and volume of 470 km^3. The year-round data serve as the basis for detailed assessments of the characteristics of accumulation, ablation, snowdrift and avalanche transport, and ice formation in the firn area. Unique measurements of glacier mass balance distribution were made during the surge.

The operational hydrometeorological data received daily from the Abramov Glacier by the Hydrometeorological Centre of the Republic of Uzbekistan have proved invaluable in short- and long-range weather forecasts for central Asia and in the forecasts of large rivers flows in the Amudarya and Syrdarya basins.

Background environmental pollution studies began here in 1972, as part of an integrated monitoring of precipitation, water, air, soil and biota contamination. Several cores have been taken in the firn area, at 4400 m, for continuous sampling to a depth of 100 m of the long-term dynamics of pollution. Tritium concentration in the cores showed that its variation has been almost the same as that on the Fedchenko Glacier and is similar to the character of tritium accumulation on the Earth's surface. The various data have revealed the dynamics of natural pollution for the last 80–100 years. Annual layers were dated by different methods: spore and pollen analysis, stratigraphy, and ratio of oxygen isotopes. Results from different seasons indicated that the anthropogenic contribution to atmospheric pollution (including radioactivity) increases, both in the Earth as a whole and in central Asia in particular.

Results from the Abramov Glacier are published regularly and are widely known. These include: "The materials of observations in mountainous glacial basins of IHD in the Soviet Union"; "Review of background state of environmental pollution in the territory of the USSR"; "Bulletin of pollution state analysis based on the data of background stations situated in the countries-members of the Council for Mutual Economic Assistance"; collections of observational data on glacier fluctuations published by the World Glacier Monitoring Service; the monograph "Abramov Glacier" (1980); the departmental "Guide on expeditional glaciological practice"; and about 50 volumes of reports stored in the Hydrometeorological Stock Department of Glavgidromet containing observations and analyses from the various studies carried out at the glacier. The testing of new instruments and equipment has led to the development and modification of equipment for boring, radar sounding, remotely sensing the snow cover, and recording hydrometeorological data.

Very many specialists from other countries and regions have visited the glacier. There is an annual camp on field hydrometeorological practice for students from different educational institutions and universities. Some of them become professional glaciologists and are employed in SANIGMI. Many more write diplomas using results from observations made at the Abramov Glacier. Seven students from Tashkent, Moscow and St Petersburg based their theses on the unique data from the Abramov Glacier. The Administration of SANIGMI has done much to improve the living and working conditions at the Abramov Glacier, the quality of observations, and to apply the data to better understand the state of glaciation and the environment in the high Alpine regions of central Asia.

Submitted by Vladimir Konovalov

International Glaciological Society

ANNUAL GENERAL MEETING 1996

MINUTES OF THE ANNUAL GENERAL MEETING OF THE INTERNATIONAL GLACIOLOGICAL SOCIETY

15 August 1996 in Victoria, British Columbia, Canada

The President, Dr Bjørn Wold, was in the Chair. 28 members from 10 countries were present.

1. The Minutes of the last Annual General Meeting, published in *ICE*, 1995, No. 109, p. 8–10, were approved on a motion by G. K. C. Clarke, seconded by K. Ricker and signed by the President.

2. The President gave the following report for 1995–96:

Since my last report to the AGM in 1995, we have been involved in three symposia. In September 1995, we worked with the European Science Foundation on EISMINT, the International Symposium on Ice Sheet Modelling. This meeting was held in Chamonix Mont-Blanc, in France. All accepted papers are with the printer and we expect publication shortly. The Annals from the Reykjavík meeting, held a month earlier, have already been printed.

In October 1995, we were asked by the organizers of the symposium on Changing Glaciers: Revisiting Themes and Field Sites of Classical Glaciology, being held at Fjaerland, Norway, if we would publish the papers from that meeting in the Annals. Your Council had already agreed to co-sponsor this meeting and had authorized the Secretary General to act on this request, if it were received. The meeting, held at the end of June 1996, was partly a tribute to the early work of British glaciologists on Austerdalsbreen. It was wonderful to see the latest generation of glaciologists interacting with representatives of this earlier era, such as John Nye and John Glen. We expect that about 75 of the papers presented will be published early next year in *Annals* 24.

That brings me to this International Symposium on Representation of the Cryosphere in Climate and Hydrological Models. The Secretary General has worked closely with the Local Committee and the Editorial Board in organizing this meeting and I would like to thank all of them: Barry Goodison, Greg Flato and Ross Brown of the former; and John Walsh, Richard Alley, Greg Flato, Alexandr Krenke, Liz Morris, Al Rango, Mark Serreze and David McGinnis of the latter. Thanks also to those of you who have acted as referees, thus helping to maintain the quality of our publications.

The final issue of the *Journal of Glaciology*, **41**(139) has been published, as well as the first issue (**42**(140)) for 1996. We have continued to reduce production time in the Cambridge office. The second issue is now with the printer and should be published shortly. Editing for the final issue is virtually complete, so we are now starting editing work on the first issue for 1997. Eighty-one papers were submitted to the *Journal* in 1995. Of these, 41 have been accepted, 22 rejected and 18 are still with authors for revision. So far in 1996, 68 papers have been submitted. Of these, 14 have been accepted, 10 rejected, and 44 are either under review or are with authors for revision.

The third issue of *ICE* (109) was published last year with the usual Minutes of the AGM. Lack of material and the recommendation by Council last year to combine two issues of *ICE* meant that the first issue of *ICE* for 1996 (110) was delayed, but has now been printed and is available here. The second issue (111) will be combined with the third and published following this meeting, once some promised national reports have been received and the Minutes of the AGM completed. If you feel a report on your activities is overdue, contact your National Correspondent to find out when the next report will be prepared and submitted.

This year we have been experimenting with a new printer, Page Brothers of Norwich. Some problems have been encountered with the reproduction of figures, but we have also learnt how we might do some things differently. Our experience has led to recommendations from our Publications Committee for slight changes to the *Journal* that could lead to a substantial improvement in the number of words per page, thus leading to better value for members without any increase in costs; of benefit also to those of you who will be publishing in the *Annals*. In response to concern about the quality of some illustrations, we have changed the weight and type of paper to address this problem. I hope you feel as I do, that we now have a product of which we can feel very proud.

Next year we will be organizing the International Symposium on Snow and Avalanches in May in Chamonix Mont-Blanc, in France, and publishing papers from that meeting in an *Annals* volume to be edited by Dave McClung. Two months later, we will be working with the Australian Antarctic CRC on papers from the Symposium on Antarctica and Global Change to be edited by Bill Budd. Your Council has agreed to co-sponsor a meeting on Snow Hydrology being organized by CRREL in October 1998. This is the year when we will be organizing our own meeting on Large Ice Sheets in Kiruna, in northern Sweden. Your Secretary General has been working hard to line up other meetings that will serve the interests of our members and the science.

Probably the biggest change in our operations during the past year has been the implementation of e-mail. This has added to the Secretary General's work load, because many communications previously dealt with by our secretary Linda Gorman now go straight to his desk, but it has improved response time for members.

I am sure you will all be delighted to hear that our Treasurer believes our finances have been managed sufficiently well and are in good enough health that he can propose there should be no increase in the members' subscription for 1997. Unfortunately, he cannot be with us today, but his report on the accounts will be presented by the Secretary General following the conclusion of my report.

The number of junior members seems quite small in relation to the number of our ordinary members, many of whom are in teaching positions. It strikes me that at £24, junior membership in the Society is extremely good value. I urge those of you in academic positions to promote the IGS to your students and encourage them to join. I am sure they will never have any regrets.

The availability of the credit card option for IGS payments has been a great success and appears to be much appreciated by members. Lack of any return on our deposits, high charges for transactions, low usage, and the availability of the credit-card alternative led us to the conclusion that we should close our Canadian IGS account.

This week you will have witnessed the launch of a new IGS pin. Having exhausted our supply of its predecessor, we decided to have a new one designed by Crescent Corporation of Toronto. With the new pin, we have attempted to make the outer lettering more legible, we have incorporated a stylized version of the crystal that appears on the cover of the *Journal*, *Annals* and *ICE* to preserve that component of our corporate identity, and have set this off against the background colour of the *Annals*. We hope you will come to appreciate it as much as the previous one.

Having witnessed the award of the Seligman Crystal to Bill Budd, I am sure you will understand how delighted I am to be able to announce that our Council has unanimously decided to award the next Seligman Crystal to Dr Sigfus J. Johnsen from Iceland.

His research accomplishments are impressive. He has covered a broad range of experimental and theoretical science from the designing and building of equipment used to obtain data, to the interpretation of data, to the construction of models to better understand the results. Over 25 years, he has devised and formulated increasingly sophisticated ice-flow models for dating ice sheets and deep ice cores. His work on the diffusion of isotopes in firn and ice remains the standard in the field, and he was the one largely responsible for using deuterium excess to demonstrate that subtropical waters are the dominant source of moisture for snow falling at high elevations on the Greenland ice sheet. His combined ice-flow and heat-transport model reproduces the measured temperature profile along the 3000 m deep bore hole at Summit, Greenland with a mean deviation of 0.03°C. His work on ice-core drilling technology has led to arguably the best shallow drill in use today, as well as the deep drill used to obtain the recent GRIP ice core. Through 30 years, Sigfus Johnsen has enriched glaciology with so many excellent contributions — technical, experimental and theoretical — that we feel he richly deserves the honour of a Seligman Crystal.

On behalf of you all, I would like to express my thanks to our headquarters staff: to Simon Ommanney, our Secretary General; his assistant Linda Gorman; the Production Manager, David Rootes; and those others who help maintain the quality of our publications and service to members — Ray Adie (who has now been associated with the *Journal of Glaciology* for some 45 years), Ken Moxham, Sally Stonehouse, Brenda Varney and Sylva Gethin. To Doug MacAyeal, our Chief Scientific Editor, and the members of his editorial board, we also express our warmest thanks.

Finally, I would like to thank the IGS for giving me the great experience of being President of such an interesting and exciting international organization. In completing my term at this AGM I would like to especially thank our Secretary General, Simon Ommanney and our Treasurer, John Heap for very good cooperation and guidance.

Our new President, Dr. Norikazu Maeno, regrets very much that he cannot be here at this meeting due to other obligations. He has, however, asked me to convey his sincere thanks for being elected President and promises to do his best to serve the Society.

For those of you who do not know him, I will give you a brief outline. He has been a member of the IGS for more than 30 years. He graduated from the Geophysics Department of Hokkaido University in 1963, was a research fellow at McGill University from 1967 to 1969, and then Assistant Professor at the Institute of Low Temperature Science, Hokkaido University from 1974; becoming a Full Professor there in 1984. His main scientific interests are the physical properties of ice and snow, snow avalanches, blowing snow, and planetary glaciology. He has written a couple of books on ice science and fundamental glaciology which are available in Japanese and Russian. His hobbies are music, travel and Japanese hot springs. He will be our first President from an Asian country.

K. Steffen proposed and D. M. McClung seconded that the President's report be accepted. This was carried unanimously.

3. The Treasurer, Dr J. A. Heap, expressed regrets that he was unable to be present. He submitted the following report, with the audited Financial Statements for the year ended 31 December 1995, that was read by the Secretary General.

"The state of the Society's finances is best summarised by considering the changes from 31 December 1994 to 31 December 1995 in the following funds:

Seligman Fund: increased from £1047 to £2089, as a consequence of interest accrual and a donation from Mrs Loris Seligman;

Accumulated Fund: increased from £16,493 to £20,798 consequent upon a transfer of £4305 from the General Income and Expenditure Account;

Contingencies Fund: maintained at the same level of £12,684;

Annals Fund: increased from £24,484 to £35,501;

Publications Fund: increased from £10,893 to £11,975.

In 1994 the Society published 596 pages in the *Journal of Glaciology* and 510 pages in the *Annals of Glaciology*. In 1995 the figures were 646 for the *Journal* and 421 for the *Annals*, there being only one issue of the *Annals* in this year. As I noted in my report for 1994, the Society's publications are still very much dependent on the provision of page charges. I wish to register the Society's warm thanks to all those authors who have been both able and ready to support the Society in this way.

May I, again make a plea to all members of the Society to do all in their power to increase the membership and to ensure that libraries in any institutions in which they have influence either maintain their subscriptions or take out a subscription."

K. Ricker proposed and G. M. Flato seconded that the Treasurer's report be accepted. This was carried unanimously.

4. Election of auditors for the 1996 accounts. W. F. Budd proposed and C. F. Raymond seconded that Messrs Peters, Elworthy and Moore of Cambridge be elected auditors for the 1996 accounts. This was carried unanimously.

5. Election to the Council 1996–99. 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:

President	N. Maeno
Vice-Presidents	K. Hutter
	T. H. Jacka
	C. F. Raymond
Elective Members:	D. K. Hall
	P. E. J. Holmlund
	P. A. Mayewski
	C. B. Ritz
	W. B. Tucker, III

W. F. Budd and K. Steffen have been co-opted to the new Council.

The President thanked those members who had served on the previous Council and were now retiring and indeed all those who had helped him during his term of office.

The Secretary General, on behalf of the incoming President and all IGS members, thanked the President warmly for his service to the Society during his term of office.

SELIGMAN CRYSTAL AWARD 1996

Dr William F. Budd

13 August 1996, Victoria, B.C., Canada

The Society's Council agreed unanimously in 1995 that a Seligman Crystal be awarded to Bill Budd. The Crystal was presented, in the presence of about 80 members and friends, by the President of the Society, Bjørn Wold, who introduced the recipient as follows:

"Thirty-five years ago, Bill experienced his first year in Antarctica as the wintering glaciologist with the Australian National Antarctic Research Expeditions (ANARE). During that year he spent several months on Law Dome, up to 100 km inland, carrying out glaciological and meteorological observations. On his return to Australia, Bill wrote up this work under the guidance of Fritz Loewe and Uwe Radok and, in 1965, presented it as his Masters dissertation to the University of Melbourne.

Bill Budd was born at Mount Hope, a small sheep-grazing town in the Riverina district of New South Wales, Australia.

At the age of 20, he obtained his Bachelor of Science degree in Applied Mathematics from Sydney University and, a year later, a Diploma of Education. Bill taught mathematics at the Secondary School level for one year before joining the Australian Antarctic Division in 1960.

Before completing his Masters degree, Bill had already spent another season in Antarctica, this time as the 1964 ANARE glaciologist at Mawson. During this year, his field studies included a study of the Amery Ice Shelf—a project which continued for several years and remains the subject of a substantial part of the current Australian glaciological effort. Bill now combined the results from Law Dome and the Amery Ice Shelf, with an uncanny knack for developing ideas and for translating physical observations into mathematical theories, into his Ph.D. thesis. The Ph.D. was awarded in 1968, and a year later the thesis was published as an ANARE Research Report under the title 'The Dynamics of Ice Masses'. This publication was the best advanced-glaciology text at the time and was used by many glaciology teachers worldwide. At this time also, the Australian Antarctic Division formally established the Glaciology Section. It was to be located at the University of Melbourne, where it would work in close collaboration with the Meteorology Department, and be headed by Bill Budd. The collaboration would last for 24 years and during this time, Bill worked on an enormous range of glaciological and meteorological problems covering numerical modelling of ice sheets and glaciers, examination of the surging potential of glaciers, ice-core studies, ice mechanics, ice crystallography, relationships between sea ice and climate, katabatic wind studies and much more.

At the same time, he was teaching and supervising others, thus developing the Australian glaciology program. During the mid-1970s, Bill added to his repertoire atmospheric general circulation models for climate studies and climate/ice sheet response studies: work which still continues.

In 1979, a new Chair of Meteorology, for which Uwe Radok had been fighting for many years, was established at Melbourne and Bill resigned from the Antarctic Division Glaciology Program to become the first Professor of Meteorology at the university.

Research through the 1980s included modelling ice-sheet changes through the ice ages, simulations of the present Antarctic ice sheet and its response to future warming, the inclusion of sea ice in global climate models, and general circulation modelling of future warming.

At the same time, Bill was carrying out the management functions of the Chair of the Department of Meteorology and for some of the period also of the School of Earth Sciences at Melbourne. In addition, he was serving on several international committees requiring extensive travel. Financial and administrative pressures were mounting within the University and, to put it bluntly, Meteorology and Glaciology were being pressured to lose their separate identity within a merged School of Earth Sciences in the University of Melbourne. It must have been a welcome opportunity when, in 1992, the new Cooperative Research Centre for the Antarctic and Southern Ocean Environment (known as the Antarctic CRC) was established in Hobart.

The new Antarctic CRC was a gathering together of several groups with interests in Antarctic glaciology, meteorology, oceanography and geology. While Bill and some of the other meteorologists transferred from Melbourne to Hobart to join the new Centre, so did the entire Glaciology Section of Antarctic Division, and the collaboration that had been so strong for more than 20 years continued.

Within the new Antarctic CRC, Bill is Professor of meteorology, Leader of the Polar Atmospheres Program and an active participant in the Ice Sheet Mass Budget, Ice Cores and Sea Ice Programs. He continues to work on an enormous range of problems, especially involving ice-sheet and sea-ice modelling and ice/ocean/atmosphere-coupled modelling. Bill has been and continues to be a major influence in the study of Glaciology in Australia and worldwide.

His early work at Wilkes, and later at Mawson, on the mass balance of the Antarctic ice sheet, was quickly followed by major, fundamental studies of drifting snow at Byrd and the dynamics of the Amery Ice Shelf. This led to some pioneering experimental work on ice rheology and then to theoretical studies of ice properties and ice dynamics. An interest in the interpretation of temperature profiles in the Antarctica ice sheet broadened to interpretations of the paleo record in Antarctica, and to some very sophisticated numerical modelling experiments, including glacier instabilities and surging. From there, it was a short step to studying the response of polar ice to global climate change.

In between these major phases of his scientific work were numerous studies, both of a fundamental and applied nature. Such studies included satellite remote sensing of sea ice, radio-echo sounding of ice sheets, the distribution, movement, and melt rates of icebergs, the use of snow in constructing ice runways, the relationships between sea-ice extent, Southern Hemisphere atmospheric and oceanic circulation, and climate, and a return to his earlier interest in the mass balance of Antarctica, this time in the context of global climate change. His publication record to date includes more than 140 titles.

Bill has always inspired others with his ideas, not only his own students and national colleagues, but also internationally. He has had extended visits and has worked closely with colleagues in New Zealand, Canada, U.S.A, Japan, U.K., France, Russia and elsewhere. He has also planned and organized studies through such diverse organizations as IAMAP, SCAR, WCRP, ICSI and IGBP, to many of which he has been elected or appointed an officer.

Bill's genius and scientific talent have been recognized in his own country and internationally through the award of medals, appointments to prestigious scientific bodies and other honours. To his colleagues, which include scientists worldwide, he is known for his innovative experiments in glaciology, his advanced and comprehensive numerical modelling studies, and his inspired theoretical research which has been compared to the work of Nye and Weertman.

In awarding the Seligman Crystal to Professor William F. Budd, we see him as a unique person, an original thinker with a far-ranging mind, a theoretician as well as a practical field scientist, who has made major scientific contributions in many glaciological areas, ranging from the ice-caps of Mars to sea ice, glaciers, and ice-sheets of both polar regions on Earth.

Bill, it is a great pleasure and honour for me, on behalf of the International Glaciological Society, to present to you the Seligman Crystal."

After the presentation of the Crystal, Bill Budd made the following reply:

"Climbing on the shoulders of giants to see more of snow and ice".

I am deeply honoured to receive the award of the Seligman Crystal and wish to acknowledge the assistance of colleagues, collaborators, supporting organisations, and, not least, the International Glaciological Society, in the contributions to glaciology which have been attributed to me. In fact, in this presentation, I wish to show that, if at times I may have been able to see a little further, it has been because I was able to climb on the shoulders of giants and others among my friends, colleagues and those who were before me. I thank Bjørn Wold for his kind remarks and I am amazed at the detailed survey of my career which he presented. I wish to show how my career has continually benefited from the work of colleagues across the range of activities with which I have been involved. I believe that I have benefited also from the good fortune of being able to take advantage of unique opportunities that have arisen at critical times through the course of my career.

I will begin with the period when I was completing a B.Sc. degree at the University of Sydney. This was at the time of the International Geophysical Year (IGY) 1957–58. I majored in Applied Mathematics and the Head of Department at that time was Prof. K. E. Bullen, whose text books *Introduction to the theory of mechanics* and *Introduction to the theory of seismology* were used in the applied mathematics courses: the latter in particular gave me a useful background for the future oversnow traverse work in Antarctica. Keith Bullen was well known for his work with Harold Jeffreys, of the University of Cambridge, on the structure of the Earth from seismology. He had been involved with the international planning of the IGY, and became the first Chairman of the Australian National Committee for Antarctic Research (ANCAR) of the Australian Academy of Sciences. With the formation of SCAR (Scientific Committee for Antarctic Research) Bullen became the Vice-President. Little did I know that I would be following in the footsteps of Bullen in those two positions some 25–30 years later. The organisation of the Australian National Antarctic Research Expeditions (ANARE) had taken place in 1947. Research stations were established at Heard and Macquarie Islands in 1948 and at Mawson, on the Antarctic continent, in 1954. The IGY brought a lot more publicity to Antarctic activities, including the films and television documentaries of the inland traverses, such as the Fuchs–Hillary Trans-Antarctic Expedition crossing, and accounts of the Australian research presented at science summer schools.

By 1960, I had completed the B.Sc degree and a Diploma of Education and was teaching mathematics and science at High School when an advertisement appeared for Expeditioner Positions with the ANARE, including geophysics and glaciology for inland traverses over the ice cap. I applied and was interviewed and selected by Dr P. G. Law, head of the Antarctic Division, the Government body that organised the ANARE. When I joined the Antarctic Division I was appointed as the glaciologist to go to Wilkes and winter over during 1961, including participating in the oversnow traverses to carry out an extensive range of observations into the interior of the continent. The Bureau of Mineral Resources and the expedition geophysicist were to take responsibility for the basic geophysical observations while the properties and dynamics of the ice sheet were to be left to the glaciologist. Although Australia had relatively little research activity in snow and ice, we were fortunate to have at the University of Melbourne, Department of Meteorology Drs Fritz Loewe and Uwe Radok who had promoted glaciology within the ANARE. Loewe was one of the pioneers of glaciology and meteorology. He had been on the Greenland Expedition with Alfred Wegener and wintered in central Greenland at Eismitte with two others under extremely arduous conditions. Loewe had visited glacier areas in many parts of the world and wintered in Antarctica at Port Martin with the French in 1951. Uwe Radok was my principal mentor in the development of my career in glaciology. He had a keen insight into a wide range of glaciological and meteorological topics and, together with Loewe, established the ANARE glaciology program on a firm foundation. The first professional glaciologist for the ANARE was Malcolm Mellor, who worked with them and overwintered at Mawson in 1958 during the IGY. Mellor was another of the giants in glaciology and left a legacy of extensive observations, particularly in the Mawson–Amery Ice Shelf–Lambert Glacier region, upon which those of us who followed were able to build. Loewe and Mellor each carried out assessments of the Antarctic mass balance just after the IGY which were remarkable in their similarity to modern assessments, considering the limited data available.

Wilkes station was established by the USA at the beginning of the IGY and occupied by them during 1957 and 1958. During these years two teams, each of three glaciologists, overwintered. The first was led by Dick Cameron and the second by John Hollin. These teams carried out an extensive range of observations which our programs were to build upon in later years. The Australians took over the station in 1959, but for a number of years the US continued to send some expeditioners to winter-over as part of a cooperative program. John Hollin sent all the US reports on the work they had carried out, including: topographic surveys, accumulation and ablation, flow of the fast Vanderford Glacier and the slow plateau flow of the Cape Folger ice cliffs, the inland site S2 strain grid, and the S2 deep pit and tunnel. Dick Cameron and his colleagues dug the pit and tunnel in 1957. We continued the measurements they started and found the tunnel closure rates fitted the pattern of primary, secondary and finally steady-state tertiary creep as a function of strain continuing for over 30 years — much longer than most laboratory tests and at a lower stress and temperature than can be readily managed in a laboratory. Some new work, undertaken in 1960–61, included blizzard snowdrift and the inland traverses. The snowdrift program was a continuation of work carried out by Loewe in Terre Adélie, and Mellor and Radok with measurements at Mawson.

Many of the drift measurements in 1961 were carried out at S2 (80 km inland, 1160 m elevation) where during winter drifting snow occurred most of the time. Although we learnt a great deal from the Mawson and Wilkes observations, the culmination of the snowdrift program came with the comprehensive study organised by Uwe Radok in collaboration with the US at their station Byrd in West Antarctica. An indefatigable Australian weather observer, Bob Dingle, who had wintering experience at all of our five Antarctic and sub-Antarctic stations, wintered with the US team at Byrd during 1962, and, in addition to his weather observer duties, carried out extensive snowdrift measurements throughout the year. This work provided an excellent data set which was used to test the turbulent drift theory, including the effects of particle size distributions and their dependence on the wind profile.

The oversnow traverse program was able to continue on from the work of the previous year's party, led by the officer-in-charge Harry Black, and which extended to about 370 km inland. The new work of 1961 included seismic and gravity measurements along with detailed barometric levelling, accumulation rates and borehole temperatures with accurate temperature–depth gradients. Uwe Radok had arranged for the precise borehole temperature apparatus to be constructed, based on platinum resistance techniques, which proved to be very reliable at the low temperatures encountered. These temperature–depth gradients were obtained to 460 km inland in 1961 and were extended to Vostok in 1962.

These temperature–depth gradients, and those from Malcolm Mellor's traverse, provided the clearest confirmation of the heat-conduction theory applied to large ice sheets available at that time and, together with the accumulation rate and ice thickness, provided the basis for an additional estimate for the ice-sheet velocity.

One of the most remarkable results coming from the inland traverses was the observation of the relatively large and fairly regular surface undulations (~30 m × 10 km) superimposed on the relatively smooth large-scale ice-cap curvature. Some of the undulations were so large that the ice was actually flowing uphill (i.e. against the surface slope) for several km, or considerably more than the ice thickness. These large variations in surface slope along the presumed direction of ice flow raised the question — over what scales do the surface slopes need to be considered for governing the down-slope flow of ice? This question was to be further addressed by detailed measurements of elevation velocity, strain rates and ice thickness over Law Dome from 1965–67, but the same results for the much larger variations of the inland region were not obtained until detailed deformation and ice thickness studies were carried out over these undulations in the late 1970s.

The period at Casey extended several months into 1962 with the exploration and aerial survey of the large stretch of coastline, from the Vanderford and Adams Glaciers around 110° E, to Cape Adare in Victoria Land, 170° E. The survey was led by Phil Law in the *Thala Dan* with helicopters and a fixed-wing Beaver aircraft with floats. This work provided an excellent introduction to the pack ice (at one stage the ship was entrapped in pressure ice for some time) and the differentiation between glaciers, glacier tongues, icebergs, iceberg tongues and ice shelves around the coast.

By my return to Melbourne I had obtained some experience with the properties of the ice sheet, accumulation and ablation, snow drift, meteorology and Antarctic climatic conditions, ice-sheet flow and outlet glaciers, but not with the large Antarctic ice shelves which play such an important role in the dynamics. This was to be remedied by a three-year program for the Amery Ice Shelf culminating in my overwintering at Mawson in 1964.

In 1962 Ian Landon-Smith and colleagues from Mawson carried out an oversnow traverse for a reconnaissance survey of the ice shelf. This successful work, using tractors and dog teams, allowed plans to be developed for a detailed study, starting in 1963, with an array of markers for accumulation, strain and velocity to be set up over the ice shelf and then remeasured in 1964. For this survey the dog teams were replaced with Weasels and a motor toboggan. An attempt to measure the ice thickness in 1964, with a modified aircraft radar altimeter (440 Mhz), was thwarted. After successful testing near Mawson, the equipment broke down on the ice shelf and could not be repaired. The long distance inland also made the barometric surface elevations unreliable for ice-thickness control. These problems were eventually overcome by the special Amery wintering expedition of 1968. Nevertheless the 1963–64 program was reasonably successful and provided sufficient information for a first assessment of the dynamics and mass balance.

In 1960, as part of preparations for glaciological work in Antarctica, Radok and Loewe introduced me to the glaciological literature and advised me to read: all the *Journals of Glaciology* (they were only up to Vol. 3 then), the ICSI (International Commission of Snow and Ice) symposia volumes, the texts by Seligman (*Snow structures and ski fields*) and Shumskiy (*Principals of structural glaciology*), texts on glacial geology, e.g. Charlesworth (*The Quaternary era*) and Flint (*Glacial and Pleistocene geology*), and various Antarctic Expedition reports, e.g. Wright and Priestley (*Glaciology, British Antarctic Expedition 1910–13*), the Norwegian–British–Swedish Antarctic Expedition 1949–52 Scientific Results, and Loewe's 1956 Report (*Études de Glaciologie en Terre Adélie, 1951–52*). The landmark texts by Lliboutry and Paterson were not then available.

The basic dynamics of natural ice bodies had been well developed, particularly by Nye, Weertman, Shumskiy and Lliboutry. The thermodynamics of ice sheets and ice shelves were also well developed, e.g. by Robin, Bogoslovsky and Crary. Finally the flow properties of ice to the first order had been well established, e.g. by Glen and Steinemann. It was particularly rewarding to find that the observed ice-sheet and ice-shelf dynamics appeared to be reasonably compatible with the known flow properties of ice, taking account of features such as the low stresses and temperature, the scale effects of ice flow over undulations and the restrictions of the sides of ice shelves within embayments. It was also clear that, to improve our understanding of the dynamics, we needed more observations of the ice masses, including boreholes for deep ice temperatures and velocity profiles as well as ice cores for the ice-crystal structure. These problems became the focus of the ANARE glaciology field program concentrating firstly on a detailed study of Law Dome as a manageable sized cap and secondly on the Amery Ice Shelf and Lambert Glacier system.

An important additional aspect of the ANARE glaciology program concerned the study of surface heat balance and sea ice. This work was led by Peter Schwerdtfeger and the Antarctic field work was initiated by Gunter Weller who overwintered at Mawson in 1961 and 1965. This work was continued by Ian Allison and a series of colleagues whom he subsequently supervised. The results of this work provided the basis for the sea-ice modelling which developed later.

Even in 1960 Dick Jenssen and Uwe Radok were carrying out numerical modelling using the early developmental CSIRAC computer built in the 1950s. They were the first to commence numerical computer techniques for atmospheric prognosis in Australia and had developed a scheme for the computation of transient temperature–depth profiles in ice sheets and ice shelves.

By the mid-1960s the computer power available made it possible to extend the single-column analysis to whole flowlines. With the publication of the Soviet Antarctic Expedition Atlas of Antarctica in 1966 a set of basic fields interpolated over the whole Antarctic continent became available to form the basis for computing a comprehensive range of parameters for the entire ice sheet based on the assumption of steady state. The basic theory was in hand and the computer schemes had been tested so the basic data sets for elevation, ice thickness, accumulation rate and surface temperature were digitised by hand at about 200 km resolution along flowlines. The results for the whole ice sheet were constructed from computations for a large number of flowlines. This work resulted in the publication of *Derived physical characteristics of the Antarctic ice sheet* by Budd, Jenssen and Radok in 1971.

The fundamental importance of the flow properties of ice to ice dynamics meant it was necessary to have reliable data for the low stresses and temperatures of the Antarctic. A number of workers had also demonstrated the prevalence of crystal anisotropy in ice masses, particularly George Rigsby, Barclay Kamb and Tony Gow. The large blue-ice area, inland of Mawson, had extensive ice-deformation information from Mellor's observations and our subsequent work. This provided an ideal location for obtaining ice-crystal orientation fabrics directly related to in situ deformation before we had a deep core drill. In 1965 Uwe Radok and I arranged for Koshiro Kizaki to come from Japan and winter over at Mawson in 1966 to carry out such a study. This began a long line of collaboration with overseas groups in ice crystallography and deformation studies.

To obtain vertical profiles of information through the ice we needed a deep core drill. Here we were greatly assisted by the US Army CRREL (Cold Regions Research and Engineering Laboratory), particularly Malcolm Mellor and Lyle Hansen. We were able to obtain from them a CRREL Thermal Drill of the type that had successfully operated at Byrd and on the Ross Ice Shelf. This coring drill went to the Amery Ice Shelf with the special 4 man Amery Wintering Expedition of 1968 and was successfully used to core to 313 m depth — the deepest ice-shelf core at that time. This small group, led by Max Corry, carried out one of the most productive ANARE glaciology programs. Besides the core drilling and meteorology observations at the fixed site (G1), they surveyed and later resurveyed the ice shelf for ice movement and carried out optical levelling and radio-echo sounding across and down the centre line as well. The mass continuity results showed a near balanced state for the ice shelf, but with substantial basal growth. This was confirmed by the borehole temperatures and the ice-core results.

During 1968, the Antarctic Division Electronics and Engineering group, led by Ian Bird, built a new thermal drill, of similar design to the CRREL one, in an insulated caravan for winter operations. This went to Law Dome for drilling at the summit and near the coast at Cape Folger during 1969. This drilling program continued at Law Dome, alternating with traverse programs for the following decade. Ian Bird's group also developed borehole-logging equipment and much of the special scientific equipment for the traverse. This included developing new radio-echo sounders, after the first one which was obtained from SPRI (Scott Polar Research Institute) in 1966, with the assistance of Gordon Robin and Stan Evans.

The first international conference I attended was at Sapporo in Hokkaido, Japan, on the Physics of Snow and Ice in 1966. There I met many new colleagues, opening the way for future collaboration and interaction, in particular Gorow Wakahama who presented movie films of the deformation of thin sections of snow and ice. The Antarctic Division had sponsored a small cold room at the Meteorology Department for the study of the ice cores from the drilling program. Uwe Radok arranged a fellowship for Gorow Wakahama in 1970. That year he carried out a comprehensive analysis of the crystallography of our ice cores from the Amery Ice Shelf and Law Dome. In addition, he made movie films of the deformation of thin sections of the Amery ice core to study the recrystallisation process. We also set up apparatus to see if we could generate the fabrics found in the ice masses by the same type of deformation history in the laboratory. This collaborative work with Gorow Wakahama was continued with his postgraduate student Masuyoshi Matsuda. He also spent a year with us and carried out biaxial compression to establish 2-maximum fabrics and used *a*-axes directions to analyse the apparent twinning in the large crystal multi-maximum basal ice from Cape Folger, as well as other locations.

A large number of deformation rigs were constructed and operated in the cold rooms, as well as in a number of commercial freezers and the ice-core storage cold rooms. Ice deformation and crystallographic studies were undertaken for higher degrees over the next two decades by: Bob Lile, David Russell-Head, Jo Jacka, Xiang Qun Gao, Li Jun and Wang Wei Li. The objectives were to determine the flow properties of ice relevant to modelling, as well as the evolution of the crystallographic structure and ice properties in the ice sheets. Following a visit to Australia by Shi Ya Feng in 1979, a collaborative program was started with the Institute of Glaciology and Cryopedology in Lanzhou which resulted in a continuing series of visitors from Lanzhou for Antarctic and laboratory research in glaciology.

With Australia having no glaciers, my visits to colleagues and glacier regions overseas have been particularly valuable. This started in 1965 with a visit to New Zealand to work with Ian McKellar and his colleagues on the glaciers of the Mt Cook region. This collaboration was continued by other ANARE glaciologists for a number of years. Then, after lapsing, was reactivated in the 1980s with Andrew Ruddell from the Meteorology Department working for a higher degree on the changes of the New Zealand glaciers, in collaboration with Trevor Chinn and other New Zealand colleagues.

In 1968, I had my greatest opportunity to visit glacier regions, and groups working on glaciology, through a trip sponsored by the Antarctic Division and arranged by Uwe Radok in conjunction with my participation in the International Symposium on Antarctic Glaciology, held at Hanover, New Hampshire. This trip was something of a Grand Tour which led to a wide range of collaborations in subsequent years. It included the Pacific Northwest (University of Washington and the U.S.G.S. in Tacoma), Colorado (Boulder and Fort Collins), University of Wisconsin, CRREL in Hanover, Montréal (McGill University) and Ottawa (Glaciology Subdivision of the Inland Waters Branch, the Continental Polar Shelf Project, and the National Research Council Cold Laboratories). Olav Løken, who had been one of the IGY Wilkes glaciologists and was then head of the Glaciology Subdivision, arranged for me to work with his colleagues and others from the Defence Research Board for about 6 weeks in the Canadian Arctic. This included visits to Thule in Greenland, Ellesmere Island (Alert, Tanquary Fiord and Per Ardua Glacier, Ward Hunt Ice Shelf), Axel Heiberg Island, Meighen Island and Resolute. After the ISAGE meeting, I attended the conference on Surging Glaciers at St Hilaire in Canada and, on the way back to Australia via Europe, visited a number of glaciology groups in England (Cambridge, Birmingham, Bristol, Manchester), France (Paris, Grenoble, Chamonix) and Switzerland (Zürich, Davos). These visits proved very helpful for me at the early stage of my career in established contacts and collaboration with colleagues around the world. Several particularly important developments resulted.

Firstly, at the ISAGE meeting informal discussions between Bauer, Crary, Radok, Robin and Shumskiy led the way to the establishment of the International Antarctic Glaciological Project for collaborative research over a large sector of East Antarctica involving Australia, France, UK (SPRI), USSR and USA. The project planning combined both logistics and scientific participation and subsequent national representatives included: Bentley, Budd, Kotlyakov, Korotkevitch and Lorius. This project was influential in the operation of the inland traverses from Mirny, Casey and Dumont d'Urville, extensive aerial ice-thickness sounding over the region and deep core drilling at Vostok, Dome C and Law Dome. In particular, it facilitated 6 years of Australian participation in the Soviet traverses from Mirny to Dome C. This work has provided an extensive data set for inland velocities, accumulation rates, ice thickness, and other ice-sheet features to control the dynamics and the state of balance.

A second consequence of the 1968 visits came from the Surging Glaciers meeting where excellent observational papers were presented, including the classic survey by Meier and Post, and results of surges recorded by many others from different regions. In addition, the 3-dimensional glacier modelling work of Campbell and Rasmussen was very impressive. On my return to Melbourne, Dick Jenssen and I adapted our flowline model to ordinary temperate glaciers with the objective of modelling a large number of ordinary glaciers as a prelude to modelling surging glaciers.

A third development, which occurred following the 1968 travel, was the invitation and support offered by Norbert Untersteiner to spend a year working with the group at the University of Washington in Seattle. The award of a Fullbright Fellowship from the Australian–American Education Foundation assisted further with the travel. The visit was arranged so that in most of 1971 I was able to work with colleagues in Seattle. This was a particularly exciting time for glaciology in the Pacific North West. There were active glacier programs in several nearby regions including the Olympic Mts, the Cascades and Mt Rainier. In addition, further afield other glacier programs were in progress and some were being further developed in Alaska and elsewhere. I was able to interact with the scientists involved and also visit the glacier regions with their assistance. These included Ed LaChapelle, Charlie Raymond, Will Harrison and Steve Hodge from the University of Washington, and Mark Meier, Bob Krimmell, Bill Campbell and Al Rasmussen from Tacoma.

In addition to the glacier research, this period saw the start of the new large sea-ice project AIDJEX (Arctic Ice Dynamics Joint Experiment) with a mammoth cast, including Joe Fletcher, Norbert Untersteiner, Gary Maykut, Alan Thorndike, Drew Rothrock and many others. Campbell and Rasmussen already had a viscous sea-ice model, coupled to an atmosphere, which showed very impressive results. The AIDJEX project eventually supplied the form of the improved sea-ice rheologies, as well as the dynamics and thermodynamics which led the way to the improved modelling of sea ice by Hibler, Semtner, Washington and Parkinson and the current state-of-the-art treatments.

On my return to Australia, the activities in ice-core studies, deep drilling, oversnow traverses for the IAGP and modelling, were all in full swing. The modelling of the Greenland Ice Sheet (with Jacka, Jenssen, Radok and Young) was carried out along with transient borehole temperature simulations for the Cambridge Workshop in 1973 organised by Gordon Robin. This subsequently resulted in the publication *The climate record in polar ice sheets* and our report *Derived physical characteristics of the Greenland ice sheet*.

The glacier modelling was extended to transient responses and deductions of climate change with Phil Kruss and Ian Smith. The surging-glacier program, although started with Al Rasmussen in 1971, was developed by Barry McInnes and later extended by Ian Smith. Our full 3-dimensional transient ice-sheet modelling had been limited by computer power until the late 1970s. The initial 3D work of Campbell and Rasmussen for glaciers, and of Mahaffy and Andrews for ice sheets, inspired us to extend the ground-breaking work of Hans Weertman, on the growth and decay of equilibrium ice sheets under Milankovitch orbital radiation forcing, to fully dynamic 3-dimensional ice sheets. This work was carried out by Ian Smith and the results presented, with a colour movie film made from our own very early in-house computer graphics, at the IUGG in Canberra in 1979. The extension of this work to the Antarctic showed that an improved representation of the ice streams and outlet glaciers was required.

In 1974, a laboratory study of ice sliding was started which continued for 5 years with two postgraduate students, Peter Keage and Neil Blundy. The work built on the earlier experimental work of Barnes, Tabor and Walker and tried to extend their studies to larger scales and to stresses and velocities relevant to glaciers. Barry McInnes and Ian Smith subsequently were able to make use of the results in the modelling of ordinary glaciers and the fast flow associated with ice falls, surging glaciers, ice streams and tidewater glaciers.

With the publication of the SPRI Antarctic Map Folio Series by Drewry and others in 1983, it became practical and worthwhile to re-work the Antarctic Derived Physical Characteristics. This time the input data were digitised on a 20 km grid and the modelling was completely automated. This was done in collaboration with Uwe Radok, who was then at CIRES in Boulder, Colorado and able to assist the project with support from the U.S. Department of Energy. When suitable new data became available on the Mars North Polar Ice Cap in the early 1980s, the same technique was applied to derive plausible steady-state characteristics which reassuringly resulted in the derived accumulation zone corresponding reasonably closely to the observed "white ice" zone. With such a large, water, ice cap, there appears to be potentially a considerable amount of water on Mars.

In the early 1970s, global atmospheric general circulation models (GCMs) were becoming sufficiently advanced to use for climate studies. We obtained our first spectral GCM from Bill Bourke and his colleagues at the ANMRC (Australian Numerical Meteorology Research Centre) in 1975. However, it wasn't until Ian Simmonds joined our group that the model was set up well for climate studies. Ian Simmonds led this program and was able to improve the model's performance, particularly in the polar regions. This made it possible to carry out a wide range of climate experiments including studies of the role of sea ice in the climate system, the polar regions response to global warming and atmosphere–ocean feedbacks. This work provided input for the response of ice sheets to future warming, and was used with Dick Jenssen to extend the earlier studies by Budd, Jenssen, McInnes and Smith to included explicit ice shelves and changes in accumulation rates as well as basal melting. This program on the response to future warming is continuing at the Antarctic CRC with Brendan Coutts and Roland Warner. The sea-ice modelling with Ian Simmonds was developed to a fully interactive dynamic and thermodynamic model by Xingren Wu and subsequently used for a wide range of sea-ice and climate experiments which are now continuing at the Antarctic CRC in Hobart, in conjunction with the sea ice observational program led by Ian Allison.

The study of global changes through the ice ages needed both ice-sheet models and a climate model. A sophisticated energy-balance model was developed by Peter Rayner with Ian Simmonds and me to use in conjunction with the ice sheet and orbital forcing. This work on paleoclimate and ice-sheet modelling is also continuing at the Antarctic CRC, making it possible to model the ice sheets and ice shelves in both polar regions, together with the global climate and interconnected by interactive sea level, for long climate runs through the ice-age cycles.

Finally, the study of long-term climatic change requires the interactive coupling between ice-sheet–ice-shelf models and fully coupled global atmosphere–ocean–sea-ice models. This is because the possible large changes in the ice shelves greatly change the geometry for the ocean circulation and sea-ice formation over the continental shelves. Such work is now in progress as a result of a collaborative program involving Siobahn O'Farrell, and her colleagues at the CSIRO Division of Atmospheric Research, and our group at the Antarctic CRC.

Time and space do not permit an exhaustive summary of my collaboration with colleagues around the world so I hope this review may be taken simply as some selected examples of the many interactions involved and the assistance that I have received. It has been rewarding to see that, as global-change concerns arise, and the Intergovernmental Panel on Climate Change (IPCC) seeks answers to questions concerning the global responses to climatic change, research on ice and climate from around the world is progressing well to provide the information.

It has been a privilege for me to simply watch the progress made by others. Any small part I have played in this field has been greatly dependent on the contribution of my colleagues, and I believe that the award of the Seligman Crystal reflects a recognition of their work too.

To end, I wish to acknowledge the important role that the IGS has played in the development of the science and in the development of my career. The organisation of symposia, the publications of the *Journals* and the *Annals*, the unique educational value of the excursions associated with the conferences, and the opportunities provided to meet with colleagues have all been fostered by the Society. I wish to record my thanks for the benefits I have received from the IGS and for the honour bestowed on me by the award of the Seligman Crystal.

Thank you all.

JOURNAL OF GLACIOLOGY

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

J G COGLEY, W P ADAMS, M A ECCLESTONE, F JUNG-ROTHENHÄUSLER AND C S L OMMANNEY
Mass balance of the White Glacier, Axel Heiberg Island, 1960–91

K FUJITA, K SEKO, Y AGETA, PU JIANCHEN AND YAO TANDONG
Superimposed ice in glacier mass balance on the Tibetan Plateau

L R McKITTRICK AND R L BROWN
On the effect of phase transformations on saline ice compliance

I JOUGHIN, R KWOK AND M FAHNESTOCK
Estimation of ice-sheet motion using satellite radar interferometry: method and error analysis with application to the Humboldt Glacier, Greenland

V I MORGAN, C W WOOKEY, J LI, T D VAN OMMEN, W SKINNER AND M F FITZPATRICK
Site information and initial results from deep ice drilling on Law Dome

E RIGNOT
Tidal motion, ice velocity and melt rate of Petermann Gletscher, Greenland, measured from radar interferometry

C A KNIGHT
A simple technique for growing large, optically "perfect" ice crystals

C RAYMOND, B WEERTMAN, L THOMPSON, E MOSLEY-THOMPSON, D PEEL AND R MULVANEY
Geometry, motion and mass balance of Dyer Plateau, Antarctica

M STURM, J HOLMGREN, M KÖNIG AND K MORRIS
The thermal conductivity of seasonal snow

B M STONE, I J JORDAN, J XIAO AND S J JONES
Experiments on the damage process in ice under compressive states of stress

M STURM AND C S BENSON
Transport, grain growth and depth hoar development in the sub-Arctic snow

COLBECK, S C
A model of windpumping for layered snow

GUDMUNDSSON, G H
Basal flow characteristics of a linear medium sliding frictionless over small bedrock undulations

GUDMUNDSSON, G H
Basal flow characteristics of a non-linear flow

sliding frictionless over strongly undulating bedrock

A MEESTERS AND M van den BROEKE
Response of the longwave radiation over melting snow and ice to atmospheric warming

J D JACOBS, E L SIMMS AND A SIMMS
Recession of the southern part of Barnes Ice Cap, Baffin Island, Canada, between 1961 and 1993, determined from digital mapping of Landsat TM

D B STONE, G K C CLARKE AND R G ELLIS
Inversion of borehole response test data for estimation of subglacial hydraulic properties

A JENKINS, D G VAUGHAN, S S JACOBS, H H HELLMER AND J R KEYS
Glaciological and oceanographic evidence of high melt rates beneath Pine Island Glacier, West Antarctica

G WENDLER, U ADOLPHS, A HAUSER AND B MOORE
On the surface energy budget of sea ice

R M KOERNER
Some comments on climatic reconstructions from ice cores drilled in areas of high melt

C VINCENT AND M VALLON
Meteorological controls on glacier mass-balance: empirical relations suggested by Sarennes glacier measurements (France)

M O JEFFRIES, A P WORBY, K. MORRIS AND W F WEEKS
Seasonal variations in the properties and structural composition of sea ice and snow cover in the Bellingshausen and Amundsen seas, Antarctica

M J SMITH AND D M McCLUNG
Avalanche frequency and terrain characteristics at Roger's Pass, British Columbia, Canada

M J SCHMEITS AND J OERLEMANS
Simulation of the historical variations in length of the Unterer Grindelwaldgletscher (Switzerland)

R LeB HOOKE, B HANSON, N R IVERSON, P JANSSON AND U H FISCHER
Rheology of till beneath Storglaciären, Sweden

E M MORRIS, H-P BADER AND P WEILENMANN
Modelling temperature variations in polar snow using DAISY

ANTARCTICA AND GLOBAL CHANGE: INTERACTIONS AND IMPACTS

Hobart, Tasmania, Australia 13–18 July 1997
Wrest Point Convention Centre

ANTARCTIC CRC

CO-SPONSORED BY
SCAR-Global Change Programme
International Glaciological Society

LOCAL ORGANISING COMMITTEE: Dr Jo Jacka (Chairman), Lorraine Nielsen, Rodney Cameron-Tucker, Dr Ian Goodwin (SCAR-Global Change Programme), Dr Peter Harris, Dr Will Howard, Beth Pocock (Mures Convention Management) and Mike Annand (Mures Convention Management).

CHIEF SCIENTIFIC EDITOR: Professor W. F. Budd

INFORMATION: Information about the symposium may be obtained from the Local Organising Committee: Tel: +61 3 6226 2265; Fax: +61 3 6226 2973; Email: L.Nielsen@antcrc.utas.edu.au ; or Mures Convention Management: Tel: +61 3 6234 1424; Fax: +61 3 6234 4464; Email: mures@trump.net.au

PAPERS: Participants who wish to contribute to the Symposium should submit an abstract of their proposed paper in English. It should not exceed one page of typescript (500–600 words). A sample abstract is on the world wide web: http://www.antcrc.utas.edu.au/antcrc/events/antsymp.html

Information required with the abstract:

* authors' names and addresses
* fax number and Email address
* Symposium topic addressed by the abstract and whether an oral or poster presentation is preferred.

Abstracts are required in both electronic and hard copy forms. Abstracts should be mailed to:

abstracts@antcrc.utas.edu.au

as ASCII (plain text) files or as an attachment in Microsoft Word. Or, they may be post mailed on floppy disk in (preferably) Microsoft Word 5.11 (PC or Macintosh format) or Word Perfect 5. Camera-ready hard copies should be post mailed as typed manuscripts to:

Conference Secretariat, Antarctica and Global Change Symposium, Antarctic CRC, Box 252-80,
Hobart, Tasmania 7001, Australia

Last date for receipt of Abstracts: 31 January 1997

First or corresponding authors will be advised by 31 March 1997 of the acceptance or otherwise.

SUBMISSION OF FINAL PAPERS AND PUBLICATION: Papers presented at the Symposium will be considered for publication in the Proceedings volume (*Annals of Glaciology*, Vol. 27). Short papers only with a limit of five (5) Journal pages including diagrams are required. Three copies of the paper should be sent to the Conference Secretariat, Antarctic CRC, Box 252-80, Hobart, Tasmania 7001, Australia, by 30 May 1997.

Last date for receipt of final papers: 31 August 1997

INTERNATIONAL GLACIOLOGICAL SOCIETY

INTERNATIONAL SYMPOSIUM ON SNOW AND AVALANCHES

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

CO-SPONSORED BY

Association Nationale pour l'Etude de la Neige et des Avalanches (ANENA)
METEO FRANCE, Centre d'Etudes de la Neige
CEMAGREF, Division Nivologie
Laboratoire de Glaciologie et de Géophysique de l'Environnement, CNRS
Ville de Chamonix Mont-Blanc

SECOND CIRCULAR

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

SCIENTIFIC EDITORS:
David M. McClung (Chief Editor), Eric Brun, Jerome B. Johnson, Paul M.B. Föhn

INFORMATION ABOUT THE SYMPOSIUM MAY BE OBTAINED FROM:
Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, UK
Local: Tel: 01223-355974 Fax: 01223 336543 International: Tel: + 44 1223 355974 Fax: + 44 1223 336543 E-mail: 100751.1667@compuserve.com Or via IGS'97 WWW site: http://www.cnrm.meteo.Fr:8000/CEN/info.html

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

PARTICIPATION
This circular includes a form for registration. Forms for booking accommodation and the excursions can be obtained from the Secretary General. The forms and accompanying payments should be returned, in accordance with instructions given, before 1 March 1997 and 30 April 1997 respectively. There will be a UK£45 surcharge for registrations received after 1 March. Full registration refunds will not be possible for cancellations received after 7 April 1997.

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

REGISTRATION FEES	UK£
UK Participant (IGS, IGS-SAO or ANENA)	155
Participant (not a member of above)	185
Student	75
Accompanying person aged 18 or over	45
Late registration surcharge (after 1 March)	45

Refunds on registration fees will be made on a sliding scale, according to date of receipt of notification, up to 10 May 1997. After that date it may be impossible to make any refund. See booking form for methods of making payment. All who preregister will receive a copy of the third circular and programme prior to the meeting.

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

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

(a) snow properties, mechanical, physical, electromagnetic and radiative
(b) modelling snow & ice chemistry processes
(c) snow-cover distribution, stability, evolution and modelling
(d) snow structure
(e) snow drifting/blowing snow

(f) avalanches
(g) avalanche dynamics
(h) avalanche snow rheology
(i) risk assessment
(j) model verification
(k) slush flows

PAPERS

(i) SUBMISSION OF PAPERS

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

LAST DATE FOR RECEIPT OF ABSTRACTS: 11 November 1996

(ii) SELECTION OF PAPERS

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

(iii) DISTRIBUTION OF ABSTRACTS

A set of the accepted abstracts will be provided to all registered participants upon registration on 25 May 1997.

(iv) SUBMISSION OF FINAL PAPERS AND PUBLICATION

Final papers, presented at the Symposium, which have been submitted and accepted by the Editorial Board, following review, will be published in English in the *Annals of Glaciology* (Vol. 26). Four copies of the complete paper should be sent to the Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, U.K. by 21 March 1997. They should be prepared in accordance with the style instructions sent to authors with the acceptance notification. Papers will be refereed according to the usual standards of the Society before being accepted for publication. Final, revised versions of papers, diskettes and original art work must be submitted by the end of June 1997. Speedy publication of the *Annals of Glaciology* will depend upon strict adherence to deadlines.

LAST DATE FOR RECEIPT OF FINAL PAPERS: 21 March 1997

ACCOMMODATION

Details of the range of accommodation on offer and prices are available from I.G.S., Cambridge

TRAVEL

Chamonix is accessible from the following airports (sample prices at 1996 rates)

- Genève (thence by bus (200 FF), Hertz rental car (300 FF) or taxi (800 FF)
- Lyon-Satolas (thence by train, car or taxi)
- Paris (thence by train)

Train travel from Paris and Lyon involves one or two changes which complicate and lengthen the trip. The car hire price is the special preferential rate available from Hertz (see the Accommodation Form).

For those participating in the post-symposium tour, departure arrangements should be made from Nice, where the tour will finish.

MID-WEEK EXCURSIONS

Thursday afternoon will be available for a choice of three excursions:

1. Round-trip to the Aiguille du Midi (3840 m a.s.l.) by téléphérique. This provides a magnificent panorama of Mont Blanc and the surrounding massif, amongst the most beautiful scenery in the world. Because of the high altitude, this excursion is not recommended for those with weak hearts (160 FF).
2. Round-trip to Mer de Glace (the largest glacier in France which descends from Mont Blanc) on the Montenvers cog railway; an incomparable site dominated by many famous summits. A visit to the ice grotto at Mer de Glace after a 2 minute cable-car trip. (80 FF).
3. Round-trip to the Aiguille du Midi then back to the first cable-car station. From there a 1½–2 hour easy walk (no special equipment required) on marked trail to the Mer de Glace. Return to Chamonix on the Montenvers cog railway (220 FF).

Registration and payment for the excursion selected will take place during the meeting.

POST-SYMPOSIUM TOUR
The tour departs Chamonix on the morning of Saturday, 31 May and will finish in Nice on the evening of Monday, 2 June. The bus will cross the Alps, overnighting in Grenoble, with visits to the French snow and avalanche research laboratories and experimental sites operated by C.E.N., CEMAGREF and CNRS. Other stops will include Brianon, Entrevaux, St Paul de Vence, Sisteron and a night in Digne. The trip will highlight the differences between the northern Alps (around Chamonix and Grenoble), the southern Alps (around Brianon and Sisteron) and the Mediterranean coast (Nice). The last night will be spent in Nice.

TOURIST INFORMATION
Information on tourist activities in and around Chamonix can be obtained from the Office du Tourisme de Chamonix. Tel: +33 450 53 00 24; fax: +33 450 53 58 90.
In Chamonix at this time, the mean daily minimum/maximum air temperature would be 5–17.4°C. Long-term records indicate 45% of the days at this time of the year are rainy.

IMPORTANT DATES:

Abstracts due: 11 November 1996
Notification of acceptance: 20 January 1997
Preregistration 1 March 1997
Papers due: 21 March 1997
Deadline for full refund 7 April 1997
Accommodation deposit due 30 April 1997
Deadline for refund 10 May 1997
Conference starts 26 May 1997
Revised papers due 7 July 1997

INTERNATIONAL SYMPOSIUM ON SNOW AND AVALANCHES Chamonix Mont-Blanc, France, 26–30 May 1997
Registration form

Family Name: .... Tel: ....

First Name: .... Fax: ....

Address: .... Email: ....

....

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Accompanied by:

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

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

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Total registration fees sent £. . . . .

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

If payment made after 1 March 1997 add surcharge of £45 for each person

Recent meetings (of other organizations)

THE HISTORICAL ROOTS OF GLACIOLOGY

20 August 1995, Reykjavík, Iceland

In connection with the International Glaciological Society's symposium on Glacial Erosion and Sedimentation, 20–25 August 1995, a one-day satellite conference was held on *The Historical Roots of Glaciology*. The convenors were Professors Mikael Karlsson, Department of Philosophy, and Helgi Björnsson, Science Institute, University of Iceland. The program consisted of the following eight lectures and an associated general discussion led by Mikael Karlsson.

Mikael M. Karlsson (University of Iceland): The province of glaciology determined: the development of some central concepts in early glaciology.

Oddur Sigurðsson (National Energy Authority, Iceland): Sveinn Pálsson and his treatise on glaciers from 1794.

Hans Röthlisberger (ETH, Zürich): From the recognition of glaciers in the Swiss Alps to the scientific approach.

Gunnar Hoppe (University of Stockholm): Two pioneers of glaciology in Sweden: Axel Hamberg and Hans Ahlmann.

Akira Higashi (Hokkaido University): Studies on snow and ice in Japan: an historical view.

Douglas MacAyeal (University of Chicago): J. Harlen Bretz, Missoula jökulhlaups, and the Great Scablands debate: catastrophist in a gradualist court.

Charles Bentley (University of Wisconsin-Madison): Early geophysical work on ice sheets.

Johannes Weertman (Northwestern University): Personal reflections on theoretical glacier mechanics in the 1950s.

Helgi Björnsson

MIDWEST GLACIOLOGISTS

The Northern Illinois Department of Geology hosted the Fifth Annual Midwest Glaciology meeting, 19–21 April 1996, organized by Jinkui Cai and Sarah Aavang. With glaciologists and glacial geologists from as far from the midwestern U.S. as Maine, California and Alberta attending the meeting, and study areas spanning the globe from Alaska to Greenland to Sweden to Chile to Antarctica and many points in between, it becomes more evident the meeting was named only for the location in which it occurs.

The 36 presentations covered a variety of topics. Understanding the West Antarctic ice sheet has become a standard, with subtopics raging from potential ice sheet collapse to seismic profiling to deforming basal till. Subglacial processes beneath Upstream B (Antarctica) were reviewed in light of bore-hole experiments. A tethered stake was driven into the basal till layer. Its rate of movement indicated that 80% of the velocity could be accounted for by basal sliding without invoking till deformation, thus suggesting that deforming till may be more limited in occurrence than previously thought. Another study used sessile marine organisms near the grounding line of Blue Glacier to determine the extent of ice-margin fluctuations and the magnitude of sediment flux from the glacier during the last 1000 years.

Turning to the Northern Hemisphere, the problem of ice rafting the volume of debris found in the Heinrich layers across the Atlantic Ocean has resulted in an interesting hypothesis of underplating debris and ice. Atmospheric circulation was invoked to explain the apparent anomaly of advancing Scandinavian Alpine glaciers; anomalous because globally most Alpine glaciers are retreating. Several other talks discussed glacial processes, as well as till composition of glaciers in southeast Alaska. Late Wisconsinan deglacial chronology for the southern margin of the Laurentide ice sheet continues to be better constrained by additional radiocarbon dates.

Several talks were based on research in Chile. One addressed the use of different georadar techniques to acquire the highest resolution data. Marine stratigraphy and interpreted deglacial chronology were presented for the central Chilean fjords. Concluding the South American research was a presentation on the stratigraphic and radiocarbon record derived from central Chile. Five major glacial expansions of equal magnitude have been defined here, each of which corresponds within 600 years to a Heinrich event. Other presentations discussed the availability and application of remotely sensed data in glaciology studies. A Friday-night barbecue at the home of Jay Stravers occurred unimpeded by intermittent rain.

The University of Wisconsin–Madison Department of Geology and Geophysics will host the Sixth Annual Midwest Glaciology meeting, This will overlap with the North Central Section Geological Society of America meeting being held in Madison, Wisconsin in May 1997. Formal papers with abstracts will be given during the GSA symposium, while information papers without abstracts will be presented during the MGM. The focus of the glacial sessions for both meetings will be paleoglaciology. Papers should emphasize either applications of modern glacier processes to reconstruction of Pleistocene glaciers, or reconstruction of past glaciological conditions as deduced from the glacial geologic record.

The tentative schedule is:

30 April, Wednesday – Field trip along margin of Green Bay Lobe
1 May, Thursday – GSA sessions begin
2 May, Friday – GSA symposium on paleoglaciology
3 May, Saturday – Field trip transect up flow line of Green Bay Lobe
4 May, Sunday – MGM session on paleoglaciology with discussion
5 May, Monday – MGM meeting – open topics
6 May, Tuesday – WAIS meeting

Contact Dave Mickelson (mickelson@geology.wisc.edu) or John W. Attig (jwattig@facstaff.wisc.edu) for more information.

Tina M. Dochat

Glaciological Diary

1997

2-7 March

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

15-17 April

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

21-25 April

European Geophysical Society General Assembly, Vienna, Austria. Symposia on: Snow and Ice Chemistry of Alpine and Polar Regions (M. Kuhn, meteorologie@uibk.ac.at); Physically-based Snow Models and their Links to GCMs (E. Brun, Eric.Brun@meteo.fr); Hydrology of Mountainous Regions (R. Kirnbauer, rkirnbau@fest1.tuwien.ac.at); Glaciology of the Atlantic Sector of Antarctica (H. Miller, miller@awi-bremerhaven.de)

4-5 May

6th Annual Midwest Glaciology meeting, University of Wisconsin-Madison, Madison, WI (Dave Mickelson, Geology and Geophysics, University of Wisconsin, Madison, WI 53706, U.S.A. Tel: +1 608 262 7863; Fax: +1 608 262 0693; mickelson@geology.wisc.edu)

4-10 May

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

25-30 May

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

26-30 May

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

10-12 June

International Symposium on Physics, Chemistry, and Ecology of Seasonally Frozen Soils, Fairbanks, Alaska, USA (Brenton S. Sharratt, Tel: +1 612 589 3411; bsharratt@mail.mrsars.usda.gov; WWW: http://www.nstl.gov/frozen)

1-9 July

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

8-31 July

** IGS Western Alpine Branch, Bolivia (B. Francou, ORSTOM, Centre de Géomorphologie du CNRS, C.P. 9214, La Paz, Bolivia Tel: +591 2 35 77 23; Fax: +591 2 39 18 54; francou@orstom.bo)

13-18 July

* International Symposium on Antarctica and Global Change, University of Tasmania, Hobart, Australia (Lorraine Nielsen, Antarctic C.R.C., University of Tasmania, P.O. Box 252C, Hobart, Tasmania 7001, Australia Tel: +61 3 6226 2265; Fax: +61 3 6226 2973; l.nielsen@antcrc.utas.edu.au http://www.antcrc.utas.edu.au/antcrc/events/antsymp.html)

5-8 August

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

1998

8 May

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

23-27 June

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

17-21 August

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

5-8 October

* Snow Hydrology: The Integration of Physical, Chemical and Biological Systems, Hanover, NH, USA (Janet P. Hardy, Cold Regions Res. and Engineering Lab., U.S. Army Corps of Engineers, 72 Lyme Road, Hanover, NH 03755-1290, U.S.A. Tel: +1 603 646 4306; Fax: +1 603 646 4785; jhardy@crrel.usace.army.mil)

24–28 August

Global Change in the Polar Regions (Olav Orheim, Director, Norsk Polarinstitutt, Middelthunsgate 29, Postboks 5072, Majorstua, N-0301 Oslo, Norway Tel: +47 22 95 95 75; Fax: +47 22 95 95 01; orheim@npolar.no)

** IGS Symposia
* Co-sponsored by IGS

Books received

Bennett, Matthew R. and Neil F. Glasser. 1996. *Glacial geology: ice sheets and landforms.* John Wiley and Sons, Chichester, etc., 364pp. ISBN 0 471 963453; £19.99.

Carozzi, Albert V. and John K. Newman. 1995. Horace-Bénédict de Saussure: forerunner in glaciology. New manuscript evidence on the earliest explorations of the glaciers of Chamonix and the fundamental contribution of Horace-Bénédict de Saussure to the study of glaciers between 1760 and 1792. *Mémoires de la Société de Physique et d'Histoire Naturelle de Genève* 48. 149 pp. ISSN 0252 7960; SF45.00.

Sivardière, François, *ed.* 1995. *Les apports de la recherche scientifique à la sécurité neige, glace et avalanche/The contribution of scientific research to safety with snow, ice and avalanche.* Actes de colloque, Chamonix 30 mai – 3 juin 1995. ANENA, 15 rue Ernest Calvat, Grenoble, 370pp. ISBN 2 85372 424 2; 200,00FF.

Tonnessen, Kathy A., Mark W. Williams and Martyn Tranter, *eds.* 1995. *Biogeochemistry of seasonally snow-covered catchments. Proceedings of Symposium H3, XXI General Assembly, International Union of Geodesy and Geophysics, 1–14 July 1995, Boulder, CO.* Wallingford, Oxon., IAHS Press, 466pp. (IAHS Publication 228) ISBN 0 947571 44 2; US$80.

OBITUARIES

Dr W. H. Ward (1917–1996)

Glaciology was a part-time activity for Bill Ward, for he was a civil engineer by profession. Nevertheless, he gave much of his spare time to glaciology, first in field work in Baffin Island and Norway, and then for 10 years (1961–71) as an energetic Secretary of the International Commission of Snow and Ice. He served the Society on its Committee (later Council) (1948–50, 1952–54, 1959–72) and as a Vice-President (1959–66). Soil mechanics was his speciality, he loved tools and good craftsmanship (he was the son of a cabinet maker), and he loved the outdoors and the mountains; these were the threads that he brought together in his glaciological research.

William Hallam Ward, to give him his full name, was a true Londoner. He was born on 3 December 1917 at Westminster in the heart of the metropolis, and he continued to live until 1939 in the Victorian house where he was born. From his local elementary school he gained a scholarship in 1929 to the Polytechnic Secondary School, where he followed a science course. Having won an 'open Exhibition' (scholarship) to City and Guilds College (now Imperial College, University of London) in 1935, he studied civil engineering there until he graduated in 1939. As a boy, obliged by hard times to spend holidays at home, he read a great deal about travel and polar exploration. However, it was in 1935 that, on a visit to Switzerland, he climbed his first mountain and had his curiosity aroused by the Rhône Glacier. (He told me that the purpose of the visit was to produce *A Midsummer Night's Dream* at Lucerne Casino—although it sounds to me quite out of character.) Climbing in Wales, the Lake District and Norway followed, and in 1938 he went as a surveyor on the first expedition organised by Imperial College, to Jan Mayen. On that barren island he received from J. N. Jennings his introduction to geology.

In 1943 he was concerned with some difficult problems of frost-heaving under cold stores, storing food for long periods during wartime, and this brought him into contact with the British Glaciological Society, as our Society then was; he became a member of its committee soon after its foundation. He gained much of his glaciological knowledge in his two visits to Baffin Island in 1950 and 1953 with P. D. Baird's expeditions to study the two largest icecaps. He, together with Baird, Sven Orvig and the pilots, was the first to set foot on the Penny and Barnes icecaps. These expeditions led to a series of papers, on the physics of deglaciation, heat exchange at the surface of a glacier, glacier flow and a wide range of problems in glacier physics.

There was a historic meeting in London in 1949 (*J. Glaciol.*, 1, 231–240), which, in retrospect, marked the begining of modern glaciology, at which Dr Egon Orowan introduced the new idea that glacier flow was an example of the high-temperature creep of a polycrystalline solid. Orowan modelled the flow as that of a perfectly plastic solid, and pointed out that, on this basis, a tall slender column of ice could not attain a height of more than about 10 m. In the discussion that followed Bill Ward cogently suggested that this was why crevasses in glaciers attain roughly this depth. Subsequent work has shown that he was right.

His subsequent glaciological work was on Austerdalsbreen, Norway, in the expeditions started in 1955 by Vaughan Lewis. All the later expeditions, and there was one each year from 1955 to 1960, were organised and led by Ward (it was, in fact, he who first recommended to Lewis that Austerdalsbreen would be such a suitable glacier for detailed research). Mechanical and thermal boring technique in ice was his speciality, and the success of the expeditions owed much to his careful preparation and field skills, as I saw at first hand. Particularly notable were his designs for electrically heated hotpoints for glacier drilling, for inclinometers for use in pipes, and for an interesting toothed-wheel device for measuring the sliding speed at the bottom of a hole in a glacier. The inclinometer contained a resistance that, typically, he wound himself, under a watchmaker's viewing glass, to be sure that the turns were even and as close as possible to give maximum accuracy in the position of the pendulum. He brought his engineering skills to bear on his hobby of mountaineering and rock climbing, becoming Chairman of the British Mountaineering Council's Equipment Sub-Committee.

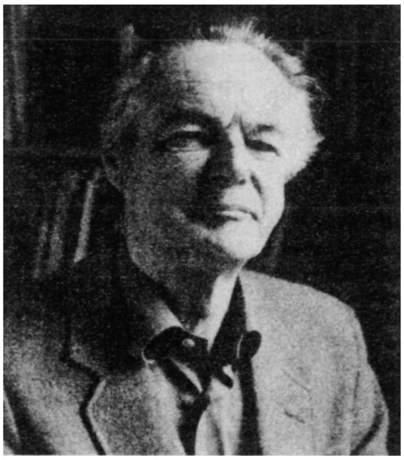
He was awarded the degree of D.Sc. by London University in 1961 for his work on soil mechanics, and became a visiting Professor at City University (1967–69). His two interests, of tunnel behaviour (tunnels in London clay were his civil engineering speciality) and glaciology, came together in 1985 when, as consultant to the Department of the Environment, he reported on how colliery spoil might be used to backfill abandoned limestone mines in the West Midlands, to prevent them collapsing and damaging overlying buildings (and a motorway). This involved experiments at Cardington with rock paste pumped into heaps on surfaces, not unlike model glaciers. I am sure this was in his mind when, more recently, he drew up detailed plans of a working glacier model for the Norwegian Glacier Museum, at Fjaerland; this also used rock paste.

For ten years from 1961 he was an influential Secretary to the International Commission on Snow and Ice, and wrote the new statutes adopted at the Moscow meeting in 1971. He was admired for his ability to produce draft minutes of a meeting, as it ended, for approval at the same meeting.

After Bill retired from his post at the Building Research Station, where he had worked since 1942, he maintained his interest in glaciology, frequently attended meetings of the Society, and was always concerned about the opportunities for young people to enter glaciology. He died on 23 April 1996. His wife, Monica, had died in January 1995, and they leave a son, a daughter and six grandchildren. I and many others have cause to be grateful to Bill Ward for sound advice, whether it be on the right way to make an ice-drill, the design of a high-altitude hut, the effect of ground movement on the cast-iron lined tunnels of the London Underground system, or the best way up a mountain. He was a good friend and colleague, whom I remember with particular affection for his unselfish field leadership on Austerdalsbreen.

John Nye

Dr T. E. Armstrong (1920–1996)



Terence Armstrong would not have claimed to have been a glaciologist yet he was a member of the International Glaciological Society for 40 years, he served on its Council and as Treasurer, and he published on sea ice. His warmth, gentleness and scholarship were well known to those many glaciologists who found their way to the Society's headquarters in the Scott Polar Research Institute. Here he was a familiar and ever-present figure, willing to share his insights on a broad range of polar problems. His achievements with respect to studies of the Soviet north from the end of the war until his death have been well documented elsewhere. Here I will touch only briefly on the highlights of his career, focusing instead on some of those aspects more directly related to snow and ice.

Terence Edward Armstrong was born in Surrey but spent his early years in Kent. He was the first student to study Russian at Winchester from where he went to Magdalene College, Cambridge to read modern languages. His studies were interrupted by the war when he served with the Army Intelligence Corps from 1940 to 1946, in North Africa and various other parts of Europe. On his return to Cambridge in 1947 he was appointed to a Fellowship in Russian at the Scott Polar Research Institute, later receiving an ad hominem Readership in Arctic Studies. He was one of the key academics who helped build and maintain the reputation of the Scott Polar Research Institute as one of the most important polar centres in the world. As Assistant Director of Research from 1956–1977 he was an important influence on several generations of Arctic scholars.

Ignorance about activities along the northern coast of Russia prompted Terence's major study on the Northern Sea Route, based on careful examination of original Russian sources, that was the subject of his Ph.D. in 1951. Sea ice was obviously the major factor that had to be dealt with by ships transiting this route so it was probably no surprise that in 1958 he published an atlas on *Sea ice north of the USSR*. This experience, doubtless combined with that in 1954 when he participated in the maiden voyage of HMCS *Labrador* through the ice-infested Northwest Passage, led to collaboration with colleagues in the Institute resulting in the application of the methodology he had devised to an atlas of *Sea ice of the Canadian Arctic* (1960). An atlas on the Falkland Islands Dependencies, also using his methodology, followed in 1963. A further contribution to the ice literature came from his collaboration with Brian Roberts and Charles Swithinbank on the *Illustrated Glossary of Snow and Ice*, published in 1966, a book familiar to many. His interest in terminology continued after this was published, leading to subsequent contributions on proposed new terms and definitions for snow and ice features.

He was a long-standing and good friend of the Society. From 1958 to 1961 he served on Council and from 1965 to 1970 was the Society's Treasurer.

Recognition of his accomplishments came from several circumpolar countries. For a time he was a visiting Fellow and guest lecturer at the Arctic Institute in St Petersburg, from 1970–72 he was on sabbatical at the University of Alaska and, following his retirement, he was visiting Professor at Trent University, Ontario. He received honorary degrees from McGill University and the University of Alaska, and the Cuthbert Peek Award (1954) and the Victoria Medal (1978) of the Royal Geographical Society.

He is survived by his wife Iris and by two sons and two daughters.

FIELD GLACIER

The U.S. Board on Geographic Names, at its June 13, 1996 meeting, approved the name Field Glacier in Haines Borough and the City and Borough of Juneau, Alaska. This name has been entered into the Nation's official automated geographic names respository and will be published in Decision List 1996. The entry will read as follows:

Field Glacier: glacier, 31 km (19 mi) long by 3.2 km (2 mi) wide, in Tongass National Forest, heads 6.4 km (4 mi) SE of Mount Hislop Ogive Glacier and Bucher Glacier, in a southwesterly direction towards an unnamed stream which flows into the Lace River; named for glaciologist Dr William Osgood Field (1904–1994); Haines Borough and City and Borough of Juneau, Alaska; T32, 33&34S, R64&65E, Cooper River Mer.; 58°55′58″ N, 134°47′05″ W; USGS map — Juneau (D-3) 1 : 63,360 mouth of feature.

GLACIER BOREHOLE VIDEO

A 24 minute composite video from a miniature borehole camera used to investigate the internal structure of the Haut Glacier d'Arolla, Switzerland in 1995, has been produced. It is intended as a resource for teachers of geomorphology and glaciology, as well as the general research community. It includes the following sections:

1. The process of hot-water drilling on a glacier
2. A journey down a borehole to see changes in ice structure with depth
3. Englacial voids and channels
4. The glacier bed
5. Changes in water turbidity down a borehole
6. Changes in hole orientation
7. Drilling problems

Copies available in PAL, NTSC and SECAM format from: Luke Copland/ Jon Harbor, Earth & Atmospheric Sciences, Purdue University, West Lafayette, Indiana, IN 47907-1397, U.S.A. luke@geo.purdue.edu or jharbor@geo.purdue.edu

LESSONS IN ICE SHEET MODELLING

An updated version of Doug MacAyeal's 335 page "unpublishable" monograph is available on the World Wide Web (in Adobe Acrobat PDF format) at: http://www2.uchicago.edu/psd-macayeal/ The update includes a new chapter that covers: ice-sheet flow equations; ice-sheet and bedrock heat-flow equations; contour-following vertical coordinate; discretization with high-order element interpolation; linear triangular elements; quadratic triangular elements; computation of u, v, w and the D-term; horizontal velocity; Gaussian quadrature; numerical integration of the heat equation; split timestep; horizontal advection equation: SUPG vs upwinding; vertical advective/diffusion equation; summary of numerical integration of the heat equation; EISMINT Level 1 fixed margin intercomparison benchmark; the "tiling instability"; and various miscellaneous material.

ICE RESEARCH NETWORK

A new e-mail network – ICE_PHYS – has been created to serve the international community of ice researchers in the areas of ice physics, ice mechanics, and ice chemistry. The network is open for discussions of experimental methods, equipment, software, announcements of positions, search for graduate students, conference information etc. The owner of the list is Professor Victor F. Petrenko: victor.f.petrenko@dartmouth.edu. To subscribe send Email to: listserv@dartmouth.edu with the contents: SUB ICE_PHYS Victor Petrenko

You will then receive a detail instruction how to manage the list.

HILDA RICHARDSON

Mrs Hilda Richardson has moved from Street Farm House, Shudy Camps, to 9, Bateman Mews, Cambridge CB2 INN, UK, Tel: 01223 327064.

JOURNAL COPIES AVAILABLE

Geoffrey Hattersley-Smith, The Crossways, Cranbrook, Kent TN17 2AG, UK, tel: 0158 712 865, has copies of the *Journal of Glaciology* up to 1975 (no. 70) available. Please contact him if you are interested.

New members

Armstrong, Richard L., University of Colorado, CIRES/NSIDC, Campus Box 449, Boulder, CO 80309, U.S.A. (Tel: +1 303 492 1828; Fax: +1 303 492 2468; Email: rlax@kryos.colorado.edu)

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