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ICE

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SYMPOSIA

1990

27-31 August **Ice–Ocean Dynamics and Mechanics, Hanover, NH, USA**

Proceedings volume: *Annals of Glaciology*, Volume 15

1991

26-30 August **Mountain Glaciology relating to Human Activities. Lanzhou, China**

Proceedings volume: *Annals of Glaciology*, Volume 16

1992

17-22 May **Remote Sensing of Snow and Ice. Boulder, CO, USA**

Proceedings volume: *Annals of Glaciology*, Volume 17

September **Snow and Snow-related Problems. Nagaoka, Japan**

Proceedings volume: *Annals of Glaciology*, Volume 18

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Contents

COVER PICTURE: Late remnant of an avalanche on a snow slope south of Col de Crête Sèche on the Italian–Swiss border. (The "Abominable Snow Pig"?) Photograph by Hans Röthlisberger.

CANADA

GENERAL GLACIOLOGY

ABLATION UNDER A DEBRIS COVER

(Eric Mattson and Jim Gardner, University of Waterloo, Waterloo, ON)

Glacier ablation rates under debris have been investigated on the Dome Glacier, Canadian Rockies, at the Kaskawulsh Glacier, St Elias Mountains, and on the Rakhiot Glacier, Punjab Himalayas. As part of this research, the energy balance over the debris surface and the energy transfer processes through the debris to the ice surface have been monitored and modelled. Despite the considerable geographical differences of the study sites, results to date indicate that local factors such as glacier surface topography have a greater impact on ablation rates than regional factors. The research is ongoing.

GLACIER HEADWALL WEATHERING PROCESSES

(Jim Gardner, University of Waterloo, Waterloo, ON)

This continuing research examines the temperature and the moisture variables in physical weathering processes at glacier margins. The primary focus has been on freeze-thaw processes in a *randkluft* environment. Data extending from April through October from the Dome Glacier in the Canadian Rockies indicate an active ice margin freeze–thaw regime through at least six months of the year. The freeze–thaw regime is restricted to a narrow 2–3 m band at the upper snow/ice rock interface.

GLACIER STUDIES, YUKON TERRITORY

(G.K.C. Clarke, E.W. Blake and D.B. Stone, Department of Geophysics and Astronomy, University of British Columbia, Vancouver)

Trapridge Glacier last surged around 1945 and its next surge is expected to occur within several years. The aims of our field study are to determine the cause and mechanics of surging. In 1988 we resurveyed the glacier, drilled 60 holes to the bed, measured subglacial water pressure, analyzed basal and outflow water for the presence of rhodamine WT tracer, and sampled the subglacial material. By planting electrolytic tilt sensors in the deforming glacier substrate we have obtained direct *in-situ* measurements of till rheology. Using large arrays of subglacial current and voltage electrodes we measured spatial and temporal changes in subglacial resistivity and electrokinetic streaming potential associated with natural and induced changes in the subglacial water system.

WEDGMONT GLACIER, NORTHERN GARIBALDI PARK, COAST MOUNTAINS, B.C.

(Karl Ricker and W.A. Tupper, West Vancouver and BC Institute of Technology, Vancouver, BC)

Fieldwork in 1988 was hampered by weather problems and tight schedules. In late October the photogrammetric survey of the snout was caried out after the arrival of snow. Plotting from the photographs is in progress. Publication of yearly results in the *Canadian Alpine Journal* has been suspended, pending further clarification on policies of the Alpine Club of Canada.

GLACIOLOGICAL INVESTIGATIONS OF PEYTO GLACIER, ALBERTA

(G. Holdsworth, National Hydrology Research Institute, Saskatoon, SA)

The mass balances of Peyto Glacier in 1986–87 and 1987–88 were once again negative. Peyto Creek has been gauged during the winter months and the data will be used to construct the winter hydrograph. D.S. Munro (University of Toronto) continued his energy-balance study. A thesis on water quality at Peyto Glacier was completed by C. Bradley under the direction of D.N. Collins (University of Manchester). Samples of preserved wood retrieved from in front of the glacier have been dated at 2900–3100 B.P. and further afield at 1140 and 505 B.P.

INVESTIGATION OF COAST MOUNTAINS' GLACIERS

(M.N. Demuth, O. Mokievsky-Zubok, A. Dalton and C. Onclin, National Hydrology Research Institute, Saskatoon, SA)

An international glaciology course under the direction of Gunnar Østrem was run at the end of July on Place Glacier.

A contract for the collection of winter-, summer- and net-mass balance data on Sentinel, Helm and Place Glaciers was awarded to G.K.C. Clarke of the University of British Columbia.

For the 1987 and 1988 balance years the specific mass changes (b_a) in water equivalent (H_2O), exhibited by the three glaciers, were as follows: Sentinel Glacier +0.15 and +0.45 m; Place Glacier −0.79 and −0.97 m; and Helm Glacier −0.85 and −0.15 m. The equilibrium line altitudes, in m a.s.l., were 1875 and 1845, 2310 and 2310, and 2030 and 2100, respectively. In collaboration with B.C. Hydro, a glacier mass-balance network was re-established on the Tiedemann and Bench Glaciers in the Homathko River basin and winter balance measurements were made in the second half of May.

HYDROLOGY

GLACIER HYDROLOGY

(C.C. Smart, University of Western Ontario)
Field data on climate, proglacial stream and spring discharge are being used with thermal drilling and dye tracing to determine the catchment areas and the conduit hydraulics of the respective drainage systems.

SNOW AND ICE HYDROLOGY PROJECT, KARAKORAM, HIMALAYA, PAKISTAN

(G.J. Young, K. Hewitt and J.S. Gardner, Wilfrid Laurier University and University of Waterloo, Waterloo)
The Snow and Ice Hydrology Project (SIHP) is a joint project of the Water and Power Development Authority, Pakistan and Wilfrid Laurier University, Canada, sponsored by the International Development Research Centre, Canada. Other universities also involved in SIHP are: Waterloo, British Columbia, Ottawa, Canada; New Hampshire, USA; and Manchester, UK. The rationale for SIHP is that the Indus River, very important for water supply to irrigation and hydro-electricity facilities, is greatly dependent on snow and ice meltwater from the Karakoram mountains. With the final aim of developing an operational forecasting model for the Upper Indus Basin, data collection and analysis rates and timing of snow and glacier melt have been undertaken each summer since 1985. The project will probably continue for several years.

MACKENZIE DELTA HYDROLOGY

(P. Marsh and S.C. Bigras, National Hydrology Research Institute, Saskatoon, SA)
The flooding regime and sill elevation of lakes in an area near Inuvik, NWT was analysed using 12 to 15 years of Mackenzie River east channel water level data. The timing of the spring rise in water levels is very consistent; peak levels occur on 3 June, ±4 days. Because the magnitude of the spring flood varies greatly from year to year, only 67% of lakes in the study area flood annually in the spring. The remaining lakes have a flood frequency >1 and <4 years. By late summer water levels drop, cutting off approximately 88% of lakes from the Mackenzie River.

Break-up in the Mackenzie Delta, NWT was monitored from 1981 to 1987. Thermal break-ups occurred in six of the seven years; a mechanical break-up in 1982. The location of frequent ice jams in the delta, as well as their formation, composition, and growth, and the backwater build-up and flow diversion patterns which results have all been documented.

Water in the delta was analysed for temperature, conductivity, pH, turbidity and ionic concentrations of calcium and magnesium. The ecology of the delta lakes is likely quite dependent of the replenishment of minerals during the flooding of lakes and channels in the spring.

THE EFFECT OF GLACIAL MELTWATER ON THE KLUANE LAKE

(E. Carmack, Institute of Ocean Sciences, Pat Bay, BC)
Summer melting results in the input of melt water from Kaskawalsh Glacier above Kluane Lake, the largest lake in the Yukon Territory of Canada. The release of this water into the lake peaks over a short period in late summer, and comes as intense, penetrating plumes of dense, silty water. This project is intended to study the hydrodynamic properties of these plumes and their effect on the lake. Data collected with conductivity and temperature profilers, current meter moorings and thermistor chains are being analysed.

SNOWMELT RUN-OFF IN PERMAFROST BASINS

(P. Marsh, National Hydrology Research Institute, Saskatoon, SA)
A field study of snowmelt run-off was carried out in the Mackenzie Delta, NWT and near Resolute Bay, NWT. The strong negative soil heat flux delayed the arrival of melt water at the snowcover base. The wetting front brakes into well-defined flow fingers which allow water to move rapidly into the snowpack without wetting the entire snow cover. If the snow is cold enough, the water will freeze making these features easy to locate. They provide an excellent method to study the natural movement of water into the dry snowcover. Field work has provided information on the frequency of flow-finger occurrence, their relationship to premelt strata, and the effect of initial snow-pack properties. Once melt water reached the snowcover base, most infiltrated the soil. Even though the soil was below 0°C, only a small portion of the melt water which infiltrated the active layer refroze. As a result, the soil warming was not as large as would be expected if all the melt water had refrozen. The large soil infiltration also limits snow-melt run-off, which has important implications for the hydrology of lakes in the Mackenzie Delta.

SNOWMELT RUN-OFF MODEL FOR NORTHERN ENVIRONMENTS

(T.D. Prowse, National Hydrology Research Institute, Saskatoon, SA)
Five models have been evaluated — CEQUEAU (Institut National de Recherche Scientifique), SSARR (Streamflow Synthesis and Reservoir Regulation), TANK (Japanese National Disaster Prevention Center), NWSRFS (National Weather Service Forecast System) and HSP-F (Hydrologic Simulation Program-F). In their present form it is unlikely that any will give reliable predictions of snowmelt run-off in Arctic environments without either extensive calibration of model parameters or major modifications or revisions to the simulation routines. The HYDROTEL model

(Université du Québec) is also being investigated as a *base* model for the project. A field site on the Norman Wells–Zama pipeline route in the headwaters of the Petitot River is under consideration. It appears to be an ideal location because it is currently experiencing the effects of climate change and also it represents terrain which contributes low-elevation run-off to the river ice break-up/flood wave on the Liard River.

METEOROLOGY

PROXY CLIMATE DATA FROM ICE CORES
(G. Holdsworth, M.N. Demuth, S. Forgarasi and B. McCarthy, National Hydrology Research Institute, Saskatoon, SA)
A significant positive correlation (teleconnection) has been found between the annual net mass balance time series (1900–1980) from Mount Logan, YT and the areal mean of the November–March precipitation from the steppe region of the central USSR. Teleconnections have also been found between the Mount Logan time series and series for the Canadian Prairies and Japan between 1900 and 1987. Stable isotope data indicate that *isotopic seasons* are generally phase lagged with respect to calendar seasons. They appear to be correlated with SSTs and ocean heat transfer curves as well as the position of the Aleutian Low rather than with air temperature or the temperature difference between the ocean surface and the core site. A preliminary time series analysis of 250 years of data shows spectral power at ENSO frequency at ~11 years and ~21 years.

An improved, shallow, ice-borehole logging system has been developed. It is capable of logging dry boreholes up to 200 m deep and may be easily transported and assembled by its two operators. Modifications have been made to the Canadian Rufli-Rand core drill by incorporating an hydraulic winch/control system.

ICING, ICE PLATFORMS, ARCTIC CLIMATE
(K. Szilder and E.P. Lozowski, Division of Meteorology, University of Alberta, Edmonton, AB)
Atmospheric ice: An experiment has been conducted to measure the overall convective heat transfer and the drag coefficient for four representative icing shapes formed on a circular cylinder.
Floating ice: A mathematical model has been proposed which gives operational criteria for the construction of artificial floating sea ice platforms by water flooding and spraying.
Permafrost: A numerical model for simulating the climate and energy balance of the Arctic tundra in summer has been developed.

FLOATING ICE

ICE CONDITIONS IN THE SEA OF JAPAN AND THE SEA OF OKHOTSK
(DF Dickins Associates Ltd, Vancouver, BC)
This study provided information on ice concentrations, ice and snow thickness, ice ridging in the Sea of Japan and the Sea of Okhotsk for shipping.

NEARSHORE ICE MOVEMENT STATISTICS FOR THE ALASKAN BEAUFORT SEA
(DF Dickins Associates Ltd, Vancouver, BC)
This study examined three characteristics of ice motion: the persistence of ice motion in a given direction, 3-hourly speeds, and 3-hourly ice-movement directions. Statistical tables for each parameter were produced from USGC satellite buoy records for three buoys in the nearshore area of the Alaskan Beaufort Sea.

RIVER ICE STUDIES
(H. Tsang and S. Beltaos, National Water Research Institute)
(S. Beltaos) Field observation of ice jams on the Restiganche River, Nebraska started this year.
(S. Beltaos) Lab. study of ice-cover break-up using the artificial "Syg-Ice".
(S. Beltaos) Management of $1.1M comprehensive computer modelling of river ice regime project that is supported by many agencies. First year seminar workshop held 17 January 1989.
(H. Tsang) A new theory is proposed for vertical distribution of frazil in turbulent water. The theory was confirmed qualitatively by field data from the Lachine Rapids.
(H. Tsang) Conceptual modelling of river cooling; frazil formation and anchor ice production.
(H. Tsang) Lab. experimental setup for study of flocculation of frazil has been completed.

SURVEY OF ICE RIDGE SAILS IN THE SOUTHERN BEAUFORT SEA
(R. Frederking and M. Sayer, IRC/NRCC, Ottawa, ON)
Statistics of ridge sail heights in the southern Beaufort Sea were examined. The measurements were conducted in the landfast ice near Tuktoyaktuk. Cross-section geometries, block sizes and height distributions were characterized.

MEASUREMENTS OF ICE FORCES ON LIGHTPIERS IN THE ST LAWRENCE SEAWAY
(R. Frederking and M. Sayer, IRC/NRCC, Ottawa, ON)
A new light pier in the St Clair River was instrumented to measure ice forces. Thus, forces on a total of four light piers are being monitored. Fluid-filled panels are used on two light piers in the St Clair River. Vibrating wire stress panels are used on "Curve #1" light pier, and load cell-supported panels on the Yamachiche light pier in Lac St Pierre.

MEASUREMENT OF ICE FORCES ON A VERTICALLY FACED BRIDGE PIER
(R. Frederking and M. Sayer, IRC/NRCC, Ottawa, ON)
A vertically faced, 90° wedge-shaped pier on the Rideau River in Ottawa has been instrumented to measure ice impact forces. The pier is located in a reach of the river in which ice removal is managed in the late winter. This facilitates determining the size, velocity and properties of ice floes impacting the pier. Measurements have been made for three winters with two different types of sensors.

ICE RUBBLE AT AMAULIGAK F-24, 1988
(R. Frederking and M. Sayer, IRC/NRCC, Ottawa, ON)
An investigation of grounded rubble behaviour around Gulf's caisson was conducted at Amauligak site in the Beaufort Sea. Stresses were measured at the edge of the rubble field in order to examine the ability of the rubble field to transfer ice forces to the berm. Rubble displacements were also monitored.

LOAD TRANSMISSION THROUGH GROUNDED RUBBLE
(G. Timco, M. Sayed, and R. Frederking, MECH/NRC, IRC/NRCC, Ottawa, ON)
A model test series was performed to investigate the transmission of load through a grounded ice rubble pile. In the tests, a section of a vertical-sided structure was built on a submerged berm. Both the structure and the berm were instrumented independently of one another so that the load apportioning could be measured between the structure and the berm. The results have important implications in the design of Arctic structures built on submerged berms.

RIVER ICE BREAK-UP ADVANCE
(T.D. Prowse, National Hydrology Research Institut, Saskatoon, SA)
During melt periods, river ice can experience significant changes in strength that partly determine the severity of breakup conditions, but *in situ* strength tests are relatively scarce. The borehole jack is a field-portable hydraulic indentation device which enables the *in situ* testing of the confined-compressive strength of ice. It was used to determine changes in ice strength during an 18 day pre-break-up melt period on the Liard River, NWT, Canada. Measurements were also made of the river ice energy balance. Strength, measured by ultimate platen pressure, decreased by approximately 50% at a rate of 0.4 MPa d^{-1} or 0.07–0.08 MPa/MJ m^{-2} d^{-1}.

Although porosity of 0.4 is commonly assumed in the case of break-up jams, there had been no field verification of this value. On 29 April 1983 an ice jam developed at the confluence of the Liard and Mackenzie rivers and increased to a maximum length of approximately 22.8 km by 4 May. Ice jam porosity was calculated by comparing the volume of ice melted within the jam to measured changes in the total (ice and water) jam volume.

ICE FIELD SUB-SURFACE CHARACTERIZATION
(H. Melling, Institute of Ocean Sciences, Pat Bay, BC)
A bottom mounted, upward looking sonar system will be used to provide a time series of the draft of moving ice. Statistics of the topography of the under side of the ice will be prepared. Funding: PERD 67160.

BEAUFORT SEA ICE MOTION PROJECT
(H. Melling, Institute of Ocean Sciences, Pat Bay, BC)
Investigation of ice/ocean coupling on a regional scale considering the momentum transfer throughout the entire water column including topographic coupling. An extensive set of year-long current meter records have been obtained from the Beaufort Sea in addition to a series of spring hydrographic surveys and summertime drifting buoy trajectories. Development of numerical models giving the response of the current field to atmospheric forcing has aided the interpretation of field data. Funding: PERD 67114.

SMALL SCALE ICE–OCEAN INTERACTION
(D. Topham, Institute of Ocean Sciences, Pat Bay, BC)
This is an investigation into the mechanism of local ice/ocean momentum transfer which aims to clarify the role of ice keels in heavily ridged ice. Field work to date consists of detailed flow measurements close to an isolated ice keel and high resolution measurements of velocity profiles in shallow ice-covered water. Laboratory measurements have been made of model ice keel drag forces under both stratified and unstratified conditions. Funding: PERD 67113.

ICE GROWTH AND MELTING
(G.B. Crocker and E. Guy, Centre for Cold Oceans Resources Engineering (C-CORE) Memorial University, St John's, NF)
Investigations of the influence of growth, melting, and contact forces on the Labrador Ice Margin are being carried out to extend the knowledge of sea-ice thermodynamics. There are currently some unanswered questions about the importance of these factors in the advance and retreat of ice edges. In particular, the influence of wave-induced melting must be determined. If the melting, growth, or contact forces are found to be important in comparison to other forces such as wind and currents, they must be incorporated into the ice-edge drift model. At present, no other model incorporates these phenomena.

LARGE-SCALE ICE PROPERTIES
(Dat Duthinh and Ken Klein, C-CORE, Memorial University, St John's, NF)
Actual ice impacts involve contact areas of 10s to 100s of square metres, or 1000 to 10 000 times larger than most available

experimental data. C-CORE is planning to make measurements in this most important data gap. Building on model-scale towing tank tests, C-CORE is preparing for a full scale (but small) iceberg impact test in Antarctica. The test will be performed in collaboration with the French Polar Expeditions at their Antarctic base in Terre Adélie. Depending on the results of this test, further, more ambitious tests are planned at the same location or, closer to home, near St Anthony, NF. With this logistical support from the French government, the Antarctic tests will provide valuable data as well as economical pilot tests for St Anthony site. The St Anthony site is particularly attractive with its accessibility, water depth, steep cliffs, and high probability of icebergs.

INTEGRATED SEA ICE AND ICEBERG FORECAST SYSTEM

(Mona El-Tahan, CORETEC Inc/C-CORE, Memorial University, St John's, NF)

An integrated sea ice/iceberg forecast system (IIFS) is under development for the Grand Banks region, Canadian east coast. The system will integrate modules to model iceberg trajectory, iceberg ensembles drift and sea ice edge drift. The system will concentrate on regional and site-specific forecasts. The long term objective will be to couple the system with the ice detection rig-mounted radar system to provide an integrated ice management system for offshore operators.

The study will proceed in three phases: (1) a conceptual design for the forecast system and refinement of the ice edge drift model; (2) improvements to the iceberg trajectory and iceberg ensemble models, and (3) implementation of the forecasting system.

A computerized data-base management system will be used to administer the available historical ice, weather and oceanic data to be utilized by the forecast system.

The forecast system will be subjected to extensive testing as it is prepared for operational application. IIFS will provide detailed site-specific forecasts suited to clients' needs and will complement the Ice Data Integration and Analysis System (IDIAS), which is currently under development by the Atmospheric Environment Service (AES).

FLOATING ICE — RIVERS AND OCEANS

(Bernard Michel, Edward Stander and Marc Cantin, Université Laval, Quebec)

(B. Michel) A study has been completed on the maximum possible stage of an ice jam at break-up. A computer program has been developed to compute the stability of ice jams in a natural river.

(E. Stander, B. Michel) A laboratory study has been completed to study the effects of currents on the formation of aligned S_3 sea ice.

(M. Cantin, B. Michel) A laboratory programme is under way to study the mechanisms of drainage of sea ice.

BOREHOLE DILATOMETER (PRESSUREMETER) TESTS IN SEA ICE

(J.R. Murat, Y. Lemoigne, B. Ladanyi and P. Huneault, Northern Engineering Centre, École Polytechnique, Montréal)

Ice property measurements were carried in spring of 1987 during a field investigation of annual sea ice off the east point of the Melville Peninsula in the Canadian Arctic. They included a crystallographic analysis to establish type and structure, measurements of temperature and salinity profiles, and an evaluation of the natural in-plane stress field by means of borehole relaxation tests.

Compared to a similar field study carried out nine years ago, the present investigation included some clear improvements, not only in the instrumentation and data acquisition system, but also in the data interpretation and processing. In particular, it was found that consistent values of creep parameters could be obtained only when a proper consideration was made of the amount of stress redistribution after each load application in the borehole pressuremeter creep test.

LABRADOR AND NEWFOUNDLAND SEA ICE STUDIES

(Researchers at Bedford Institute of Oceanography, Dartmouth, NS)

Numerical modelling, satellite-tracked ice beacons, Image Analysis and Marginal Ice Zone experiments are used by researchers at the Bedford Institute of Oceanography to understand the contributions of the atmosphere and ocean on the motion, growth and decay of the floating sea ice off Labrador and Newfoundland. Sea ice coupled models (M. Ikeda) are used to explain and predict the variability of the southern sea ice extent for periods of days to tenths of years. Sea ice coupled models (M. Ikeda, C. Tang) are also used to study specific physical processes occurring in the Marginal Ice Zone such as ice edge meanders due to current topography interaction. Modelling results are checked against regional ice drift data obtained from satellite-tracked ice beacons (I. Peterson, S. Prinsenberg), image analysis (I. Peterson) as well as against detailed site-specific data collected in marginal ice zone surveys such as LIMEX planned for the winter of 1989 (C. Tang). Beacons have and are being developed (G. Fowler, S. Prinsenberg) to obtain by ARGOS real-time ice, air and water temperature profile data to determine the seasonal variability of the ice growth and decay rates of the moving pack ice and landfast ice (S. Prinsenberg, I. Peterson, S. Smith). Iceberg drift surveys have been used in dynamic iceberg drift models (S. Smith) to determine the oceanic and atmospheric drift contributions.

REMOTE SENSING

TRACING MARINE CURRENTS BY ICEBERG MOVEMENT
(J.M.M. Dubois and P. Larouche, Université de Sherbrooke, Sherbrooke, QU)
The project aims to evaluate the direction and speed of surface currents by remote sensing of the drift of icebergs in Hudson Bay, taking into account the stress of wind and water as well as Coriolis force. Analogue and numerical modes of LANDSAT MSS images were used in this work.

WINTER MULTI-YEAR ICE DISTRIBUTIONS IN THE CHUKCHI SEA
(DF Dickins Associates Ltd., Vancouver, BC, NASA/Goddard Space Flight Center, USA)
This study used the multi-year ice fractions computed from radiance values measured by the scanning multi-channel microwave radiometer on the NIMBUS-7 satellite to map the winter distribution of old ice in the US Chukchi Sea. Results compare favourably with other available sources.

REMOTE SENSING, DOMAIN BASIN, MANITOBA
(A. Wankiewicz, National Hydrology Research Institute, Saskatoon, SA)
Ground-truth measurements of snowfall, air temperature and streamflow were obtained for six different target areas in Manitoba, Canada. Snowpack development was simulated for each target and compared with emitted microwaves. Air photos of spring flooding were obtained for the clay plain target and flooding was monitored using NOAA IR images. The microwave brightness difference between 37 and 18 GHz became increasingly negative as the cold snowpack increased from 2 to 200 mm water equivalent. By contrast, flooding from snowmelt produced a positive brightness difference when air temperature was above 0 °C, which decreased over time as meltwater receded from the targets.

BEPERS-88 SEA ICE LASER PROFILING
(H.B. Granberg, J.E. Lewis and M. Leppäranta, CARTEL/Université de Sherbrooke, McGill University and Finnish Institute of Marine Research, Finland)
As part of the Bothnian Experiment in Preparation for ERS-1 (BEPERS), 61 profiles of surface elevations were obtained over the ice in the Bay of Bothnia during the period 9–13 March 1988. The profiles range in length from approximately 6 to 24 km and were obtained using a PRAM III laser profiler in a helicopter-borne mode. The laser was operated by a crew from Centre d'Applications et de Recherche en Télédétection (CARTEL) at Université de Sherbrooke. The analysis is currently underway at McGill University, FIMR and CARTEL.

WAVE ACTION IN LABRADOR ICE MARGIN
(J.I. Clark, W.D. Winsor, G.B. Crocker, (C-CORE); B.M. Eid, R. Olsen, Eva Dunlap, (MacLaren); W. Perrie, F. Dobson, (BIO); P. Vachon, (CCRS); C-CORE/Memorial University, St John's, NF, MacLaren Plansearch, Ltd, Halifax, BIO/DFO, Dartmouth, NS, and CCRS/EMR, Ottawa, ON)
In 1984, a regional scale experiment was promoted to investigate the processes that dictate the severity and extent of the ice cover. The Labrador Ice Margin Experiments (LIMEX) have emerged as multi-organisation cooperative ventures focused on using new developments in remote sensing to aid offshore development in the cold ocean environment. A goal of this research is to improve the capabilities for ice management and for safer and more cost-effective ice engineering.

The project is directed at improving the understanding of large-scale sea-ice processes. Our focus is the study of the influence of ocean wave action on the Labrador Ice Margin. The incident waves have a dramatic effect breaking the floes and mixing the ice with the surface water. It is important to understand how these processes control ice deterioration rate at the southern ice limit.

Surface measurements can only be collected for a very limited number of points. New advances in ocean remote sensing by synthetic aperture radar (SAR) provides the means to expand the observations to a large portion of the boundary. The LIMEX experiments are now an integral part of the ice monitoring validation programmes of two future radar remote sensing satellites. ERS-1 and RADARSAT. It is anticipated that RADARSAT will make a significant contribution in the detection of ocean and ice conditions.

SNOW AND AVALANCHES

DEPOSITION OF ATMOSPHERICALLY TRANSPORTED COMPOUNDS IN ARCTIC SNOW
(Dennis Gregor, Water Quality Branch, Environment Canada)
The project addresses the depositon and recent trends of atmospheric transported organic componds in the Canadian Arctic snows. Snow-pack samples representing snow accumulation for the winters of 1985–86 and 1986–87 were collected at 12 and 15 sites, respectively, throughout the Northwest Territories, Canada, during the spring of 1986 and 1987 (from 62 °N to 85 °N and from 73 °W to 130 °W). Samples from the annual snow layers were also taken from the Agassiz Ice Cap on north-central Ellesmere Island for 17 years. All samples were collected as large volume snow samples and sealed into Teflon bags. The snow was melted at room temperature and extracted in field laboratories

for analyses of organochlorine pesticides (OCs), Ttl. PCB, polycyclic aromatic hydorocyclohexanes (PAHs) and chlorobenzenes (CBZs). Hexachlorocyclohexanes (HCHs) usually made up more than 75% of the total OCs measured. The highest concentration of HCHs was 53.2 ng L^{-1}. These were followed in abundance by α-endosulfan, dieldrin, chlordan and heptachlor epoxide at concentrations less than 1.0 ng L^{-1}. PCB concentrations ranged from 0.02 to 1.76 ng L^{-1} with most of the samples having concentrations less than 1.0 ng L^{-1}. DDT was also detected but at low concentrations. CBZs were present at most sites at concentrations between 0.2 and 0.5 ng L^{-1} while PAHs were highly variable. Annual fluxes for the pesticides and Ttl. PCB were calculated and these are only slightly less at these Arctic stations than the measured precipitation fluxes at sampling sites across southern Canada.

The Agassiz Ice Cap data suggests that the trace organic substance residues in the glacier have decreased since 1970/71; however, this is complicated due to the fact that only a small portion of, for example, HCHs are retained in the firn. Volatilization from the snow pack during the Arctic summer is hypothesized. Source areas, for the dominant pesticides at least, are thought to be Eurasian as opposed to North American.

SNOW PROPERTIES

(R.I. Perla, National Hydrology Research Institute, Saskatoon, SA)

The calibration of a capacitive cell for measuring snow liquid water was studied using 251 samples, with liquid water measured independently by acid dilution. A nonlinear model with high goodness-of-fit to the data was derived from physical assumptions.

Refinements to the International Snow Classification (ISC) have been proposed based on crystal rather than grain morphology. The classification was extended to include terms already in the ISC, but seldom used systematically, emphasising the distinction between process-oriented concepts. An index of mean grain size has been described.

The snow research laboratory at Sunshine was closed in 1988. Studies in 1989 will be directed towards improving the interpretation of remote-sensing signals from prairie snow covers.

SNOW MANAGEMENT AND SNOWMELT INFILTRATION

(W. Nicholaichukn, National Hydrology Research Institute, Saskatoon, SA)

The feasibility of stubble cropping can be improved if tall stubble strips are used for trapping snow. The average advantage in conserved soil water for tall compared to short stubble was 12.7 mm; 25% of that usually conserved by summerfallow. The economic benefit of snow trapping averaged 15–22 $/ha in dry years and 5–7 $/ha in years with average rainfall. There was no benefit in wet years. Getting the meltwater to enter the soil is still a major problem.

Subsoiling to 25 cm or deeper was performed to increase infiltration. When snow management practices resulted in an appreciable snowpack, subsoiling produced over-winter soil–water gains which were two-to-four times those with conventional short stubble and no subsoiling. The field sites are located at Richlea, Kerrobert, Saskatoon and Swift Current.

AVALANCHE HAZARD IN THE HIMALAYA

(Fes de Scally and Jim Gardner, University of Waterloo, Waterloo, ON)

In conjunction with the Snow and Ice Hydrology Project (Wilfrid Laurier University) the snow avalanche hazard in the Punjab Himalayas has been investigated. Associated with hazard mapping has been a study of avalanche mass estimation and the hydrological contribution of avalanche snow.

IN SITU TENSILE STRENGTH TESTS OF ALPINE SNOW

(J.B. Jamieson and C.D. Johnston, Department of Civil Engineering, University of Calgary, Calgary, AB)

During the winter of 1987–88, over 450 *in situ* tests of tensile strength were made in the Rocky Mountains of Alberta, Canada. The precision for seven tests was 15% with 90% confidence. Snow with a faceted microstructure was half as strong as new, partly settled or rounded snow of the same density. Notch sensitivity, rate effects and critical strain showed that the test fractures were brittle.

Measurements of tensile strength and slab thickness made at the crown fractures of 13 inconfined slab avalanches support the hypothesis that strong, thicker slabs result in wider slab avalanches.

ATTENUATION OF SOLAR RADIATION BY SNOW

(H.B. Granberg and A.V. Kulkarni, CARTEL/Université de Sherbrooke and McGill University, Montréal, QU)

A study of spectral attenuation of solar radiation by snow is being undertaken at Schefferville. The purpose of the study is to develop a better understanding of the thermal regime of the seasonal snow cover. Preliminary results using a Li-Cor LI-1800 spectroradiometer and a specially designed probe indicate that the greatest penetration of solar radiation occurs at around 580 nm. The penetration varies both seasonally and spatially. A new spectroradiometer better suited for use in spatial surveys is currently under construction at CARTEL.

SNOW/GROUND INTERFACE TEMPERATURES AT SCHEFFERVILLE

(H.B. Granberg and D.T. Destochers, CARTEL/Université de Sherbrooke and McGill University, Montréal, QU)

A study of snow/ground interface temperature variations is underway at Schefferville, Canada. The purpose of the study is to provide data for use in spatial modelling of snow-cover development and permafrost distribution. Preliminary data from two surface temperature grid installations at an alpine tundra and open woodland site show the wintertime ground-surface temperature range to be approximately 0°C in the warmest forest locations to approximately equal to the ambient air temperature in windswept and snow-free locations on the alpine tundra. Grid surveys using portable probes showed the snow/ground interface temperature in open spruce woodlands to range from approximately 0° to 13°C on 9 December 1984; from 0° to −10°C on 21 February 1985; and from 0° to −3°C on 23 April 1985. Similar grid surveys of the alpine tundra areas near Schefferville are planned.

NET RADIATION OVER SNOW

(H.B. Granberg and A. Nadeau, CARTEL/ Université de Sherbrooke and McGill University, Montréal, QU)
A detailed study of net radiation over snow at a subarctic forest edge has been undertaken using 44 net radiometers specially designed for the purpose. A model study is underway where the net radiation is spatially modelled within the forest and the results compared with different values computed from the measurements.

SOIL EROSION DURING SNOWMELT

(AÛ Pesant and H.B. Granberg, Lennoxville Experimental Farm, CARTEL/Université de Sherbrooke, Sherbrooke, QU)
A field study of soil erosion processes active during snowmelt is presently undertaken at the Agriculture Canada Lennoxville Experimental Farm. Both test plot studies and detailed field observations are made at a 1 km^2 test basin.

AVALANCHE RESEARCH IN CANADA

(D.M. McClung and P.A. Schaerer, IRC/ NRCC, Vancouver, BC)
Data from five mountain ranges were analysed and methods were developed to predict runout distances of avalanches using extreme-value statistics. Field data were analysed with respect to snow-creep pressure on structures and compared with linear creep law. Work has begun on a nonlinear creep law (shown to be necessary by the analysis). Measurements of the effect of temperature on shear failure of Alpine snow (including acoustic emissions) were completed. Snow gliding measurements for forecasting full-depth avalanches on steep rock faces were initiated. Work on measurements of avalanche speeds and impact pressures is nearly completed. Data form *in situ* snow stability tests were analysed and the methods documented.

ANALYSIS OF ICE CAP MATERIAL

(R.M. Koerner, B. Alt, R. Dubey, J. Bourgeois and M. Parnandi, Geological Survey of Canada, Terrain Science Division, Ottawa, ON)
Field: Bulk melting at several depths in a 123 m borehole on Agassiz Ice Cap was done for analysis of pollen-grain concentrations in the Sangamon, Wisconsin and Holocene ice. A datalogger with several thermistor sensors in, and above, the snow was set up to run for a one-year period. Other sensors in the system will monitor snow accumulation, relative humidity and air pressure. The mass balance of Melville south, Meighen, Agassiz north and Devon north-west ice caps was measured for the balance year August 1987. Snow samples for chemical analysis were collected by the Polar Bridge expedition on their crossing of the Arctic Ocean from the Soviet Union to Canada.
Laboratory: Research in the laboratory included setting up a Dionex ion chromatograph to measure ion concentrations in various snow and ice samples collected in past field seasons. Work was completed on a re-analysis of the Greenland and Antarctic core data in the terms of the age of basal ice in Greenland and also the effect of core records of the massive discharge of melt water from the Laurentide ice sheet 18 000 to 10 000 years ago. Pollen-grain concentrations were measured in ice-core bulk samples, surface snow samples and ground ice samples with a view to identifying the source regions of aerosols and/or the mode of origin of the ice. Synoptic analyses were drawn from ice-core data in a study of the early part of the last century to determine the effect of the eruption of the volcano, Tambora, on regional climate.

ICE ENGINEERING

ICE-STRUCTURE INTERACTION PROBABILISTIC MODELS — REVIEW OF INPUT PARAMETERS

(DF Dickins Associates Ltd, Vancouver, BC and Sandwell Swan Wooster Inc.)
The principal objective of this study was to provide a detailed assessment of the quaity of the ice input parameters available for the analysis of ice-structure interactions within a probabilistic framework. The model was tested using a number of specific offshore locations in the Canadian Beaufort Sea and the Grand Banks area. Another study for the Canadian Standards Association is an extension of this work aimed at applying the proposed standards for offshore structure design.

ICE ENVIRONMENT AFFECTING THE NEW SCOUR IN THE BEAUFORT SEA

(DF Dickins Associates Ltd., Vancouver, BC and Shearer Consulting, Bedford Institute of Oceanography, Dartmouth, NS)
This research project is producing a unique

database which combines the best available information on the distribution of new ice scour and the ice environment. This database will be used to develop the cause and effect relationships necessary to interpret historical scour data and to predict potential new scour rates in areas not covered by the existing scour database.

ICE DATABASE FOR ICE/STRUCTURE INTERACTIONS IN THE US BEAUFORT SEA

(DF Dickins Associates Ltd, Vancouver, BC)
The accumulation of the statistical database for ice/structure interactions in the US Beaufort Sea had three components: to provide a comprehensive statistical ice database for input to an ice/structure interaction model, to evaluate the feasibility of using information on sea-ice morphology to predict the safe burial depth for offshore Arctic pipelines, and to evaluate the economics of using large air-cushion vehicles to supply offshore Arctic structures.

LABORATORY TESTS OF PULVERIZED ICE EXTRUSION

(M. Sayer, R. Frederking and S.B. Savage, IRC/NRCC, Ottawa, ON, McGill University, Montréal, QU)
An analytical and experimental study was conducted to examine the behaviour of the pulverized ice layer that forms during the rapid indentation of ice. The analysis utilizes the theories developed for the rapid flow of granular materials. The experiments consisted of extruding pulverised ice between two parallel plates. Two-dimensional conditions were maintained and local stresses were measured. Several particle size distributions and plate roughnesses were used.

DYNAMICS OF THE ICE-CRUSHING PROCESS

(I. Jordaan and G. Timco, ENG/MUN, St John's, NF, MECH/NRCC, Ottawa, ON)
An analysis has been made of the ice-crushing process during fast indentation through a level ice sheet. The time variations of the load received special attention. The variation was associated with periodic crushing (pulverisation) events, followed by a vertically continuous clearing process. An analysis of the energy exchange revealed that the extension of the crushed ice is the main seat of the energy dissipation during the crushing process.

ICE-GENERATED ACOUSTIC SIGNALS

(D.M. Farmer and Yunbo Xie, Institute of Ocean Sciences, Pat Bay, and Department of Oceanography, UBC, BC)
Studies are being carried out on the underwater sound generated by cracking sea ice. Broad band recordings have been made in Amundsen Gulf and Barrow Strait with three-dimensional arrays of hydrophones. This arrangement allows the identification of the location of cracking events and also the fine structure that appears to be present in the radiated sound field.

Theory derived from earthquake mechanics has been adapted to the case of a floating ice sheet and has shown that several of the observed features of the sound made by cracking ice can be explained by two mechanisms:

(1) The crack is a propagating feature whose speed is a significant fraction of the speed of sound in water. The sound radiating from the moving ends of the crack is, therefore, quite strongly Doppler shifted with respect to a stationary hydrophone.

(2) The observed tensile cracks develop as a *slip-stick* process, the frequency of which is governed by the ice thickness and yields a well-defined peak in the sound spectrum.

FLOW OF CRUSHED ICE

(I.J. Jordaan, D.M. Masterson, P. Spencer, and D. Finn, Memorial University of Newfoundland, St John's, NF and GEOTECHnical Resources Ltd, Calgary, AB)
Observations made of the interaction between a vertical-sided structure and an ice sheet have shown that a layer of crushed ice always exists between the intact ice sheet and the structure. This pulverised ice is extruded from the contact area as the crushed layer transmits the ice forces to the structure. The cyclic nature of this loading can create severe vibrations in the structure, as has been observed on the *Molikpaq* drilling caisson in the Beaufort Sea. To gain a more complete understanding of this problem, the behaviour of the crushed-ice layer must be properly understood.

A joint effort of Memorial University of Newfoundland (MUN) and GEOTECHnical Resources Ltd is presently underway to study this behaviour. This study consists of crushing and extrusion tests performed in GEOTECH's Calgary laboratory, with subsequent data analysis by MUN's ice research team. The objectives of this study are: (a) to determine the shear stress–flow rate relationship of crushed ice, and (b) to determine the stress distribution throughout the layer of crushed ice, and its variation with time and layer thickness.

VERTICAL AND SLOPED EDGE-INDENTATION TESTS OF FRESHWATER ICE

(I.J. Jordaan, S.J. Jones, and D. Finn, Memorial University of NF and IMD/NRCC, St John's, NF)
Ice-ship and ice-structure interactions are modelled using flat-faced indenters moving through level ice. The different modes of ice failure that result influence the static forces and vibrations induced in the structure.

Preparatory work is now in progress for a series of indentation tests to be conducted in the ice tank of the National Research Council's Institute for Marine Dynamics (IMD) in August/September 1989. The tests will consist of towing vertical and inclined indenters through freshwater ice sheets at different speeds, measuring the forces exerted on the structure and the dynamic response of the structure. The various failure modes of the ice sheet — crushing, cracking, buckling, bending and creep — will be observed. The objectives of this study are: (a) to characterise the failure modes of ice when indented by flat-faced structures, both inclined and vertical; (b) to enable more accurate prediction of the forces exerted on the structure during the interaction; and (c) to investigate the dynamic response of a structure encountering various ice failure modes.

ICE-INDUCED VIBRATIONS IN STRUCTURES
(I.J. Jordaan, A.S.J. Swamidas, D.B. Muggeridge, J.P. Nadreau, R.M.W. Frederking, S.J. Jones, G.W. Timco, R.F. McKenna, C. Jebaraj, S.K. Singh, Memorial University, NRCC/IMD St John's, NF and NRCC/ICR Ottawa, ON)
Brittle failure of the ice against an offshore structure or a vessel can induce vibrations and cause a substantial threat to such structures. Ice-induced vibrations in the structure result from fracture, spalling, flexural, crushing and damage of the ice. The role of localised ice failure in compression is emphasised: numerous microcracks are formed and the ice then pulverises against the structure. The repetition of this action results in dynamic ice forces.

During ice-structure interaction, the relative velocities of ice and structures are also important. The active role of structure for the assessment of dynamic ice forces has been investigated in model tests with various vertical structures and model sea ice at the NRC Ottawa ice basin. From the experimental results and from the development of a theory for the extrusion of crushed ice, a model was developed for ice-induced vibrations in structures.

LARGE-SCALE FIELD ICE INDENTATION TESTS
(I.J. Jordaan, R.M.W. Frederking, W. Abel, D.M. Masterson, K. Kennedy and D Duthinh, Memorial University, C-CORE, Mobil Oil Canada Properties, St John's, NF, National Research Council of Canada, Ottawa, ON and GEOTECHnical Resources Ltd, Calgary, AB)
Economical development of the Arctic and sub-Arctic offshore requires an accurate and reliable methodology for the prediction of ice design loads. Along with recent work on ice-induced vibrations, the marked reduction in ice pressures recorded in the field as compared to small-scale laboratory tests indicates that a dedicated large-scale field test programme be initiated. Such a programme is made possible by utilizing the large-scale ice indenter apparatus donated to Memorial University of Newfoundland by Mobil Oil Canada Properties, on behalf of the Hibernia Joint Venture Participants. Previous field tests have been performed on a grounded iceberg at Pond Inlet, NWT in 1984 and in multiyear ice in the Canadian Arctic in 1985.

An extensive ice indentation field program has been initiated by Memorial University in conjunction with C-CORE, National Research Council of Canada, Mobil Oil Canada Properties, and GEOTECHnical Resources Ltd of Calgary. The field programme conducted during April and May 1989 was performed on "Hobson's Choice" ice island, a 10 × 5 km, 45 m thick floating block of ice that broke from the Ward Hunt Ice Shelf, Ellesmere Island, in 1982. The ice island represents a unique opportunity for large-scale field testing due to the availability of multi-year ice and iceberg-like ice. A series of ice indentation experiments were performed, leading to greater insight into the nature of ice fracture and damage during ice-structure interaction.

DAMAGE OF ISOTROPIC POLY-CRYSTALLINE ICE UNDER MODERATE CONFINING PRESSURES
(I.J. Jordaan, B.M. Stone and R.F. McKenna, Memorial University of Newfoundland, St John's, NF)
Recent work on the mechanics of ice under compressive states of stress has shown the importance of including in the analysis the effects of microcracking at high strain rates.

An experimental study of the damage of laboratory produced granular ice is being conducted. Damage, defined in the present study as the change in the apparent elastic modulus resulting from the initiation and propagation of microcracks, has been determined. The tests, conducted under uniaxial stress and moderate confining pressures, use a constant strain-rate input as the controlling feedback parameter in a closed-loop machine.

The degree of damage, or change in apparent elastic modulus, as a function strain rate, and confining pressure has led to a preliminary formulation for enhanced creep due to damage.

MODELLING OF ICE CRUSHING AND DAMAGE PROCESSES
(I.J. Jordaan, R.F. McKenna and J. Xiao, Memorial University of Newfoundland, St John's, NF)
Recent research has shown that many of the methods of classical mechanics do not apply in studying ice-structure interaction. New directions of research, recognising the extreme brittleness of ice as a material, are in progress. When ice is loaded in compression, localised crushing or pulverising of the ice occurs in the zone adjacent to the ship or structure. This is responsible for the maximum ice pressures and ice-induced vibrations. The analysis of this process requires the consideration of fracture which reduces contact stresses, damage in which the ice is degraded from its virgin state to a pulverised

state, and the extrusion of the pulverised material during which most of the energy is dissipated.

These problems are currently being addressed using finite element and other numerical techniques. Damage models have been developed to analyse the degradation of elastic shear properties of the ice using a scalar measure to represent the density of microfractures. Models which consider crack orientation are under development. Some of the features of ice behaviour in compression that are being investigated are the influence of the damage state on primary and secondary creep, and the flow of crushed material. The consideration of progressive damage and the clearing of the crushed material requires a combined Lagrangian–Eulerian formulation which is under development. To facilitate numerical computation, work is also underway on an incremental relation for primary creep.

FULL-SCALE FIELD MEASUREMENT PROGRAMME — KAUBVIK CAISSON-RETAINED ISLAND

(K.R. Croasdale, I.J. Jordaan, A.R. Marshall and J.P. Nadreau, Memorial University, C-CORE, St John's, NF and ESSO Resources Ltd, Calgary, AB)

The movement of sea ice against a wide structure, such as an artificial island, produces piles of broken ice called ice rubble. When these piles become sufficiently firmly grounded, subsequent pack-ice movements will not dislodge them and a grounded ice rubble field will form. With a proper understanding of load transmission through such ice rubble, the protective nature of grounded rubble fields may be used to advantage in the design of Arctic offshore structures.

A joint field project was carred out during the winter of 1986/87 by MUN, ESSO, and NRC at ESSO's caisson-retained island (CRI) at Kaubvik. Data from the following were collected: pressure panels on the CRI, pressure panels in the rubble, pressure sensors in the sea ice, strain rosettes, thermocouple arrays, movement surveys and rubble profile surveys. The data have been compiled and are being used to develop models for load transmission through grounded ice rubble and for landfast ice movement.

ICE PHYSICS — ENGINEERING

(B. Michel, F. Picard and Edward Stander, Université Laval, Québec)

(B. Michel, F. Picard) Tests have been completed to break ice with flat inclined indentors at narrow angles in the upward- and downward-breaking direction modes in a laboratory tank (4 × 5 m). The most interesting result is the striking difference in failure mechanisms for downward icebreaking in the brittle or ductile mode.

(E. Stander, B. Michel) An experimental set-up has been built to study, in place, the deformation under simple compression of a thin floating sea-ice sheet during formation. The objective is to study the deformation and crystal axis re-orientation during deformation.

ICING OF SHIPS

(E.P. Lozowski and W.P. Zakrzewski, Meteorology Division, University of Alberta, Edmonton, AB)

Research projects targeted at modelling and forecasting the growth of saline spongy ice on sea-going ships have been carried out since 1986. An integrated ship spraying/icing model has been developed. The model takes into account the water delivery to the ship surface, the thermodynamics of the growth of saline, spongy accretion, and the brine transport on the icing surface. The model input requirements are: ship speed and heading, wind speed, fetch, air temperature, sea surface temperature and salinity of seawater. The model predicts: the extent of the spray-receiving zone, the rate of water delivery with spray, the instantaneous and time-averaged local icing rates on several ship components, and ice loads due to icing.

A data collection programme on ship icing-related parameters was launched in the winter of 1986/87, and was successfully repeated during the winter of 1987/88. A manned system for the data collection has been developed, produced, and tested in cold rooms and on ships. Development of an automated system for the measurement and recording of ship icing-related parameters will follow.

SPONGY ICE

(G.S.H. Lock, University of Alberta, Edmonton, AB)

This is an experimental investigation of the mechanisms at work during the formation of spongy ice from a supercooled spray. The work was undertaken in the Marine Icing Wind Tunnel facility in the Department of Mechanical Engineering.

Ice fraction data revealed an insensitivity to wind speed and a weak sensitivity to air temperature. These findings applied to both fresh water and sea water.

Growth rate was found to be sensitive to air temperature. At higher (subzero) temperatures, growth was a logarithmic function of time, while at lower temperatures the growth was linear. It appears that this difference reflects a difference in morphology.

STUDY OF ICE AS A CONSTRUCTION MATERIAL

(Nirmal K. Sinha, IRC/NRCC, Ottawa, ON)

Ice bridges, ice platforms and ice islands are used quite frequently as working platforms for various purposes such as storage, transportation or winter construction. Guidelines for safe use of such ice bodies have been developed primarily on the basis of experience. As new methods are developed to build these ice structures in shorter times, there is a growing need to develop an understanding of the mechanical properties of ice as a construction material. A concentrated effort has been made to understand creep, consolidation and dilatation phenomena in ice having different structural characteristics. Both experimental and theoretical work has been carried out in the last two years. A new theory of crack-enhanced creep in ice has been proposed which seems to explain many unanswered questions on the strength and deformation of ice.

ICE/STRUCTURE INTERACTION

(Dat Duthinh and Mark Fuglem, C-CORE, MUN, St John's, NF)

C-CORE is taking the lead in applying this basic understanding of ice loading processes to several types of structures: (1) Beaufort drilling caissons with wide, vertical walls, (2) gravity-based structures with triangular-wedge ice bumpers, and (3) moored semi-submersibles. For type (1) and (3) structures dynamics are quite important, whereas for type (2) the action of triangular indentors against icebergs is of interest. Results of this work will apply as well to bridge piers and wharves in Arctic regions.

The hydrodynamics of collision are also an important aspect of the problem. For example, model tests performed by C-CORE show that wave diffraction from the columns of a semi-submersible can have a significant effect in deflecting oncoming small icebergs. An upcoming full-scale iceberg impact test will also give some indication of hydrodynamic effects due to the proximity of a large structure. A systematic study will require the use of the wave tanks at MUN and IMD and close cooperation with these organisations.

The random nature of ice loads extends beyond the fundamental processes of ice failure. Randomness also characterises the occurrence, the velocity and the size of ice masses. The reliability of detection and avoidance methods also affects operations and expected loads. C-CORE continues to develop a probabilistic framework that will draw on information from systems developed for ice management. Computer simulation is a key tool in this endeavour.

PERMAFROST

THE THERMAL REGIME IN A PERMAFROST ENVIRONMENT

(J. Kwong, National Hydrology Research Institute, Saskatoon, SA)

Two sites in northern Alberta have been selected for detailed study. The thermal regime of the Mount Watt site appears to be in equilibrium with the current climatic conditions and is very sensitive to variations in the local environment. Scattered permafrost occurrences in the Meander River site, however, could be relict.

A re-examination of occurrences of frozen ground along the Mackenzie Highway from Keg River, Alberta to Hay River, NWT indicated a local northward retreat of the fringe permafrost zone by as much as 120 km in the past 25 years. To explain the disappearance of frozen ground, climatic records of the region during the past four decades were analysed. Whereas a weak warming trend is apparent from the analysis of air temperature data, a detailed explanation of the degradation of permafrost in the region has to await analyses of other contributing parameters like vegetation cover, economic development in the region, etc.

THREE-DIMENSIONAL DISTRIBUTION OF PERMAFROST

(D. Craig, National Hydrology Research Institute, Saskatoon, SA)

Field work is progressing at one upland and one peat- and spruce-bog site in northern Alberta. Preliminary geophysical profiles obtained in August suggest that electromagnetic surveying is an excellent method for detecting permafrost at this site, providing the capability of mapping the lateral distribution of frozen ground at different times of the year.

PERMAFROST PROCESSES

(C.R. Burn, University of Western Ontario, London, ON)

Two topics are being studied: frost heave and growth of segregated ice in subaqueous lake-bottom sediments, MacKenzie Delta, NWT and the influence of porewater salinity on frost heave.

SPATIAL MODELLING OF PERMAFROST DISTRIBUTION AT SCHEFFERVILLE

(H.B. Granberg, CARTEL/Université de Sherbrooke, QU)

Permafrost observations from over 200 thermocable and 20 000 test pits at Schefferville have been digitised. A digital terrain model which includes all the thermocable sites has been developed for use in spatial modelling of discontinuous permafrost.

PERMAFROST GEOPHYSICS

(M.K. Seguin and M. Allard, Université Laval, Québec, QU)

Geophysical methods are used to determine the lateral and vertical extent of permafrost bodies and the ice thickness of the thaw (freezing) front or active layer. Specific geophysical methods are also used to estimate the temperature, water and ice content of permafrost as well as the nature of the subsurface materials. These methods were tested in various environments such as tills, glaciofluvial, marine and shoreline deposits. In coarse-grained materials, electrical resistivity soundings, induced polarisation, ground-probing radar and occasionally electromagnetic methods were used to detect the ice content of fine-grained materials. Downhole correlations of temperature, electrical resistivity and induced polarisation profiles with the ice content are obtained. The higher ice contents are observed in the upper part of permafrost.

Downhole neutron probe and variable frequency capacitancemeter measurements allow an independent estimate of the water and ice content of permafrost and/or the active layer. In shoreline environments, the salinity is another parameter to be taken into account. Surface and downhole temperature measurements taken at discrete time intervals are useful for short and intermediate term prediction of the thermal state of permafrost in two dimensions.

BEARING CAPACITY OF PILES IN PERMAFROST

(B. Ladanyi, A. Foriero and A. Thériault, Northern Engineering Centre, École Polytechnique, Montréal)

A complete analytical solution for stress redistribution with time in long, compressible, axially loaded piles embedded in permafrost was obtained and compared with laboratory and field test results. An experimental and analytical study of laterally loaded piles in permafrost is presently underway.

CONE PENETRATION TESTING IN PERMAFROST AND ICE

(B. Ladanyi, P. Huneault, Ph. Talabard and J. Sgaoula, Northern Engineering Centre, École Polytechnique, Montréal)

The objectives of this project were to evaluate the cone penetration test as a tool for testing the mechanical properties of offshore permafrost in the Beaufort Sea, in connection with the design of piles and other offshore exploration and production structures, needed in the Arctic oil and gas developments. The study included a programme of mechanical properties tests with frozen soils, typical for the Beaufort Sea region, a programme of model-scale tests and some new theoretical developments.

The laboratory study, which included a large number of triaxial compression tests with a frozen silt at different densities and temperatures, was intended to give an answer to the question how the results of cone penetration rests, involving high strain rates, could be used for the design of piles under service loads, where strain rates are several orders of magnitude lower.

The planned programme of field tests in frozen silt was realised in May 1988. the test site selected for that purpose was the US Army CRREL Permafrost tunnel at Fox, Alaska. The test programme included about 30 load-controlled cone penetration tests, as well as a number of borehole dilatometer tests, serving for comparison. The test results confirmed our previous findings that, under controlled conditions, there is a unique relationship between the applied load and the resulting penetration rate, which is the basis for the determination of creep properties of frozen soils from cone penetration test results. Theoretical work made in connection with this project has led to the development of a new theoretical model for the deep penetration in the creep domain, based on the flow line theory.

An important spin-off of this project was the development of the Sharp-Cone-Test (SPT). The test, intended for measuring the creep parameters of frozen soils and ice by enlarging a conical pre-drilled hole, has up to now been successfully tested on both polycrystalline ice and frozen sand.

LABORATORY STUDIES OF MASS AND HEAT TRANSPORT

(J. Kwong, National Hydrology Research Institute, Saskatoon, SA)

Two pieces of apparatus have been designed and constructed. The soil/water freezing apparatus facilitates controlled axial freezing of a soil/water mixture. The frozen soil/water test apparatus will be used to study the effects of thermal and chemical perturbations on frozen soil.

GLACIAL GEOLOGY

DATING OF LATE PLEISTOCENE–HOLOCENE MORAINES, CRAGIEBURN RANGE

(Karl Ricker and T. Chinn, W. Vancouver, BC and New Zealand Geological Survey)

While on sabbatical to New Zealand, Ricker was introduced by Chinn to the rind weathering methodology of assigning ages to moraines of Holocene to late Pleistocene ages. The rock used is a lithic arenite of the Torlesse subgroup which has a broad outcrop exposure in New Zealand. The weathering rinds increase in thickness at a relatively uniform rate for the first 10 000 years of exposure. For boulders on older moraines, surface attribution reduces the overall increase in rind thickness until equilibrium is reached at about 30 000 to 35 000 years. The moraines in two cirque-to-valley outlet drainage systems were sampled and assigned ages based on the rind weathering thicknesses.

The results revealed a full succession of late, mid and early Neoglacial, Holocene, and several stages of late Pleistocene moraines. Equilibrium rind thickness was found to be 9.0 mm for boulders lying on a well-developed moraine which is ≈35 000–120 000 years in age. The project also used other relative age-dating methodologies but none was as versatile and consistent as the rock rind weathering tool. Application of the technique to the Cordilleran region of Canada is now being investigated.

GLACIAL GEOLOGICAL AND GEOCHEMICAL STUDIES, GASPÉSIE, QUÉBEC, CANADA

(Peter P. David, Pierre Bédard and Remi Charbonneau, Département de Géologie,

Université de Montréal, Montréal, QU)
Research continues on identifying and evaluating lithofacies and glacial sedimentary environments (P.P.D.) in north-central Gaspésie Peninsula. The glacial sedimentary investigations are complemented by lithological (R.C.) and geochemical (P.B.) dispersal studies based on observations and sampling in 160 artificial excavations made to bedrock. The results of the analysis of more than 200 lithological and 480 geochemical samples (Cr, Mn, Fe, Co, Ni, Cu, Zn, Pb, As, U content of the matrix, $<2\mu$ fraction) are used to evaluate the glacial processes responsible for the formation of the various lithofacies that constitute the one or possibly two till sheets of the area. The three-dimensional geometry of the lithological and geochemical plumes traced across the diverse glacial sediment facies can yield invaluable information on the origin of the glacial sediments present in the areas.

Saprolites (P.B.) of varying thickness (10 to >280 cm) occur in 25 of the excavations, underlying either glacial or preglacial (colluvium) deposits. Their geochemical and mineralogical composition coupled with other physical properties suggest that they were formed by long-term and deep weathering. Their preservation in particular geographic positions in relation to ice-flow directions will help greatly to elucidate the question of mode and timing of Quaternary glaciation in Gaspésie Peninsula.

Submitted by William Winsor

International Glaciological Society

SYMPOSIUM ON ICE AND CLIMATE

Seattle, WA, USA, 21 – 25 August 1989

The symposium was held in the University of Washington and attracted twice as many participants as normal for our events. The Local Committee, chaired by Charlie Raymond, did a magnificent job coping with these numbers, while the HQ office in Cambridge was stretched almost to its limits in fulfilling overall organizational duties, including the provision of materials for the participants. Many willing volunteers helped the Secretary General during the week in Seattle with registration and other administrative chores. The Chief Editor, Doug MacAyeal, and four associate editors also worked long hours, to ensure that all authors were involved in the editing work on their papers.

A reception was held on the first evening, and a cruise and banquet took place later in the week. A mid-week excursion, led by Bernard Hallet, was held to examine margin and bed features of the Puget Sound Lobe of the former Cordilleran Ice Sheet.

Bernard Hallet taps a beer keg for the refreshment of participants

Lively discussions took place on the mid-symposium tour

Two post-symposium tours were held. A two-day tour visited Mt. St. Helens and Mt. Rainer, led by Steve Hodge, to see volcano–glacier interactions and effects from the 1980 eruption of Mt. St. Helens.

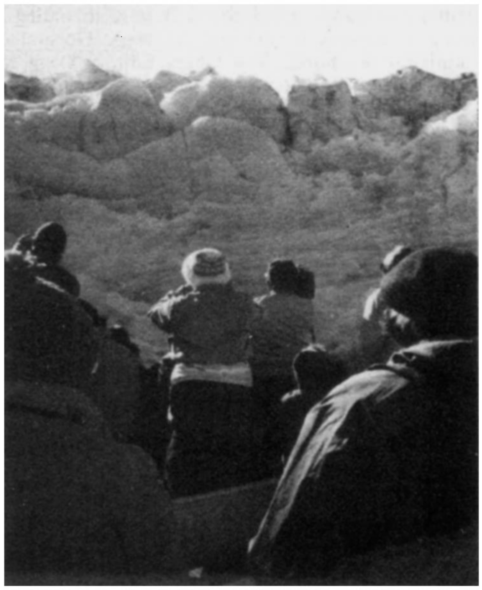
— A brief rest among the debris surrounding Mt. St. Helens

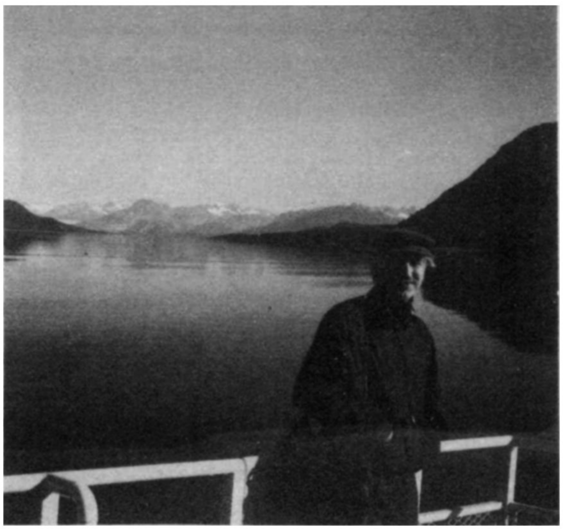
Steve Hodge (on left) points out features on Mt. Rainier. Charlie Raymond (chairman of Local Committee) is on the right.

A week-long tour to see some of the tidewater glaciers of Alaska was led by Larry Mayo. It began in Juneau, and then was followed by a series of flights in small planes over the Juneau Icefield to Glacier Bay.

Glacier Bay, in perfect weather for cruising, was appreciated by everyone, especially by Andrei Glazovskiy, who was the guest of the Society. He contributed much interesting information about the Russian period in Alaska, using hitherto unpublished material he had discovered in Moscow libraries.

The boat got as close as it could to the glaciers —



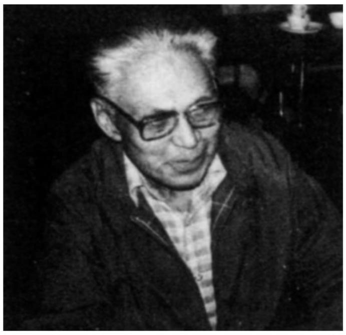


Andrei Glazovskiy

After two days in Glacier Bay, the small planes took us to Yakutat, flying over numerous large glaciers along the Gulf of Alaska shore. In the two days here, we had a varied programme: flying into Russell Fjord on an amphibious plane to visit the Hubbard Glacier; examining archaeological sites near to Yakutat; and enjoying a Tlinget "pot-latch", hosted by the city.

IGS President Sam Colbeck with the Mayor and Mayoress of Yakutat

The pot-latch was greatly appreciated. We learned much about the history and culture of the Tlinget Indians. Important chiefs were present —



and special songs and dances were performed for us, with traditional instruments and clothes.

From Yakutat we flew to Valdez, where we joined a 34-seater boat which took us into Prince William Sound. In inclement weather we visited Columbia Glacier, then spent the night in tents on an island, before resuming our boat trip to Whittier, then by surface transport to Alyeska ski resort, Portage Glacier, and Anchorage.

A dinghy trip in the rain to see Columbia Glacier

Throughout the Alaska tour, participants enjoyed many good meals

Jo Ann and Jay Zwally

Larry Mayo and
Charles Swithinbank

Laura Mathews   Peter and Heidi Escher-Vetter   H. Moser   Bill Mathews   Denis Trabant

SELIGMAN CRYSTAL AWARDS 1989

22 August 1989, Seattle, WA, USA

The Society's Council agreed unanimously in 1988 that Seligman Crystals be awarded to Wilford F. Weeks and Hans Oeschger for their notable contributions in two fields of glaciological research. The Crystals were presented by the President of the Society, Sam Colbeck, in the presence of 100 members and visitors. In welcoming people, he said: "Our subject, glaciology, covers a very wide range of topics and this evening we honor top glaciologists from two of those sub-fields. Few things are more pleasurable for a president than honoring those who have significantly advanced our field. Tonight I have the rare opportunity to make two such presentations.

When I was a student at this University, I never met Willy Weeks but his was certainly one of the names I knew. At that time Willy was a pioneer in the fundamental studies of sea ice, laying the ground work for understanding its properties and behavior. Willy's contributions span the spectrum from these basic contributions to being in the forefront of transfering this knowledge to present-day problems in the Arctic. Furthermore, Willy is to me the complete professional glaciologist. This award is made not just for his technical contributions, but also because of the many others he has inspired and the many contributions he has made through his work in professional organizations. For example, he was the first president of IGS from outside of Europe. So for both the breadth and depth of your glaciological career, we have pleasure in awarding you the Seligman Crystal."

Willy Weeks receiving the Seligman Crystal from the President

After the presentation of the Crystal, Willy Weeks made the following reply:

"My mother told me that I was born on frigid night in January when the city of Champaign in central Illinois was shrouded in snow and ice. This must have had some magical influence on me, but, as with most other influences, it took a considerable period of time (roughly 26 years) to have an identifiable effect. Champaign was a fine place to be a kid. Life was simple, and by today's standards a bit dull. During the late '30s and early '40s, Champaign was definitely not operating in the "fast lane". I delivered newspapers, detassled corn and tolerated my pesky brother, whose main goal in life appeared to be to do whatever would cause me maximum irritation.

I guess the most exciting thing that occurred during that period of my life was my discovery of music and the contrabass or bull fiddle as it was sometimes referred to in those parts. I had played or played at playing the violin since I was six or seven as the result of my mother attempting to instill within me some small modicum of culture. By the time I was 11, I had convinced myself and my violin teacher that I was not the successor to Paganini and had retired as a violinist. But miracle of miracles, just at that time the local bandmaster was looking for a bassist. Qualifications? You had to be fairly tall (I was), read music and know a bit about string instruments (I did) and maybe even be able to carry a tune (I thought I could). Anyway, I loved to play the bass and have continued to do so until this day. My years of playing jazz have definitely expanded my vocabulary and my understanding of human nature and have provided me with an offcentered view of life that I find to be very useful. What would I have been like if the bandmaster had not needed a bassist? It's hard to say but I would certainly have been duller and less happy. Why do I mention these matters here? Because my scientific career shows certain parallels in the matter of just the right thing happening at just the right time.

My parents would have found it very difficult to have sent me to college, but fortunately the University of Illinois was located in Champaign so I could live at home, play jazz in the evenings and go to school during the day. What should I major in? I tried chemistry (too many dull labs), then history (yawn) and finally I took a course in geology which seemd just right as it would allow me to combine lab. and field work and maybe even permit me to visit some part of the world that wasn't flat. I had heard rumours that such places existed but I had never been far enough from home to check these matters out personally. Now at that time the geology department at the Univesity of Illinois, although largely oriented toward turning out students that would become employed by the oil industry, also had a very good small faculty in the mineralogy/ petrology/geochemsitry end of the rocks business. They lavished considerable attention upon me and ultimately shipped me off to the University of Chicago for final polishing. There I was subjected to large doses of thermodynamics, crystal growth theory and even mathematical physics (subjects that were unheard of as part of a geology curriculum at that time). What would I have been like if I had not gone to Chicago? Certainly more of a "normal" geologist but one rather unequipped to do battle with the problems of ice in the sea that ultimately caught my attention.

To explain how I made the lateral arabesque from high temperature silicate/ carbonate chemistry to drifting ice floes, I must now add a sub-plot to the above story. While I was still at the University of Illinois, the Korean War broke out. Being that Champaign was a college town, the fact that I was a graduate student of geology did little to impress the local draft board who were hell bent on enlisting me in the infantry so I could be sent off to the Far East to engage in innumerable battles. This was an occupational speciality that held little attraction for me. However, this was also the first year that the Air Force had a Reserve Officers Program, so I dashed over to see if they needed my services. They did! Even better, as hostilities in Korea died down, they deferred me to continue my graduate studies at Chicago. Thank you, Air Force.

Ultimately when I finished my PhD thesis, the Air Force sent me a letter saying in effect that although I might like to forget about them they had not forgotten about me and it was time for me to report for active duty. They even asked me to suggest profitable research activities to occupy me during my tour. (This probably revealed the fact that they did not know what to do with me.) So I suggested that they might utilize me in studies of snow and ice. Where did I come upon such an outlandish idea? Well, when I was at Chicago, I had the opportunity to hear a lecture on the metamorphism of snow by Henri Bader, a Seligman Crystal recipient, who at the time was Chief Scientist at SIPRE. Henri was, and still is, an inspiration to me. "Now that's the sort of subject I would like to look into", I thought, and I informed the Air Force of this fact. Lo and behold they assigned me to the Air Force Cambridge Research Center where a very small Arctic program existed staffed with such luminaries as Bert Crary and Irene Browne. Was I assigned to that effort? NO! Instead I was assigned to study soil mechanics. SOIL MECHANICS?? Aaaarrrgh!! There was no glamour in that, no exploring, no climbing of unclimbed peaks, no revealing of the myriad mysteries of the polar regions in dazzling research reports. Somehow I had to get into that Arctic Group. There must be a way.

Again opportunity struck in an unlikely form as a research request from an operational air command. It seemed that the Northeast Air Command was having problems in resupplying radar sites along the Labrador coast and they wanted research carried out on the bearing capacity of sea ice and the associated multifarious properties of this off-beat material. The Cambridge Research Center administration said "Yes sir, we will take care of that right away!" Then they asked the staff members who were not already tied up in Arctic research, "Who wants to spend an exciting winter at Hopedale, Labrador?" The answer was an unanimous "Not me, boss", except for 2nd Lieutenant Weeks who, after looking for literature on the subject of sea ice and coming up with a near zero, responded "I'll go". A subject without a vast and confusing literature? Unheard of! Just think of it, I would only have to reference myself. I had discovered a gold mine.

The next thing I knew I was placed in charge of the Joint Services Sea Ice Physics Project (it was a military program and I was in the military so I was in charge). Ultimately I was joined in this effort by a number of people who knew what they were about: the SIPREites Andrew Assur and Ted Butkovich, and Owen Lee from the Hydrographic Office. After Hopedale, we moved the project to Thule, Greenland for the winter of '56–'57 where I was joined by 2nd Lt. Don Anderson, a reserve officer like myself (by that time I was an illustrious 1st Lt.). The subject of sea-ice properties was wide open and we made some real progress. It gives me great pleasure today that I still see current references made to the varied papers that came out of that project.

By the summer of 1957 my two-year Air Force tour was over and I moved to Washington University in Saint Louis where I taught Earth Science for five years. However, I couldn't escape from my past. The frozen seas held me in thrall. During the summers I was carrying out experimental studies on NaCl ice at SIPRE and as time passed, it became increasingly apparent to me that what I really wanted to do was to go into glaciology full time. And so I did, by joining the staff of what was to become the Snow and Ice Branch at CRREL. Now I will not regale you with the details of my 26 years at CRREL where I played at being Branch Chief for a little over two years and stayed in the scientific trenches, where I was much happier, for the remainder. During that time I worked on a variety of subjects including alpine snow, river ice thermodynamics, Antarctic shelf ice and the snow/ice transition in central Greenland. However, whatever the distraction of the moment was, I consistently kept returning to studies of sea ice. Now at CRREL this was not an easy task as sea ice is not considered to be a responsibility of the Corps of Engineers. The fact that not only was I allowed to concern myself with the subject, but that I was allowed to talk my associates into participating on cooperative projects, still amazes me. Admittedly we always had to beg, borrow or steal the money from some other source, but we were still allowed a scientific freedom that appears to be increasingly rare in government agencies.

Why was I so stubborn in sticking to studies of sea ice? There were several reasons. First, I always believed that we were making progress on some aspect of the subject and that our efforts really made a difference. Second, I felt very strongly that anything that covers as much of the surface of the earth as sea ice does has to be important and that it was about time that it received a small percentage of the attention that it deserved. I think that history has shown that I was quite correct in this belief. Third, as there was never sustained funding for any aspect of sea-ice research, I was always forced to undertake research topics on new aspects of the sea-ice problem. As a result, although I commonly felt that I was operating completely out of my depth, I was, at the least, always learning something new. Andrew Assur once said that a major portion of my success was the result of my knowing so little about what I was doing that I didn't know that I shouldn't be doing it. Finally, as defense mechanism against my own inadequacies, I developed the habit of teaming up with other scientists to work on problems of mutual interest. This approach always seemed to be very profitable both personally and scientifically. I had the opportunity of working with people that I liked who possessed many skills that I lacked. I particularly liked working with individuals who were less gifted in the fine art of procrastination than I was. I can only hope that they profited as much by working with me as I did by associating with them, and avoided acquiring my bad habits.

As many of you know, I have just this last February retired from CRREL and am happily ensconced at the Geophysical Institute of the University of Alaska Fairbanks where I am continuing my sea-ice studies and am also serving as the Chief Scientist at the Alaska SAR Facility (ASF) under the direction of my long-time colleague Gunter Weller. This latter effort is a real departure for me as it forces me to consider sea-ice problems on a much larger scale. It also requires me to interact with a rather different group of scientists located largely on the west coast, namely at JPL, Stanford and the University of Washington as well as at the University of Alaska. This promises to be great fun both professionally and personally. The first SAR satellite in the ASF program will be launched by ESA in 1991. I believe that it is safe to say that if the projected ASF sea-ice and oceanography program is even partially successful it will result in a major advance in our understanding of the behavior of the pack-ice cover of the World Ocean. I also suggest to you that satellite SAR technology has a most useful role to play in studies of ice sheets and glaciers and perhaps even of permafrost. I believe that the research future for glaciology is very bright and I am looking forward to these explorations. I invite you all to join me in these endeavors.

Now, a number of years ago, while I was serving as the president of IGS, I had the unusual experience of announcing to an individual that he had just been awarded the Seligman Crystal and having him refuse the award because he believed himself to be unworthy of the honor. I also note that by the following morning he had regained his senses and accepted. Now during this brief period of rejection I discussed this dilemma with Hans Röthlisberger, who was serving on the Council at that time, and we decided to swear a solemn oath that went roughly as follows: We swear that if the Council ever awards the Seligman Crystal to either of us, WE WILL ACCEPT even if we are obviously unworthy of the honor. And so I do. I would like to thank the Council of the Society for giving me the opportunity to accept it.

However, I would like to add a few comments on what I believe to be the real reasons why I am receiving the Crystal. I believe I am being rewarded for stubbornness in sticking with a subject that was so out of favor that it had never been in favor, and that turned out to be important. Let us admit that, with a subject as wide open as sea ice was in 1955, even I could make some progress.

Finally, I believe I am also being rewarded for my good taste in scientific associates. Without their varied talents and support we all would know far less about ice than we do today. Here I would like to acknowledge a few of these people: Don Anderson, Owen Lee, Wayne Hamilton, Frank Carsey, Steve Mock, Larry Dingman, Charlie Keeler, Bill Campbell, Gary Lofgren, René Ramseier, Moira Dunbar, Joachim Schwarz, Gunter Weller, Peter Barnes and Erk Reimnitz. I would also like to give particular thanks to the sea-ice appreciation group at CRREL: Steve Ackley, Mike Frank, Tony Gow, Austin Kovacs, Bill Hibler, Jackie Richter, Malcolm Mellor and Terry Tucker. Finally I would like to acknowledge 34 years of support and argumentation from Andrew Assur who would not let me quit studying sea ice even if that had been my wish.

My exploration of the world of sea ice has been a long, exciting and sometimes frigid journey. It's been both interesting and fun. I think that I will keep at it for a few more years. After all, I can't play contrabass all the time."

The President continued:

"For as long as I have known about ice-sheet coring, one name has dominated one very important aspect of the analysis of those cores. Hans Oeschger, with his group at the University of Bern, is known throughout the world, to both scientists and the public, for having made significant contributions to our knowledge of the level of CO_2 through the ice-core record. While a generation ago Hans' work may have seemed to be of only academic interest, today this work is recognized for providing the type of information we need if we are to understand the climatic future of our planet. As much as anyone, Hans Oeschger has truly contributed to our knowledge in a way that has enriched glaciology. So, for contributions that have helped put glaciology in the forefront of today's sciences, we have pleasure in awarding you the Seligman Crystal."

Hans Oeschger receiving the Seligman Crystal from the President

Following the presentation of the Crystal, Hans Oeschger replied:

"When I received a phone call late one night and was told that I would receive the Seligman Crystal, I was totally surprised and extremely pleased. Afterwards, upon quietly thinking about the great honour to be bestowed upon me, I entertained some serious doubts regarding deserving what I consider to be a very special award with great symbolic value. It seemed to me that some of my colleagues in the glaciological field have accomplished more than I have and are perhaps more deserving of the honour. Upon further deliberation, I came to the conclusion that there are probably at least two good reasons to accept the Seligman Crystal:

(1) I consider it as much an honour for my colleagues as for myself. I think of Chet Langway, Claude Lorius, and my co-workers in Bern, especially Bernhard Stauffer, who have done such original and important glaciological research on ice cores over tens of years.
(2) I am particularly pleased that ice core research is becoming prominently recognized within glaciological science, the IGS and the scientific community at large. The significance of the results of ice core research are widely documented in the literature. They concern a broad range of earth matters and processes including variations in atmospheric gases, chemical impurities, paleotemperatures, volcanic activity and many more. Results of ice core studies have greatly changed our concepts of an Earth system essentially dominated by physical processes. Through many ice core investigations we are now more aware of the equally important role played by biological and chemical processes.

I became involved in glaciological research in the early 'fifties when I first constructed a very sensitive counter for radio-carbon dating which could also be used for measuring tritium concentration in natural waters. A little later, during the mid-fifties, a high school teacher from Lausanne, Switzerland, named André Renaud, who was also a member of the Swiss Glacier Commission, visited my boss Professor F.G. Houtermans. During this visit Professor Houtermans called me into his office to ask if I could measure tritium levels in glacier ice to investigate possible changes in the concentration levels before and after the fusion-bomb tests. Later, A. Renaud provided us with a shallow ice core from the Jungfraujoch. We did indeed measure a clear and strong increase in bomb-produced tritium.

The next step in my glaciological journey was also due to A. Renaud: he introduced me to Chet Langway at a meeting in Obergurgl, Austria, in 1962. Langway told me of some of his exciting results of the early ice core studies from the Thule and Site 3 Greenland areas, and we discussed the possiblity of conducting a ^{14}C dating study of the CO_2 in air bubbles in glacier ice from the Tuto Tunnel. Since we already had sensitive counters for small samples, we would "only" need to melt a few tons of ice to obtain the necessary amount of CO_2 for measurement.

Chet and I developed and conducted in both 1964 and 1966 a joint USA CRREL and University of Bern project at the Tuto Tunnel near Thule in north Greenland. The work was cumbersome and difficult, especially mining the huge ice blocks, but the results were encouraging and published in a scientific journal. In 1968 we both again collaborated in *in situ* carbon-dating studies in the Byrd Station deep boreholes. During this study we demonstrated for the first time that ^{39}Ar can be successfully used to date up to 1000 year-old ice.

The results which probably received and deserved the most attention during the early history of ice core studies were the oxygen isotope studies made on the first ice core ever to reach bedrock (1380 m deep) from an inland ice sheet location obtained by B. Lyle Hansen and co-workers from USA CRREL. The $^{18}O/^{16}O$ profiles measured by Willy Dansgaard and colleagues clearly showed the Wisconsin/Holocene transition and numerous minor climate oscillations during the Wisconsin that still remain to be convincingly explained, based on underlying Earth system mechanisms.

In the seventies, the rising concentration of atmospheric CO_2 due to human activities received more and more attention. Model calculations showed that by as early as the first half of the next century, significant changes of the Earth's climate might result from the increasing greenhouse effect, caused by the increase of CO_2 and other radiatively active gases. One question received special attention: "What was the pre-industrial concentration of atmospheric CO_2?" Our proposition to determine this value by measuring the CO_2 concentration in the air occluded in ice formed in pre-industrial times was received with scepticism, but was supported nevertheless in the frame of the US DOE CO_2 Program. In the meantime, the measurement techniques for the gas composition of ice cores have continuously been perfected on our laboratory, and in 1979 the unexpected observation was made that the CO_2 concentration of glacial ice was significantly lower than in the interglacial. The result was obtained both for the Camp Century and for the Byrd Station ice cores. Initially it was hardly taken seriously by the scientific community, but almost at the same time the Grenoble team, lead by C. Lorius, found corresponding results for two ice cores from Antarctica. Somewhat later, N. Shackleton found independent evidence for atmospheric CO_2 changes in the $^{13}C/^{12}C$ ratios of planktonic and benthic foraminifera in ocean sediments. These results stimulated widespread interest among the scientific community in the causes and effects of changing atmospheric CO_2 concentrations.

In the early 1980s, no ice core was available for the past few hundred years that contained a high-accumulation high-resolution record that was also free of distinctive melt layers which damage the reliability of the CO_2 records preserved within them. This situation changed when in 1984 a US and Swiss team core-drilled at Siple Station, Antarctica, a location which was optimally suited to reconstruct the CO_2 history of the past 200 years. The convincing results measured by Neftel, Stauffer and others showed atmospheric CO_2 concentrations increased from 280 ppmw around 1800 AD to values compared to and overlapping with the atmospheric data collected at Mauna Loa, Hawaii, since 1958. This reconstructed atmospheric CO_2 curve will reside in the files as a most valuable record of man's induced changes in our atmosphere.

A highlight in our ice core research career was the the successful US–Danish–Swiss drilling to bedrock project at Dye 3 in south Greenland. In 1981 bedrock was reached at a depth of 2037 m. The drilling was accompanied by state-of-the-art "in field" measurements in an under-snow laboratory on the freshly drilled ice cores, and a wealth of new information on Earth system processes was obtained. Nevertheless, due mainly to the profusion of melt layers and their effects on the gas composition measurements, some of the most urgent questions, such as the phase and their relationship between CO_2 and climate change which was first, could not be resolved.

To answer some of the above questions and to advance and expand the study of deep ice cores, the Greenland Ice Sheet, and the study of past global environmental processes in general, the Dye 3 participants now turned their attention to follow-on plans. We determined that the next logical step was to drill a new deep ice core at a location in central Greenland, then later in Antarctica, that would, in our considered opinion, be the most optimal and potentially rewarding in terms of scientific information recovery. With this in mind, Chet Langway, Willy Dansgaard and myself prepared a comprehensive, internationally collaborative, cost-sharing, multi-disciplinary science and operations plan (in part included in AGU Monograph 33, p. 5-6, 1985) and submitted it to the US National Science Foundation in the spring of 1983. Apparently the proposal was not acceptable, and a formal reply to our request was not received. Time passed and pressing questions became more persistent from our colleagues and other interested scientific groups. It was decided to attempt a collaborative European deep ice core drilling programme in central Greenland by utilizing available equipment and existing experience gained during the Dye 3 operation.

Finally, thanks to the commitment of several countries and within the framework of the European Science Foundation an intra-European project to ice core drill in central Greenland was formed and initiated in the summer of 1987. This operation will be conducted in close association with the US GISP II effort which will be carried out at a site 30 km to the west of the European drill site.

We strongly hope that both projects will be successful and provide a wealth of new Earth system information. The newly formed Scientific Steering Committee on "Global Changes of the Past" expects from these projects, together with information from other continental and ocean records, deep insight into the essential mechanisms of the organism Earth and an ideal base for the development and testing of Earth system models.

In summary, I would like to thank all the colleagues who influenced, guided and were essential to my life as a scientist. I have only barely touched upon the strong influence on me from various members of the Swiss Glacier Commission where interdisciplinary collaboration was practised long before it became fashionable in the seventies. One of these colleagues is in the audience, Hans Röthlisberger, former president of IGS. A deep appreciation is extended by both myself and co-workers at Bern for the chance to have a perfect collaboration with C.C. Langway during the last 28 years. I hope that Langway's great merits one day will find the recognition they deserve. Essential to the progress of our laboratory in Bern was the excellent close teamwork and collaboration between all the scientists and technicians who work there. This was characterized by the fact that each member played an indispensable role and was a fully integrated partner and important in the final results: a credit to their professionalism.

Finally, I would like to express my full heartfelt appreciation to both W. Dansgaard and Claude Lorius for working so tirelessly with me to persuade the European Science Foundation and other countries of the importance of obtaining a new deep ice core from central Greenland. The initial obstacles, including funding, were nearly overwhelming in light of the past history of such scientific ventures. Through the combined strength and experience we were able to overcome all obstacles and launch what we collectively feel is the start of a fruitful and rewarding research programme and one that will continue into the distant future."

Recipients of the Seligman Crystal present at the ceremony on 22 August 1989

J.F. Nye, (1969) J. Weertman, (1983) W.F. Weeks, (1989) H. Oeschger, (1989) W.O. Field, (1983) M.F. Meier (1985)

ANNUAL GENERAL MEETING 1989

MINUTES OF THE ANNUAL GENERAL MEETING OF THE INTERNATIONAL GLACIOLOGICAL SOCIETY

24 August 1989 at the University of Washington, Seattle, WA, USA

The President, Dr Sam Colbeck, was in the Chair. 60 members from 13 countries were present.

1. The Minutes of the 1988 Annual General Meeting, published in *ICE* 90, p. 11-12, were approved and signed by the Chairman.

2. The President gave his report for 1988–89. Let me start off by thanking you for coming to this meeting. It is necessary for me to have contact with as many members as possible and I see rather different people at these different symposia.

Before we start the formal part of this meeting I will take a few minutes to thank those who have made this conference possible. Charlie Raymond has put a great effort into organizing it and into taking care of our needs this week. Doug MacAyeal and the other editors are providing us with a permanent record of the meeting. Bernard Hallet and Derek Booth organized a very enjoyable field trip for our midweek diversion. Larry Mayo and Steve Hodge have organized especially exciting trips for post-symposium tours.

Partly because this meeting is so well attended, we have four past presidents with us (John Nye, '66–69; Willy Weeks, '72–75; Charles Swithinbank, '81–84; Hans Röthlisberger, '84–87), six Seligman Crystal recipients (Bill Field, Mark Meier, John Nye, Hans Oeschger, Willy Weeks, and Hans Weertman), and four Honorary Members (Bill Field, Mark Meier, Uwe Radok and Hilda Richardson).

The Society has arranged several meetings which ensure an exciting future. In 1990 we will meet in Hanover at Dartmouth College on the subject of ice–ocean dynamics and mechanics. Unfortunately we are starting to get some competition for this subject from other organizations sponsoring meetings at about the same time. Our meeting was set some time ago and advertised but others have since chosen to hold meetings which may detract from ours. In 1991 we will go to China for a meeting on mountain glaciology relating to human activities. A tour to Tibet has been arranged to follow the meeting. In May 1992 a meeting on remote sensing will be held in Boulder and later in that summer we will hold a meeting on snow and snow problems in Nagaoka, Japan, at the invitation of the city. In 1993 there will be a meeting in Finland on applied snow and ice research and we are trying to organize a meeting on glacial erosion and sedimentation in that year or in 1994. Several countries are interested in hosting this meeting. Other meetings have also been proposed.

The publications are continuing to improve and respond to changes in technology and content. *ICE* has undergone a format change to make it more attractive and has expanded its scope of responsibility to include some of the things which used to be in the *Journal*. Information about the Society, such as the members of Council, now appear in *ICE* and I would like to see book reviews and obituaries appear there too. We need to conserve *Journal* pages for technical articles because we are again in a position of having more pages to publish than supporting budget. This has occurred in part because of the speed with which we can now produce articles. Having made the *Journal* a more attractive outlet, we now have to finance an increasing number of articles that are being submitted and accepted. The large number of editors dealing with diverse topics in their individual ways has also led to some problems with the *Journal*. The Council feels that we need a chief editor who could help formulate and enact policy decisions regarding standards for acceptance and procedures for ensuring rapid processing of submitted manuscripts. We have had some house editing problems with *Annals*, although the series itself continues to be a great success. Ray Adie helped with one volume so we have been able to produce the symposia volumes without delays despite temporary staff problems. I would like to see *Annals* used for purposes other than just symposia proceedings. We have the capability to produce monographs or collections of reviews in glaciology as well. Our distribution and advertising capability would ensure ready access to the glaciological community and wide distribution of the work.

Last year I spoke of starting one or both of two series of publications which could be valuable additions to the glaciological literature. It has been suggested that we publish a "benchmark" series and a facsimile series. A facsimile volume would simply be a republished work which is now out-of-print, much as we did with Seligman's book, but probably in a less expensive manner. A benchmark volume would be a collection of classic papers in a particular topic area. Garry Clarke has taken on the task of producing a volume on the mechanics of glacier flow but progress has been slow because of the high value which he places on the quality of reproduction. My own bias is to emphasize the need to make the volume available and not worry about its appearance beyond the obvious need to make it useful. I am hoping to start other volumes in this series soon but, again, what we can do along the lines of publishing is limited by our financial resources. It will be necessary to find sources of money to get this series started. Once going, sales can help finance future volumes.

In response to our desire to have more *Journal* space and to initiate other publishing activities in glaciology, the Council at its last meeting voted to establish two new categories of membership. As the Treasurer's report shows, the Society is not in financial trouble but it is also not in a position to expand because of limited resources. We hope that members who have benefitted from the Society will view these new categories of membership as an opportunity to give something back to the Society, to help it grow and thus ensure its future. The normal membership dues for 1990 will continue to be set at £30, the Contributing Member will give an additional £20, and the Supporting Member will give an additional £100. These additional contributions will not qualify the donor for any extra privileges but will be purely for the purposes of expanding the activities of the Society. There are already members who qualify for these categories and, if they so desire, their contributions can continue to be anonymous or they can be listed under these new categories.

One of the greatest pleasures of a President is to deal with the awards. The Seligman Crystal is held in high esteem among glaciologists and its award by the Council is given serious consideration. This year the Council voted to award two Crystals, in two areas of glaciology. The presentations of these Crystals will be made at the Hanover meeting in 1990. The first Crystal will be awarded to Charles Bentley for his long series of contributions on Antarctic glaciology with special reference to the recent work he and his group at Wisconsin have done on the flow of ice streams in West Antarctica. The second Crystal will be awarded to Akira Higashi for his long series of contributions to our understanding of lattice defects in ice and for a career which was recently capped by the publication of his book on this subject.

Since many of you do not know what the process is for selecting Honorary Members and Seligman Crystal recipients, it is worth reviewing to ensure that the Council gets as much input from the membership as possible. In the case of the two awards made this year, both candidates were nominated by letters written to the Society on their behalf. The Awards Committee then reviewed a number of potential candidates, some having been on the list for three or four years, and made a recommendation to the Council, which discussed and voted on the awards. We have always encouraged members to submit proposals by means of informative letters, preferably from more than one country. Thus broad recognition of an individual's work could be well established.

3. The Treasurer, Dr J.A. Heap, submitted a report with the audited accounts. He expressed his regrets that he was not able to be present. The President highlighted some items in his report and suggested that anyone wishing to see more details of the finances should get them from the Secretary General.

The general state of the Society's finances remains good. The General Income and Expenditure Account for 1988 shows a small surplus. In fact, this surplus was £750 out of an operating budget of £74,715, or a surplus of about 1%. At this rate there is no margin in our budget for unanticipated circumstances such as a large increase in rent or the need to update our office equipment. While the Treasurer has recommended that we do not increase membership dues in 1990, I am hoping that the Society can gain some increased revenues from the new classes of membership just established. All other charges have been increased for 1990.

R. Hooke proposed and H. Röthlisberger seconded that the audited accounts for 1988 should be adopted. This was agreed unanimously.

4. Election of auditors for the 1989 accounts. C.S.L. Ommanney proposed and G.K.C. Clarke seconded that Messrs Peters, Elworthy and Moore of Cambridge be elected auditors for the 1989 accounts. This was carried unanimously.

5. Elections to the Council 1989–92. After circulation to all members of the Society of the Council's suggested list of nominees, no further valid nominations were received, and the following people were therefore elected unanimously:

Treasurer:	J.A. Heap
Elective Members (4):	P. Duval
	F. Nishio
	G. Weller
	N. Young

. . . .

After the conclusion of the formal business of the meeting, an informal discussion took place in which opinions were expressed about the Society's role in publishing monographs, the need for timely publication of the benchmark volumes, the new classes of membership, and other issues.

EXCLUSION CLAUSE

NORTHEASTERN NORTH AMERICA (NENA) BRANCH

7–8 April 1989

The Northeastern North America branch of the IGS held meetings at Trent University on 7 and 8 April 1989. The universities represented included McGill, Ottawa, Wilfrid Laurier, and Queen's. Members from NRC and others groups also attended.

The folowing papers were presented:

Peter Glenday (Trent University)
Mass balance of the White Glacier. A computerized approach using remote climate data.
Dave Collins (Wilfrid Laurier University)
Suspended sediment: melt water in the Swiss Alps.
Peter Johnson (University of Ottawa)
Variability in small glacierized basins.
Peter Doran (Queen's University)
Observations on a rare second-year ice cover on a high arctic lake.
Gordon Young (Wilfrid Laurier University)
Canadian glacier research in Pakistan.
John Glew (Queen's University)
Changes in moraine surfaces in the Pangnirtung fiord area, Baffin Island, Canada.
Lyn Arsenault (Cold Regions Remote Sensing)
Sea ice concentration, type, and extent by space borne radiometer: assessing two algorithms for the special sensor microwave imager (SSm/I).
Graham Cogley (Trent University)
Global snowline.
Peter Adams (Trent University)
Science and politics.

Further information may be obtained from Peter Adams, Department of Geography, Trent University, Peterborough, Ontario, Canada K9J 7B8.

WESTERN ALPINE BRANCH

31 August–3 September 1989

The 1989 annual meeting was held at Vanoise, and was the 18th meeting since the creation of the branch in Chamonix in 1972. Three IGS members and 36 people listed as Branch members attended.

On the first evening, participants were entertained to a reception by the Municipality of Pralognan.

On 1 September, cloudy skies and cold rain made changes to the planned excursion essential. On 2 September, continuing rain again cut short the planned excursion, but nevertheless the group was able to see the work on glacier fluctuations undertaken on the Gibroulaz Glacier by the Laboratoire de Glaciologie et Géophysique de l'Environnement in collaboration with CEMAGREF. The Annual Banquet of the Branch was held that evening, so morale was high despite the rain.

On 3 September, papers were presented by some participants and a film shown by the Parc National de la Vanoise. Finally, the annual general meeting of the Branch was held.

BRITISH BRANCH

14–15 September 1989

The annual conference was held in the new conference room at the British Antarctic Survey, Cambridge. The meeting followed the normal format with two days of talks and poster displays, an Annual Dinner in the University Centre, and the branch AGM. The only disappointment was that a planned punting excursion on the River Cam to ferry folk to the dinner was abandoned because of rain.

It was a great pleasure to welcome visitors from abroad to the meeting. Together with a strong contingent from Université Libre de Bruxelles, there were visitors from the US, Poland and Japan.

At the Annual Dinner, the President, Julian Paren, welcomed the Secretary General, Hilda Richardson, and Professor and Mrs Akira Higashi. In a short speech he congratulated Professor Higashi on being awarded the Seligman Crystal for his pioneering studies in ice physics.

The programme of lectures covered a wide range of glaciological topics. The list of presentations is given below. If you are interested in these topics, please contact the authors directly: most provided abstracts for the meeting.

Julian Paren (BAS)
The warming Antarctic (by J.G. Paren and K.W. Nicholls)
Jacek Jania (Sosnowiec, Poland)
Report of Polish expedition to Spitzbergen
David Sugden (Edinburgh)
Topography and ice sheet growth in Scotland
David Peel (BAS)
Climate signal at the end of the Little Ice Age in the Antarctic Peninsula
Charles Warren (Edinburgh)
Can palaeoclimatic significance be attached to Holocene ice-margin deposits in central west Greenland?
Mark Drinkwater (NASA/JPL)
Synthetic aperture radar polarimetry of polar ice and snow
Robert Mulvaney (BAS)
200 years of sea ice in the Weddell Sea — from historical and ice core records
Andrew Reid (BAS)
Ozone related changes in nitrate depositon in snowfall in the Antarctic

Jefferson Simoes (SPRI)
The record of anthropogenic pollution in snow and ice in Svalbard
Martin Rist (University College, London)
Experimental observations on the brittle and semi-brittle deformation behaviour of polycrystalline ice
Heidy Mader (Bristol)
Geometry of the water vein system in ice
David Mantripp (MSSL)
Past and future satellite altimetry over shelf ice
Paul Cooper (BAS)
Geometric corrections to satellite altimeter data over glaciers
Jonathan Bamber (MSSL)
Altimeter waveform retracking over land ice
Gordon Robin (SPRI)
Hard till glaciology: fast sliding/grinding
Richard Hindmarsh (Edinburgh)
Coupled ice sheet/bed kinematics
Charles Swithinbank (SPRI)
Blue icefields in the Antarctic
Roland Souchez (Brussels)
Isotopic characteristics of basal ice from the dispersed facies in west Greenland (by R. Souchez, G. Fierens, M. Lemmens, R. Lorrain, J.-L. Tison, and D. Sugden)
Ian Willis (Cambridge)
Seasonal and short-term velocity variations of Midtdalsbreen, Norway
John Reynolds (Polytechnic SW)
Glacier hazards in the Cordillera Blanca, Peru
Jean-Louis Tison (Brussels)
Stratigraphy, stable isotopes and salinity in multi-year sea ice from the rift area, south George VI Ice Shelf: preliminary results (by J.-L. Tison, E.M. Morris, R. Souchez, J. Jouzel)
John Nye (Bristol)
Interpreting the field evidence of past ice sheets: structural stability and genericity
Rick Frolich (BAS)
A general model for ice streams
Adrian Jenkins (BAS)
Ice–ocean interaction on Ronne Ice Shelf, Antarctica
Eric Wolff (BAS)
Glaciology in the stratosphere
Diederik Kornhorst (Edinburgh)
Avalanche boulder tongues in Scotland
Seymour Laxon (MSSL)
Recent progress in altimetry over floating ice at the MSSL
Julian Paren (BAS)
The present Antarctic environment (part of BAS Open Day exhibit)
Peter Knight (Keele)
Observations at the bed: preliminary observations in a sub-glacial cavity network, Breidamerkurjökull
Fiona Tweed (Keele)
The prediction of glacial lake formation and catastrophic drainage events at Solheimajökull, southern Iceland
David Vaughan (BAS)
Modelling ice shelves in the vertical plane

The following elections for 1989–91 took place at the AGM: Professor G.S. Boulton; Vice President, P.W.F. Gribbon; Secretary/Treasurer, D.R. Mantripp.

The 1990 British Branch Meeting will be held at the Mullard Space Science Laboratory, of the Department of Physics and Astronomy, University College London, on 12 and 13 September. MSSL is situated in rural Surrey, with easy access by road, rail and air (Gatwick or Heathrow). Accommodation will be organised at the University of Surrey, and we hope that the traditional sleeping-bag floor space will also be arranged. Further details will be circulated to all UK members and to people from abroad if they express interest. For information contact D.R. Mantripp or Libby Daghorn, Remote Sensing Group, Mullard Space Science Laboratory, University College London, Holmbury St Mary, Dorking, Surrey RH5 6NT, U.K.

JOURNAL OF GLACIOLOGY

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

Y FUKUSHIMA, G PARKER
Numerical simulation of powder-snow avalanches.

D L WRIGHT, S M HODGE, J A BRADLEY, T P GROVER, R W JACOBEL
A digital low-frequency, surface-profiling ice-radar system.

S A FERGUSON, M B MOORE, R T MARRIOTT, P SPEERS-HAYES
Avalanche weather forecasting at the Northwest Avalanche Center, Seattle, Washington, USA.

J B JAMIESON, C D JOHNSTON
In-situ tensile tests of snow-pack layers.

P L VORNBERGER, I M WHILLANS
Crevasse deformation and examples from Ice Stream B, Antarctica.

F REMY, C BROSSIER, J F MINSTER
Intensity of satellite radar-altimeter return power over continental ice: a potential measurement of katabatic wind intensity.

R LeB HOOKE, T LAUMANN, J KOHLER
Subglacial water pressures and the shape of subglacial conduits.

B HANSON
Thermal response of a small ice cap to climatic forcing.

K HUTTER, A ZRYD, H ROTHLISBERGER
On the numerical solution of Stefan problems in temperate ice.

W T PFEFFER, T H ILLANGASEKARE, M F MEIER
Analysis and modeling of melt-water refreezing in dry snow.

J FIRESTONE, E WADDINGTON, J CUNNINGHAM
The potential for basal melting under Summit, Greenland.

INTERNATIONAL SYMPOSIUM ON REMOTE SENSING OF SNOW AND ICE

Boulder, Colorado, USA 17 – 22 May 1992

FIRST CIRCULAR: March 1990

The Society will hold an international symposium on Remote Sensing of Snow and Ice in 1992. Registration will take place on Sunday 17 May and sessions will be from Monday 18 May to Friday 22 May in Boulder, Colorado, USA.

Snow and ice are interactive components of the earth system, and knowledge of these interactions with the land, oceans, atmosphere, and ecosystems is vital to our understanding of global change. Snow and ice varies at all spatial and temporal scales, and remote sensing is, therefore, a critical tool for research and monitoring. In recent years, considerable interest has developed in the study by remote sensing of extraterrestrial ices, which broadens our understanding of ice physics and the radiative properties of ice surfaces. New developments in remote sensing techniques, such as tomography, may have important applications to solving difficult observational problems in glaciology.

TOPICS

The following topics will be open for discussion:

1) Remote sensing aspects of
   a) seasonal snow on land
   b) sea, river and lake ice
   c) glaciers, ice sheets, and ice shelves
   d) permafrost
   e) planetary and cometary ice
2) New remote sensing techniques applied to snow and ice problems
   a) new sensors or new use of existing sensing systems
   b) tomography and other image-building techniques
   c) new signal processing, deconvolution techniques
   d) information systems and technology
   e) the scale or hierarchy problem
   f) use of remote sensing data in large-scale models

TUTORIALS

We are considering holding one or more tutorials in connexion with the symposium. Possible topics include:

1) imaging spectrometry
2) principles of microwave remote sensing
3) introduction to satellite remote sensing of snow and ice
4) new opportunities in the EOS Program

Please indicate on the attached form if you would be interested in attending such tutorials.

SESSIONS

Sessions will be held on four full days and one half-day. An excursion will be held on one half-day. We plan to provide ample opportunity for poster displays. In the Second Circular we will ask you to indicate, when submitting your summary, if you wish to participate in the poster sessions.

PUBLICATION

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

ACCOMMODATION

Details will be given in the Second Circular.

TOUR

A post-symposium tour will be held. We hope to arrange visits to the Department of Astrogeology, U.S. Geological Survey, in Flagstaff, Arizona, and to the NASA Jet Propulsion Laboratory in Pasadena, California. Geomorphological features of desert and canyon country will be seen en route.

FURTHER INFORMATION

You are invited to attend the symposium. Please return the attached form as soon as possible. The Second Circular will give information about accommodation, general programme, preparation of summaries and final papers. Requests for copies of the Second Circular* should be addressed to the Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, U.K.

*Note: Members of the International Glaciological Society will automatically receive a copy.

SYMPOSIUM ORGANIZATION

H. Richardson (Secretary General, I.G.S.)

LOCAL ARRANGEMENTS COMMITTEE

M.F. Meier (Chairman) (other members to be appointed)

- -

INTERNATIONAL GLACIOLOGICAL SOCIETY: SYMPOSIUM ON REMOTE SENSING OF SNOW AND ICE

Family Name . . . .

First Name/s . . . .

Address . . . .

. . . .

I hope to participate in the symposium in May 1992 [ ]

I expect to submit a summary of a proposed paper [ ]

I will be interested in attending tutorial number [ ]

I hope to join the post-symposium tour [ ]

TO BE SENT AS SOON AS POSSIBLE TO: Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER,

Future meetings (of other organizations)

The Second World Climate Conference, sponsored by WMO, UNEP, UNESCO and ICSU, will be held in Geneva 29 October to 7 November 1990. Attendance will be by invitation only, but will include senior authors of accepted poster session papers.

The poster session is intended to present results of studies dealing with the main themes of the conference with an emphasis on regional aspects of climate and climate change.

Papers related to all components of the World Climate Programme (data and applications, impacts and research) are invited. However, papers already published or to be published by the time of the conference normally will not be accepted unless they are of an exceptionally important nature. Papers consisting primarily of descriptions of new hardware or software will not be accepted. The deadline for submissions is 15 May 1990.

Main themes for poster papers include:

– remote sensing and climate: quantitative verification/ground truthing; major observation projects and their results;
– detecting climate change: quantitative indicators, especially those other than temperature;
– climate change and risk manangement;
– climate change and natural disasters;
– climate applications and sustainable development;
– integrated case studies of climate applications;
– regional climate research and impact studies;
– greenhouse gas emissions and energy futures;
– climate change and ecosystems;
– climate and climate change in polar regions.

For further information on poster session papers write to: Co-ordinator SWCC, c/o World Meteorological Organization, P.O. Box 2300, 1211 Geneva 2, Switzerland.

Glaciological Diary

** IGS Symposia
* Co-sponsored by IGS

1990

24 April
Session on Glaciers, Ice Sheets and Climate Research, Copenhagen, Denmark as part of the XV General Assembly, European Geophysical Society (R.J. Braithwaite, The Geological Survey of Greenland, Øster Voldgade 10, DK-1350 København K, Denmark)

12 May
Royal Meteorological Society, Specialist Group on the History of Meteorology and Physical Oceanography, meeting on "The history of polar meteorology and oceanography", Scott Polar Research Institute, Cambridge, U.K. (J.M. Walker, Department of Maritime Studies, University of Wales, P.O. Box 907, Cardiff CF1 3YP, U.K.)

14-18 May
3rd International Conference on Ground Penetrating Radar, Denver, Colorado, U.S.A. (Gary R. Olhoeft, U.S. Geological Survey, P.O. Box 25046 DFC MS964, Denver, CO 80225-0046, U.S.A.)

29 May-1 June
MSA/AGU Spring meeting, Baltimore, Maryland, U.S.A. (Christine N. Hooke, American Geophysical Union, 2000 Florida Avenue N.W., Washington, DC 20009, U.S.A.)

7-8 June
47th Eastern Snow Conference, Bangor, Maine, U.S.A. (Nabil Elhadi, Water Resource Planning Branch, N.B. Environment, P.O. Box 6000, Fredericton, N.B., Canada E3B 5H1)

11-15 June
* International Conference on the Role of the Polar Regions in Global Change, Fairbanks, Alaska, U.S.A. (Cindy Wilson, Conference Coordinator, Geophysical Institute, University of Alaska Fairbanks, Fairbanks AK 99775-0800, U.S.A.)

12-24 June
AGU: Chapman Conference on Hydrologic Aspects of Global Climate Change, Lake Chelan, Washington, DC, U.S.A. (Lake Chelan Chapman Conference, American Geophysical Union, 2000 Florida Avenue N.W., Washington, DC 20009, U.S.A.)

12-15 June
International Symposium on Water Resources Systems Application, Winnipeg, Canada. (S.P. Simonovic, Civil Engineering Department, The University of Manitoba, Winnipeg, Manitoba, Canada, R3T 2N2)

10-12 July
Northern Hydrology Symposium, Saskatoon, Saskatchewan, Canada. Sponsored by the National Hydrology Research Institute and Canadian Water Resources Association. (C.S.L. Ommanney, Scientific Information Division, National Hydrology Research Institute, 11 Innovation Boulevard, Saskatoon, Saskatchewan, Canada S7N 3H5)

21-25 July
Western Pacific Geophysics Meeting, Kanazawa, Japan. (Christine N. Hooke, American Geophysical Union, 2000 Florida Avenue N.W., Washington, DC 20009, U.S.A.)

20-23 August
10th IAHR International Symposium on Ice, Helsinki University of Technology, Espoo, Finland. (Mauri Määttänen, Helsinki University of Technology, Department of Mechanical Engineering, Otakaari 1, SF-02150 Espoo, Finland)

27-31 August
** IGS Symposium on Ice-Ocean Dynamics and Mechanics, Hanover, NH, U.S.A. (Secretary General, IGS, Lensfield Road, Cambridge CB2 1ER, U.K.)

18-20 September
2nd International Conference on Ice Technology, Downing College, Cambridge, U.K. (Elizabeth Newman, Conference Secretary, Computational Mechanics Institute, Ashurst Lodge, Ashurst, Southampton SO4 2AA, U.K.)

24-28 September
3rd General Assembly of the European Network of Experimental and Representative Basins, Conference on Hydrological Research Basins and the Environment, Wageningen, The Netherlands. (IAC-Section OCC, P.O. Box 88, 6700 AB Wageningen, The Netherlands)

23-28 September
ICSI International Symposium on Interaction of Glaciers with the Ocean and Atmosphere, Leningrad, USSR. (V.M. Kotlyakov, Institute of Geography, Academy of Sciences USSR, Startomonetny 29, Moscow 109017, U.S.S.R.)

29-31 October
IWAIS '90: 5th International Workshop on Atmospheric Icing of Structures, organized by the Japanese Society of Snow and Ice, Tokyo (IWAIS '90 Secretariat, c/o Inter Group Corporation, Akasaka Yamakatsu Bldg., 8-5-32, Akasaka Minato-ku, Tokyo 107, Japan)

29 October-7 November
Second World Climate Conference, sponsored by WMO, UNEP, UNESCO and ICSU, Geneva, Switzerland. (Co-ordinator SWCC, c/o World Meteorological Organization, P.O. Box 2300, 1211 Geneva 2, Switzerland)

1991

May
Symposium on Tropospheric Chemistry of Southern High Latitudes, Boulder, CO, U.S.A. (B.A. Bohharne, NOAA Environmental Research Laboratory, 325 Broadway, Boulder, CO 80303-3328, U.S.A.)

2-9 August
XIII INQUA Congress, Beijing, China. (Chinese Academy of Sciences, 52 Sanlike, Beijing 100864, China)

11-24 August
20th General Assembly of the International Union of Geodesy and Geophysics, Vienna, Austria.

26-30 August
** IGS Symposium on Mountain Glaciology relating to Human Activities, Lanzhou, China. (Secretary General, IGS, Lensfield Road, Cambridge, CB2 1ER, U.K.)

1-6 September
Symposium on the Physics and Chemistry of Ice, Sapporo, Japan. (Norikazu Maeno, Institute of Low Temperature Science, Hokkaido University, Sapporo 060, Japan)

1992

17-22 May
** Symposium on Remote Sensing of Snow and Ice, Boulder, CO, U.S.A. (Secretary General, IGS, Lensfield Road, Cambridge CB2 1ER, U.K.)

29 June-3 July
Interpraevent 1992: Protection of Habitat against Floods, Debris Flows and Avalanches, Berne, Switzerland (Interpraevent 1992, c/o Bundesamt für Wasserwirtschaft, Postfach 2743, CH-3001 Bern, Switzerland)

September
** Symposium on Snow and Snow-Related Problems (as part of an International Forum on Snow Areas), Nagaoka, Japan. Co-sponsored by the Japanese Society of Snow and Ice and the City of Nagaoka. (Secretary General, IGS, Lensfield Road, Cambridge CB2 1ER, U.K.)

News

The Ohio State University Board of Trustees has appointed a federal geophysicist, **Kenneth C. Jezek**, as director of the Byrd Polar Research Center.

New members

Masahiko Arakawa, Institute of Low Temperature Science, Hokkaido University, Sapporo 060, Japan.
Robert J. Benedict, 10527 20th N.E., Seattle, WA 98195, U.S.A.
Julia Branson, School of Geography, University of Birmingham, P.O. Box 363, Birmingham B15 2TT, U.K.
Gian C. Cortemiglia, Via Massa Saluzzo no. 13, 15057 Tortona (AL), Italy.
Paul Cutler, Department of Geography, University of Toronto, 100 St George Street, Toronto, Ontario M5S 1A1, Canada.
Karen E. Dobbie, Grant University of Geology, University of Edinburgh, Kings Buildings, West Mains Road, Edinburgh EH9 3JW, U.K.
Yves Durand, Centre d'Etudes de la Neige, B.P. 44, 38402 St Martin d'Hères Cedex, France.
Takuya Fukuzawa, Institute of Low Temperature Science, Hokkaido University, Sapporo 060, Japan.
Jost Heintzenberg, Department of Meteorology, University of Stockholm, S-10691 Stockholm, Sweden.
John B. Hunt, Grant Institute of Geology, University of Edinburgh, Kings Buildings, West Mains Road, Edinburgh EH9 3JW, U.K.
Felix Keller, Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie, Gloriastrasse 37/39, ETH-Zentrum, CH-8092 Zürich, Switzerland.
Jack Kohler, Department of Geology and Geophysics, University of Minnesota, 108 Pillsbury Hall, 310 Pillsbury Drive S.E., Minneapolis, MN 55455, U.S.A.
Juhani Lillberg, Valtakatu 2 R, 96100 Rovaniemi, Finland.
Reginald Lorrain, Faculté des Sciences (CP160), Université Libre de Bruxelles, 50 Avenue F. Roosevelt, B-1050 Brussels, Belgium.
David R. Mantripp, University College London, Mullard Space Science Laboratory, Holmbury St Mary, Dorking, Surrey RH5 6NT, U.K.
Carolyn J. Merry, Department of Civil Engineering, The Ohio State University, 470 Hitchcock Hall, 2070 Neil Avenue, Columbus, OH 43210-1275, U.S.A.
Steven J. Mock, US Army Research Office, P.O. Box 12211, Research Triangle Park, NC 27709, U.S.A.
Chris G. Rapley, 22 Artington Walk, Portsmouth Road, Guildford, Surrey GU2 5EA, U.K.
Frédérique Remy, 18 avenue E. Belin, 31055 Toulouse Cedex, France.
Jun Shimizu, Institute of Low Temperature Science, Hokkaido University, Sapporo 060, Japan.
Bruce Smith, Bruce Smith Snow Studies, P.O. Box 2037, Ketchum, ID 83340, U.S.A.
Jean-Louis Tuaillon, c/o ANENA, 15 rue Ernest Calvat, 38000 Grenoble, France.
Stephan Wagner, Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie, Gloriastrasse 37/39, ETH-Zentrum, CH-8092 Zürich, Switzerland.
Gregory A. Zielinski, Department of Geology, George Mason University, Fairfax, VA 22030-4444, U.S.A.

INTERNATIONAL GLACIOLOGICAL SOCIETY

Lensfield Road, Cambridge CB2 1ER, England

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Lensfield Road, Cambridge CB2 1ER, England

DETAILS OF MEMBERSHIP

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

ANNUAL PAYMENTS 1990

Private members	Sterling	£30.00
Supporting members	Sterling	£130.00
Contributing members	Sterling	£50.00
Junior members	Sterling	£15.00
Institutions, libraries	Sterling	£90.00 for Volume 36 (Nos.122, 123, 124)

Annals of Glaciology – prices vary according to size of volume. For further information, apply to the Secretary General.

Note: Payments in currencies other than £ sterling should be calculated at the exchange rate in force at the time of payment. Then add sufficient money to cover the bank charges (currently £6). The Society needs the full payment, so that the extra £6 to cover bank charges should be paid by you. Thank you.

ICE

Editor: H. Richardson (Secretary General)
Assisted by D.M. Rootes and S. Stonehouse

This news bulletin is issued to members of the International Glaciological Society and is published three times a year. Contributions should be sent to the Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, England.

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Sterling £12.00

All enquiries about the International Glaciological Society should be addressed to the Secretary General of the International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, England.