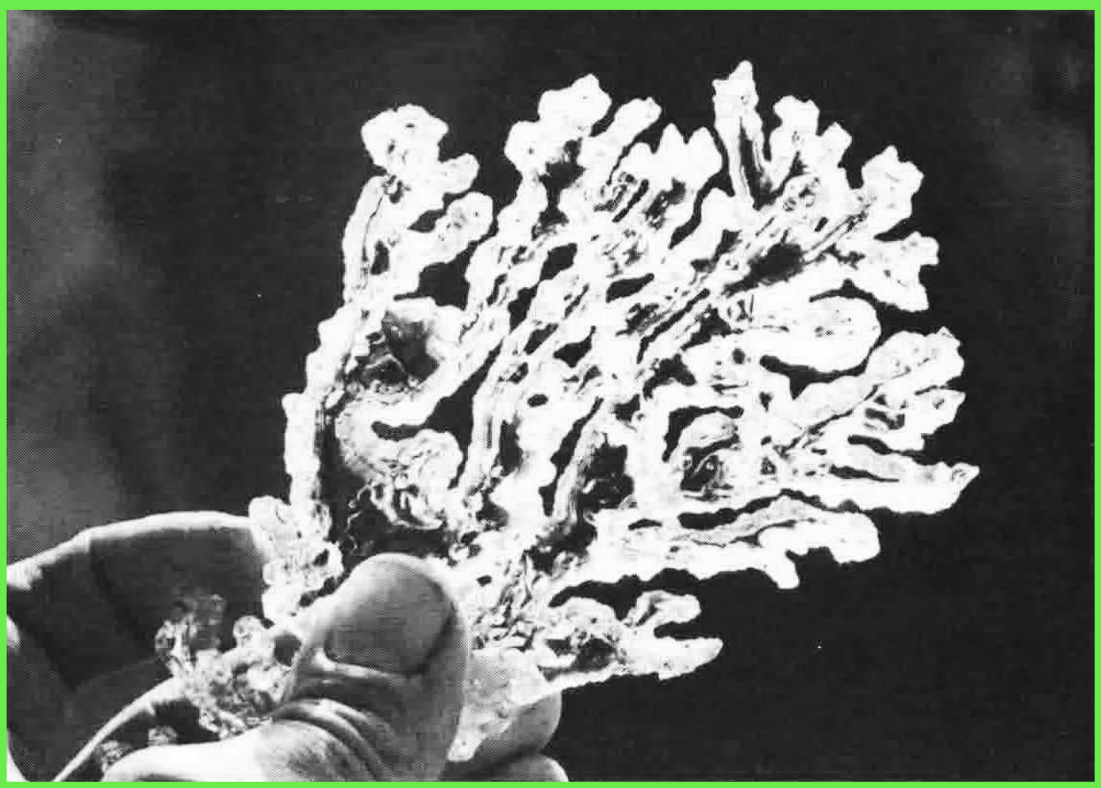
NUMBER 85 3rd ISSUE 1987

# ICE

## NEWS BULLETIN OF THE INTERNATIONAL GLACIOLOGICAL SOCIETY



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COVER PICTURE: Branched single ice crystal from an ice cavity on the Blue Glacier, Washington, USA.
Photograph by E.R. LaChapelle. (Published in *Journal of Glaciology*, June 1968, 7(50))

# CANADA

## GENERAL GLACIOLOGY

### *ISOTOPE GLACIOLOGY*

(M.G. Maxwell, R.D. Russell, G.K.C. Clarke, GPHYS/UBC)

M.G. Maxwell is studying processes of ice accretion and debris entrainment at the base of glaciers. The work involves analyses of water quality, crystal fabric, debris properties and isotopic fractionation of D/H and $^{18}O/^{16}O$ for ice samples taken from Backe and Trapridge Glaciers, Y.T. The results suggest that: (1) Basal freezing from a permeable substrate leads to accretion of basal ice which is isotopically variable due to basal water isotopic variations or fractionation process variations. (2) Basal and bulk ice have different relationships between oxygen and hydrogen heavy isotopes, but it is not always possible to distinguish between bulk and basal ice if only a few samples are analyzed. (3) Bulk ice is isotopically altered during evolution from precipitation to ice.

### *SEA ICE DATA BASE*

(Arctec Canada Limited, Kanata)

A data base has been developed for the Canadian Coast Guard which provides probabilistic values of ice concentration, thickness, floe size and other environmental variables on a 15 n.mile grid in Canadian Arctic waterways. The data base is mounted on an Apple MacIntosh computer and includes facilities for interactive editing and mapping. The statistical values are derived from the A.E.S. Digital Archive and many other sources.

## GLACIER STUDIES IN DIFFERENT AREAS/ROCK GLACIERS

### *LATE QUATERNARY GLACIERS*

(J-M.M. Dubois, M. Parent, Q.H.J. Gwyn, L. St-Pierre, P. Bigras, GEOG/SHER; P. Bail, A. Larocque, G. Larocque, A. Morissette, UofM)

In the Cantons de l'Est, the stratigraphy and chronology of Wisconsinian glacial and deglacial events, as well as relationships between Appalachian ice masses and the Laurentide ice sheet, have been studied. Some emphasis is being placed on pre-Champlain Sea glaciolacustrine water-bodies, particularly the Fort Ann phase of Glacial Lake Vermont. On Anticosti Island, a study of glacial and deglacial events and related sea-level changes spanning the last 85,000 years is being completed. On the Magdalen Islands, a study of Late Quaternary glacial events and related sea-level changes is being initiated.

### *MODERN GLACIERS*

(A. Champoux, J-M.M. Dubois, GEOG/SHER; C.S.L. Ommanney, SWD/NHRI/EC)

Modern glaciers were studied in Glacier National Park (British Columbia); a study of glacier volume variations has now been completed and a paper will be published shortly. This paper presents and discusses glacier physiognomic characteristics as well as glacier variations since the Little Ice Age.

### *FIELD WORK/SNOW AND ICE CHEMISTRY/ICE FLOW MONITORING*

(B.T. Alt, J. Bourgeois, D. Fisher, R. Koerner, M. Parnandi, N. Reeh, PCSP and GSC/EMR)

The mass balance of four High Arctic ice caps was remeasured. Samples were collected from the margins of Devon and Agassiz Ice Caps, and from the Tuto and Nuna ramps on the Greenland Ice Sheet, for oxygen isotope and chemistry analysis. The purpose is to investigate ice-flow characteristics by comparison of these results with those from boreholes at the top of the flow line at borehole sites. Two further bulk (50 l) samples were melted at depth in an old borehole for pollen analysis. Borehole diameters were remeasured in a hole drilled to bedrock on Agassiz Ice Cap in 1984. Microparticle concentrations in snow and ice meltwater were measured in the laser device described above. A new strain net was set up to cover all three boreholes on Agassiz Ice Cap in Northern Ellesmere Island. A pilot study was made of wind pumping in the snow at the same locality. Samples were collected in three 2–3 m snow pits to attain a complete view of pollen, particulate and chemistry variations from season to season and from year to year. A levelling profile was made across a small ice cap close to the northwest edge of Devon Ice Cap; when repeated in several years' time it will serve to quantify ice-cap shrinkage or expansion. This was the third such profile made in three years on different ice caps.

### *ICE CAPS' MASS-BALANCE DATA BASE*

(B.T. Alt, J. Bourgeois, D. Fisher, R. Koerner, M. Parnandi, N. Reeh, PCSP and GSC/EMR)

All the mass-balance results for Meighen, Devon and Melville South Ice Caps have been organized for micro-computer storage. Programs have been written to calculate for missing data and compute basic statistics. All results have been sent to an international glacier data bank. Preliminary work was completed on calculating the mass balance of a theoretical Queen Elizabeth Islands Maximum Ice Cap using present-day values. In three of the past 25 years the ice cap would have had a positive balance.

### *SNOW AND ICE CHEMISTRY*

(B.H. Alt, J. Bourgeois, D. Fisher, R. Koerner, M. Parnandi, N. Reeh, PCSP and GSC/EMR)

Several samples collected for us by other field parties and expeditions on the Ward Hunt Ice Shelf and the Arctic Ocean were analyzed for particulates, chemistry and pollen concentrations in a continuing study of High Arctic air-mass circulation and snow chemistry. Bulk samples from a borehole on Agassiz Ice Cap, Northern Ellesmere Island, were analyzed for pollen concentrations and the results studied with a view to distinguishing between glacial and interglacial ice.

The regional congruence of present-day vegetation and summer climate patterns in the Queen Elizabeth Islands was studied in cooperation with Dr Edlund (GSC) as part of an ongoing evaluation of climate-related variables used in paleoclimate reconstructions. A laser device for measuring microparticle concentrations in 1 ml samples was developed.

### *ICE-FLOW MODEL*

(B.T. Alt, J. Bourgeois, D. Fisher, R. Koerner, M. Parnandi, N. Reeh, PCSP and GSC/EMR)

A computer model of the Laurentide Ice Sheet was completed and shows the importance of possible deforming beds. A model study of the ice flow down a ridge leading to a borehole site on the Devon Ice Cap was completed. The study indicates a highly variable depth/deformation relationship along that ridge. The volcanic stratigraphy of 3 Agassiz Ice Cap cores was used to align and date the oxygen isotope and summer melt feature time series accurately. Borehole closure rates in the 3 holes were related to the degradation of the volcanic signatures in "dirty" Wisconsinian ice.

### *ROCK GLACIER FORMATION, DALTON RANGE, S.W. YUKON*

(P.G. Johnson, M.D. Lacasse, GEOG/Ottawa)

All the east-facing cirques and valleys of the Dalton Range have well-developed glacier ice–cored rock glaciers. These had a number of periods of activity in the pre-recent period, which it has not been possible to date, and have a number of surfaces which are of recent date, probably from the Neoglacial and Little Ice Age. A "modern" date has been established for wood from one of the surfaces. There is no evidence from the two rock glaciers studied in detail for any synchroneity of advances.

### *GLACIER ICE-DAMMED LAKE, KASKAWULSH GLACIER, S.W. YUKON*

(P.G. Johnson, J. Kasper, GEOG/Ottawa)

An annually draining ice-dammed lake on the margin of the Kaskawulsh Glacier has a history of late summer draining. The lake is filled from the Kaskawulsh Glacier and from a small basin containing three glaciers. The heavy sediment-laden water from the basin forms turbidity flows along the lake bed, producing sequences of rhymite deposits. Fossil deposits indicate a lake history for the last few hundred years. The lake drains subglacially by floating of the glacier margin. Drainage occurred in September 1986 over a period of five days.

### *GLACIOLOGICAL AND GLACIER HYDROLOGICAL CONTRASTS IN KASKAWULSH GLACIER BASIN, S.W. YUKON*

(P.G. Johnson, GEOG/Ottawa)

Three small alpine glaciers in a sub-basin of the Kaskawulsh have marked contrasts glaciologically. One is currently surging, one is downwasting and has an extensive ice-cored moraine system, and the third is downwasting without an extensive moraine system. Geological and morphological contrasts between the glacier valleys, causing differences in glacier-bed conditions and accumulation/ablation patterns, are being investigated as the possible causes of the glaciological contrasts. Discharge regimes from the three systems are different but are all very variable. Water release from the surging glacier, disrupted by the highly crevassed nature of the ice, occurs in pulses as channels open through the glacier. Discharge regimes from the ice-cored moraine glacier are dominated by course changes through the moraine with outburst floods caused by tunnel collapse and course reorientation. The regime of the third glacier is more regular but experiences variability in the early ablation season as the drainage system develops.

### *FYLES GLACIER AND APE LAKE, PURGATORY GLACIER; PACIFIC RANGES, SERVICES AND MINISTRY OF ENVIRONMENT, VICTORIA COAST MOUNTAINS, B.C. (BELLA COOLA DISTRICT)*

(K. Ricker, J. Desloges, GEOG/UBC)

On 2 August, exactly after Ape Lake had re-filled to full pool level, the second jökulhlaup occurred, bringing yet more downstream damage to roads, bridges, forest reserves, and salmon spawning beds, as well as debris to litter the oceanic waterway South Bentinck Arm. The second event took less than 20 hours again to drain the Lake to the same low levels of the first event, and river-water levels were distinctly higher during this event, which was monitored by a pressure recorder implanted into the Lake only two weeks before the outburst. Pilot observations, coupled with the notes of downstream logging-camp inhabitants, suggest that peak discharge occurred when only 40–60% of the total discharge or emptying had taken place. The entire lake and river-water course, as well as the silt plume in South Bentinck Arm, was aerially photographed at 1:20,000 scale near the conclusion of the event on the afternoon of 2 August. Sedimentological studies of the lake basin were concluded this session and a paper on this part of the study has been submitted

by Desloges for publication. Purgatory Glacier, which oscillates wildly at its snout, has again advanced 65 m between the 31 October 1984 and 2 August 1986 observation period.

***WEDGEMOUNT LAKE AND GLACIER, NORTHERN GARIBALDI PARK, COAST MOUNTAINS, B.C.***

(K. Ricker, W.A. Tupper, BCIT)

The phototheodolite survey of the lower reaches of the glacier was repeated at the end of the 1986 melt season. Pronounced recession on the north side of the snout has taken place, whereas the south side continues to hold a near-constant position, with calving of icebergs into the Lake. The northeast (on Mt Weart) arm of the glacier is now completely separated from the main arm, due to excessive ice melt and the warm August temperatures, which produced a higher equilibrium line than normal on the main arm. The entire glacier was re-surveyed by phototheodolite from its head, from atop Wedge Mtn on 15 August 1986, and thereby the original 1928 survey has been replicated. Targets set to monitor velocity on the lower glacier were replaced with drilled-in stakes this year so that the ablation could be measured directly as well. The results of the annual surveys continue to be published in each yearly edition of the Canadian Alpine Journal.

***OVERLORD GLACIER, CENTRAL GARIBALDI PARK, COAST MOUNTAINS, B.C.***

(K. Ricker, W.A. Tupper, BCIT)

This glacier lies near the resort of Whistler and is easily reached by a well-built trail. In 1986, monuments were established to position its snout. A substantial advance of 175 m from a 1951 position was calculated, of which a growth of 76 m had occurred since 1972. Moraines around the glacier were mapped, and age studies of them will be carried out in conjunction with the next snout survey in 1987.

***TCKAIKAGAN GLACIER, PACIFIC RANGES, COAST MOUNTAINS, B.C. (CHILCOTIN DISTRICT)***

(K. Ricker, J. Lixvar, Alpine Club of Canada)

The snout of this glacier was remeasured this year, showing yet another large withdrawal, of 100.5 m, since the 1982 survey. The adjacent Friendly Glacier was not visited.

***GLACIER STUDIES - YUKON TERRITORY***

(G.K.C. Clarke, E.W. Blake, F.H.M. Jones, GPHYS/UBC; J. Shaw, GEOG/Queens; C.C. Smart, GEOG/UWO)

Trapridge Glacier last surged around 1945 and its next surge is expected to occur within a few years. The aims of our field study are to determine the cause and mechanics of surging. In 1986 we resurveyed the glacier, drilled 68 holes to the bed, measured subglacial water pressure, analyzed basal and outflow water for the presence of a Rhodamine WT tracer, sampled the subglacial material, tested a new impulse radar, examined ice structures formed by previous surges, and analyzed the "slurry till" layer exposed in the lower part of Trapridge basin.

***RAKHIOT GLACIER, PUNJAB HIMALAYA, PAKISTAN***

(J. Gardner, E. Mattson, N. Jones, GEOG/Waterloo)

Research continued during June, July, and August 1986 on margin fluctuations, surface velocities, ablation rates, and sediment yield rates at the Rakhiot Glacier. The research is partially supported by the joint Canada–Pakistan Snow and Ice Hydrology Project. Data from 1986 indicate that the Rakhiot is presently in a recessional state (ca 5 m/yr) and that ablation-zone debris cover produced by surface meltout of englacial debris has a strong conservative impact on ice loss. The principal focus of the 1986 research was relationships between ablation, debris cover, and meteorological conditions.

***HILDA ROCK GLACIER, CANADIAN ROCKIES***

(I. Bajewsky, J. Gardner, GEOG/Waterloo)

Monitoring of discharge from the Hilda rock glacier was continued in the summer of 1986. In addition, suspended sediment load and total dissolved solids were monitored. Together, these data and related meteorological data are being used to make inferences about the internal structure of the rock glacier and the role of the rock glacier in local erosion rates and patterns.

***WHITE GLACIER, AXEL HEIBERG ISLAND***

(W.P. Adams, GEOG/Trent)

Mass-balance measurements were made on the White Glacier, Axel Heiberg Island, N.W.T. All ablation area stakes were re-drilled to 3 m+ and measuring cables cut to 1 cm at the end of August 1986. The accumulation-area stakes will be measured before the melt, 1987.

***GLACIER INVENTORY OF CANADA***

(C.S.L. Ommanney, SWD/NHRI/EC)

The glacier inventory has been shelved, following the move of the NHRI to Saskatoon and the reassignment of staff to other projects. All records were transferred and it remains to be seen what access to them will be provided.

***ICE-CORE CHEMISTRY PROJECT, MOUNT LOGAN, Y.T.***

(G. Holdsworth, SWD/NHRI/EC; D. Raynaud, R. Delmas, CNRS, Grenoble; M. Monaghan, U of C; P. Mayewski, UNH)

This project complements and overlaps with the above. A detailed ion balance was carried out on a section of core, to help interpret the chemistry of the core in general. The carbon-dioxide content of air bubbles was measured

at various depths (ages). Reports on this work will be published in 1987. Major anion analyses, through selected volcanic events, are being carried out (UNH). Comparison with Greenland ice-core data is planned. Analyses of $^{210}Pb$ and $^{10}Be$ are being done at U of C to study the flux of these isotopes and to use them for dating if possible. Sampling includes sites other than Mount Logan.

### *ICE-CORE CLIMATE CHANGE PROJECT, MOUNT LOGAN, Y.T.*

(G. Holdsworth, M. Demuth, SWD/NHRI/EC; H.R. Krouse, E. Peake, PHYS/University of Calgary)

Research now focuses on the extraction of climatic and other atmospheric-process information from an oxygen isotope time series covering almost the last 300 years. Data will be included from 1980–1986 as soon as samples are analyzed. These were collected in summer 1986, at which time the borehole was relocated for logging purposes. Some preliminary results indicate that volcanic events and the $\delta^{18}O$ signature associated with them have climatic implications.

Acid anions have been measured through major volcanic events and significant lags between nitrate, sulfate and the halides are noticed. These data have implications for the study of acid precipitation: acid-gas loading in the atmosphere also has repercussions vis à vis climate-change scenarios.

### *BRIDGE RIVER WATERSHED, COAST MTS, B.C.*

(O. Mokievsky-Zubok, SWD/NHRI/EC)

Although mass-balance measurements were discontinued this year on three glaciers in the Bridge River watershed, a Data Collection Platform (DCP), below Bridge Glacier, continued its operation, providing meteorological and hydrological data.

### *SENTINEL AND HELM GLACIERS, COAST MTS, B.C.*

(O. Mokievsky-Zubok, SWD/NHRI/EC)

Mass-balance measurements continued on both glaciers. Although only 10 km apart, within the same elevation range and with the same aspect, mass-balance results are persistently different. Sentinel Glacier had a negative balance of -0.32 whereas Helm Glacier had -1.33 m $H_2O$. Meltwater flow measurements at Sentinel Glacier were not renewed after the gauging station was washed away by an October flood in 1984.

### *PLACE GLACIER, COAST MTS, B.C.*

(O. Mokievsky-Zubok, SWD/NHRI/EC)

Measurements of winter and summer balances and meltwater flow continued on Place Glacier. A slightly below-average winter accumulation and warm summer produced a strongly negative mass balance of -1.31 m $H_2O$. This is the tenth consecutive year that Place Glacier has recorded a negative mass balance.

### *GLACIER MASS BALANCE AND METEOROLOGICAL DATA*

(A. Letreguilly, SWD/NHRI/EC)

The winter, summer and net mass balances and equilibrium-line altitude of three glaciers (Peyto, Place and Sentinel) were compared with meteorological data from neighbouring stations for 1966–1984. Peyto mass balance is almost entirely related to summer temperature, Sentinel mostly to winter precipitation and Place to both. The equilibrium-line altitude of the three glaciers has the same correlation with meteorological data as the mass balance.

### *PEYTO GLACIER, ALBERTA*

(G. Holdsworth, M. Demuth, SWD/NHRI/EC)

A number of visits were made to Peyto Glacier in 1985 and 1986 to determine the mass balance and to survey the glacier-tongue geometry.

### *KLUANE TO PARTICIPATE IN THE JUNEAU ICEFIELD RESEARCH PROGRAM*

(B. Liddle, Kluane National Park)

Kluane National Park will participate in the fortieth year of a long-term research project held on the Juneau Icefield, Alaska. The research program will study the total environment of the fifth-largest icefield in North America, to understand the resource potential of Arctic and mountain regions better.

The University of Idaho's Institute of Glaciological and Arctic Sciences sponsors the program under the leadership of Dr Maynard Miller, who is now preparing for his 27th summer season atop the icefield. He will be joined by an international collection of scientists and a select group of high-school and university students, each involved in a variety of field work and research projects. These projects include such unusual tasks as glacier mapping, subglacial cave exploration, seismic depth profiling and lichenometry (the measuring of lichen in order to date periods of glaciation on rock surfaces).

"These are real scientific problems that the students and scientists are working on, not models or manufactured ones," Miller pointed out. "Normally you bring nature into the classroom. At the institute we turn this around and take the classroom and the laboratory into nature."

Studies and research done on the icefields have been published in scientific journals, and have been the topics of many masters' theses and doctoral dissertations.

## ATMOSPHERIC ICE/CLIMATE/METEOROLOGY

### *NEW TYPE OF PRECIPITATION GAUGE*

(B.C. Ministry of Transportation and Highways, Snow and Avalanche Section)

Extensive development and testing of a new type precipitation gauge over the past four years has produced promising results. The standpipe gauge, a PVC plastic container holding an ethylene glycol-and-water solution,

incorporates an electronic pressure transducer which indicates the amount of precipitation to an accuracy of 1-2 mm. A submersible circulating pump, installed in the gauge and operating on a time cycle, circulates the solution, preventing freezing over of the gauge and significantly increasing the service interval. The gauge is relatively inexpensive to produce and has proven to be accurate and reliable. It can also easily be configured to a variety of data collection platforms, allowing the data to be telemetered in conjunction with other remote-weather-station data.

### *ENVIRONMENTAL ATLAS FOR BEAUFORT SEA OIL-SPILL RESPONSE: PHASE II*

(DF Dickins Associates Limited, Vancouver, with ESL Environmental Sciences Limited and S.L. Ross Environmental Research Limited)

An environmental atlas is under production to assist in planning and implementation of year-round nearshore and offshore response to oil spills in the Canadian Beaufort Sea. The study area includes the coastline from the Yukon/Alaska border to Baillie Islands. The physical environment, including seasonal ice conditions and climate, is presented in maps and graphs. Environmental sensitivity rankings, based on biological and human-use resources and oil persistence in the environment, are presented on 1:150,000 scale maps. Site-specific oil-spill countermeasures accompany the maps.

### *RECENT WORK AT HYDRO-QUEBEC ON FIELD OBSERVATION OF ATMOSPHERIC ICING IN RELATION TO TRANSMISSION-LINE DESIGN AND OPERATION*

(B. Félin, Hydro-Québec)

Since 1974, Hydro-Québec has had an on-going program to measure freezing precipitation deposits on passive collectors at manned stations. Approximately 140 stations throughout the province of Québec report at least twice a day the thickness of ice deposits observed on the rods and plates of the instrument. All the data are archived on an IBM computer.

Hydro-Québec has also developed a new automatic ice detector to be used in remote areas with restricted power supply. Data is transmitted through our micro-wave network by satellite data-collection platforms or by standard telephone lines. The acquisition is computer-driven and fully automated. The 20 detectors presently in operation are used for monitoring in real-time icing conditions along existing high voltage transmission lines or in areas where new line routes are planned. The data are also archived to constitute a data base for long-term studies.

## FLOATING ICE (SEA, LAKE, RIVER AND ICEBERGS)

### *DRIFT ICE*

(A. Lavoie, J-M.M. Dubois, P. Larouche, GEOG/SHER)

In the field of drift ice, two remote-sensing projects on winter ice coverage are being conducted. One of these studies monitors floating-ice changes in the Manicouagan River estuary between 1984 and 1986, utilizing MSS and TM Landsat imagery. A second study is just beginning; TM imagery is being used to study drift ice displacements and, possibly, current velocities in eastern Hudson Bay.

### *EFFECT OF SEA ICE ON BEAUFORT SEA COASTAL PROCESSES*

(Arctec Newfoundland Limited., St John's)

Arctec is presently in the final stages of a study to assess the significance of sea ice as a shoreline erosion/accretion agent for the southern Beaufort Sea. This study incorporates a review of present knowledge regarding shoreline sea-ice processes and makes recommendations aimed at filling critical gaps.

### *COMMERCIAL ICEBREAKER EVALUATION*

(Arctec Canada Limited., Kanata)

A series of field trials was performed for the Canadian Coast Guard in western Viscount Melville Sound to evaluate the icebreaking and ice-escort capabilities of a commercial icebreaker. The project involved instrumented transits in level ice and ramming of ridged first-year and multi-year ice. Ice properties were measured throughout the test region.

### *LABRADOR COAST ICE*

(G. Symonds, BIO/DFO)

Historical sea-ice data for the Labrador–East Newfoundland Shelf area, based on AES ice charts, are analyzed in conjunction with atmospheric, oceanographic and satellite imagery data.

### *LABRADOR ICE-MARGIN STUDY*

(C. Tang, M. Ikeda, BIO/DFO)

This research topic investigates oceanic structure, processes and dynamics in the Labrador marginal ice zone that are important to ice distribution, ice-mass growth and loss and ice movement, by analyzing field data and numerical modelling.

### *ICEBERG DRIFT-TRACK MODELLING*

(S.D. Smith, BIO/DFO)

Measure drift tracks of a number of icebergs while simultaneously recording current profile and wind speeds.

Measure iceberg mass and cross-sectional area in air and in water, during three cruises of CSS *Dawson* in Newfoundland/Labrador areas.

Compile and verify data to obtain reliable set of iceberg tracks, with associated environmental data.

### *ICE GROWTH AND DECAY ANALYSIS*

(W.D. Hume, AES/EC, Edmonton)

Ice growth and decay versus time has been examined at 35 locations across northern Canada. Where possible, regression equations have been determined for growth and decay at each site. Plots of mean ice growth versus

mean accumulated freezing degree days have also been produced. The report is in the final stages of preparation.

### *GULF OF ST LAWRENCE ICE STUDIES*

(G.L. Bugden, BIO/DFO)

Variations in the seasonal ice cover in the Gulf of St Lawrence are of great importance to transportation, fishing, and oil exploration interests. Documenting and understanding these changes is vital to Gulf resource utilization and for improving predictive ability.

### *PACK-ICE DRIVING-FORCES RESEARCH*

(K.R. Croasdale, Esso; R. Frederking, NRCC; L. Lewis, DFO)

This work was sponsored by the Government of Canada and was performed in collaboration with Arctec Canada. Logistics support was provided by Gulf Canada. A multi-year floe in the southern Beaufort Sea was instrumented with very sensitive stress sensors; the hypothesis is that, under converging ice conditions, the compressive stresses in the floe could be correlated with the creation of pressure ridges around it, pressure ridges being a limit to the driving forces that can be transmitted through pack ice.

### *OIL SPILL IN PACK ICE (ICE COMPONENT)*

(DF Dickins Associates Limited, Vancouver, with S.L. Ross Environmental Research Limited)

Three experimental crude-oil spills, of 1 $m^3$ each, were carried out in pack ice offshore Cape Breton Island, Canada. Ice conditions for the spills ranged from 6/10 dynamic open pack ice to 9+/10 pack ice in a state of moderate compression. Oil spreading was dramatically reduced compared to that on open water. No water-in-oil emulsions were observed. Only minor oiling of floes in a swell was observed; the significant oil/ice interaction was with brash and slush ice between floes. No pumping of oil between converging ice floes occurred. In-situ burning of oil contained by brash in high pack-ice concentrations was an effective counter-measure; nothing seemed feasible for oil in dynamic pack-ice conditions.

### *ICE JAMS*

(B. Michel, CIVIL/Laval)

Laboratory test data and field measurements are being re-analyzed to determine the maximum possible water-level rise that may occur in an ice jam. This will be used in a statistical model to predict flooding by ice jams.

### *ANISOTROPIC $S_3$ ICE*

(B. Michel, E. Stander, CIVIL/Laval)

A laboratory study is underway to study the mechanisms of formation and some physical properties of anisotropic $S_3$ sea ice.

### *SEA-ICE DRAINAGE*

(B. Michel, M. Cantin, CIVIL/Laval)

Fast drainage of various types of sea ice is simulated in a laboratory tank. The mechanisms under study are those of gravity, melting and flushing.

### *BEAUFORT SEA-ICE MOTION*

(H. Melling, W.P. Budgell, DFO/Sidney; J.Y. Cherniawsky, Borstad Assoc. Limited/Sidney)

A co-ordinated observational and computer-modelling study of pack-ice dynamics in this shallow-shelf sea has been conducted over an annual cycle through 1985/86. In-situ measurements of ocean current, hydrography, surface meteorology and ice drift, obtained over an area of 100,000 square km, are being analyzed in conjunction with satellite AVHRR images from which regional ice cover and motion have been derived. A barotropic ocean model of the entire Beaufort Sea at 18 km resolution, with a matched viscous-plastic ice-dynamics model, has been developed to aid in the interpretation of data and to enable testing of hypotheses generated from the data. The objective of the study is an assessment of the need to incorporate ocean dynamics into pack-ice prediction models in shallow seas if accurate predictions of motions are required up to two days in advance.

### *HYDRODYNAMICS OF UNDERICE FLOWS*

(D.R. Topham, H. Pite, DFO/Sidney)

Study of the interaction between ocean currents and underice topography, such as pressure keels, is underway, with three avenues of approach. Field measurements of flow profiles and their variations, and of flow structure visualized using an array of echo sounders, have been acquired for a tidal flow beneath a pressure keel of 12 m draft in Barrow Strait. These observations, showing boundary-layer separation and its suppression in stratified flow, internal wave generation and a variety of other phenomena, are being used to guide laboratory experiments in a 10 m towing tank, and corresponding numerical simulations. The general conceptual framework of internal hydraulics based on a Froude number is proving productive. The objective of the investigation is a better understanding of the mechanisms and rates of momentum transfer between moving ice and the underlying ocean.

### *OCEANIC NOISE AND THE BREAKUP OF FAST-ICE FIELDS*

(D.M. Farmer, S. Waddell, DFO/Sidney)

Measurements of acoustic background noise in five frequency bands between 50 Hz and 14 kHz were obtained beneath fast ice in 200 m of water in eastern Amundsen Gulf in the spring and summer of 1986. Distinct noise signatures associated with thermal disequilibrium in the ice, with high winds and with ice-floe interaction following break-up of the ice field, have been identified. Noise signatures apparently related to the actual break-up of the continuous land-locked ice sheet in early July are being examined in conjunction with satellite and radar imagery of the ice sheet, and with

meteorological data. Oceanic acoustic precursors of the actual break-up of the floating fast ice are being sought.

### *RIVER-ICE BREAK-UP AND ICE JAMMING*

(T.D. Prowse, SWD/NHRI/EC)

Field studies of break-up and ice jamming along the Liard and Mackenzie Rivers have continued. The physical characteristics of thermal and mechanical break-ups have been identified and an ice-jam stage–discharge relationship has been defined for the Liard River mouth, using the theory of floating equilibrium jams. The importance of hydrothermal heat flow to the decay of ice jams has been established and an analysis is continuing of the importance of atmospheric heat flows to ice melt and decay.

### *LAKE REGIMES, MACKENZIE DELTA, N.W.T.*

(S. Bigras, SWD/NHRI/EC)

From 1980 to 1985, baseline data on the hydrologic cycle of lakes and channels throughout the Delta were collected to assess the potential environmental impact of regulation of the main stem of the Mackenzie River.

Preliminary analysis suggests that spring break-up is the most significant event. Ice jams, and the resultant backwater flooding during break-up, are essential to the replenishment of the delta lakes. Indications are that regulation would increase the land-to-water ratio and create problems similar to those in the Peace–Athabasca Delta.

### *WATER TEMPERATURE AND HEAT FLUX IN ICE-COVERED RIVERS*

(P. Marsh, SWD/NHRI/EC)

Work is continuing on determining the processes controlling water temperature in ice-covered rivers and developing a model predicting both cross-channel and temporal changes in temperature. The convective heat flux from the water to the overlying ice cover has been determined. A number of techniques for calculating heat flux were compared. A major conclusion is that an ice-roughness term is required and the Colburn analogy method was in closest agreement with the measured heat flux.

### *CHEMICAL CONTENTS OF ICE COVER*

(W.P. Adams, GEOG/Trent)

Studies of the ice cover of Colour Lake, Axel Heiberg Island, N.W.T., continued with an emphasis on chemical aspects. This is a naturally acid lake which provides special opportunities for tracking inputs from the land. At the end of the 1986 melt season, 80% of the lake was still covered by a 1 m thick ice cover.

Work on Knob Lake, Québec, and Plastic Lake, Ontario, also continued.

### *SEA-ICE CLIMATE INFORMATION SYSTEM*

(T. Agnew, AES)

A Sea Ice Climate Information System called CRISP has been developed to analyze and display ice cover and distribution information for any location on Earth. CRISP workshops have been held in Ottawa and more are planned for other parts of the country for 1987. In this regard, I am aware of the ice-information system that C-CORE has developed and feel each is complementary. I feel there is room for cooperation between the two systems.

### *BREAK-UP/FREEZE-UP STATISTICS*

(T. Agnew, AES)

A methodology to investigate longer-term trends in lake break-up/freeze-up dates using AES's archive of lake-ice data has been tested out on Long Lake, N.W.T. The methodology promises to be useful in monitoring possible warming trends in the Canadian Arctic. A similar analysis will be done for a selection of pre-screened lakes across the Canadian Arctic in 1987.

## REMOTE SENSING OF SNOW AND ICE COVERS

### *RADIO ECHO-SOUNDING, YUKON TERRITORY*

(F.H.M. Jones, G.K.C. Clarke, B.B. Narod, GPHYS/UBC)

Jones successfully tested a prototype of a digital impulse radar system on Trapridge Glacier in 1986. The system is fully back-portable and records sounding results on digital cassettes. Five lines were surveyed for glacier depth. At one site, instrumented with a bottom-water pressure transducer, soundings were automatically taken every 20 minutes for 60 hours. Using principal-component analysis, Jones is attempting to detect temporal variations in reflection character and relate these to water-pressure changes. To guide interpretation of the radar data, Jones has developed a linear system model to study how varying basal debris and water content affect the shape of the bottom-reflected pulse.

### *RADIO ECHO-SOUNDING, ALASKA*

(G.M. Cross, G.K.C. Clarke, B.B. Narod, GPHYS/UBC)

Research involves a radioglaciological investigation of the ice-filled summit caldera at Mt Wrangell, Alaska. In April 1982, the UBC ice-sounding radar was employed along 21 airborne traverses of the caldera. A well-defined vertical sequence of radio-reflections was recorded. The radar stratigraphy is attributed to high-acidity layers deposited during past eruptions at Mt Wrangell and suggests a significant extension of the volcanic history.

*SNOWLINE AND GLACIER-MARGIN FLUCTUATIONS, CANADIAN ROCKIES*
(J. Gardner, P. Howart, E. LeDrew, GEOG/Waterloo)
The purpose of this research is to test the utility of Landsat imagery (hard-copy and digital) in mapping extent and fluctuations of high-elevation snow cover and glacier margins as surrogate indicators of short-term climatic variability and medium-term climatic variability and change, respectively. Test areas have been chosen in the Canadian Rockies. MSS and TM data are being utilized.

*BREAK-UP PATTERNS*
(W.D. Hume, AES/EC, Edmonton)
Using satellite imagery, break-up patterns of the Beaufort Sea landfast-ice regime have been monitored for the past 11 years. A final report on this study is currently being prepared.

## SNOW AND AVALANCHES

*AVALANCHE HYDROLOGY AND HAZARD, KAGHAN, PAKISTAN HIMALAYA*
(F. deScally, J. Gardner, GEOG/Waterloo)
The research continues work begun in 1985 under the joint Canada–Pakistan Snow and Ice Hydrology Project to estimate snow/water yields from numerous large avalanche deposits in the Himalayan front range area of Kaghan. In addition to estimation, the research focuses on the development and evaluation of methods for estimation. Data collection includes inventories of avalanche occurrence and monitoring of meteorological conditions. Field mapping of avalanche–hazard areas and the development of hazard identification criteria for the Himalayan environment continues.

*CHEMICAL CONTENTS IN SNOW COVER*
(H.G. Jones, INRS/University of Québec)
Work is presently being focused on the chemistry of N-containing species ($NO_3$, $NH_4$, N-org.) in the snow cover, meltwater and runoff of boreal forest ecosystems. Inorganic nitrogen depletion in the snow cover due to microbiological activity during melt has been quantified both in the field and in the laboratory, whereas N dynamics in surface runoff are strongly controlled by the intensity of the hydrological flux in the early part of the melt.

*SNOW PROPERTIES*
(R. Perla, SWD/NHRI/EC)
Stereological and topological parameters were derived from sections and serials prepared in seasonal snow samples collected from mountain snowpacks. Computer algorithms were developed to describe specimen microstructure, using parameters that correlate with electrical, optical, mechanical and thermodynamic properties. Theoretical models of snow metamorphism and sintering were developed in terms of the section and serial parameters.

*SNOW MANAGEMENT AND MELTWATER INFILTRATION ENHANCEMENT*
(W. Nicholaichuk, SWD/NHRI/EC; D.M. Gray, Division of Hydrology, University of Saskatchewan; B. McConkey, Agriculture Canada Research Station, Saskatoon)
A study was initiated in October 1986 to improve the application and efficiency of snow-management techniques for soil–water augmentation by increasing infiltration into frozen soils through the use of deep tillage and subsoiling practices.

*AVALANCHE SPEEDS MODEL*
(D.M. McClung, P.A. Schaerer, IRC/NRCC)
Based on speed measurements from Rogers Pass, B.C., and from Europe, an engineering model prediction of avalanche speeds was developed using granular flow concepts. A geometrical model for avalanche terrain was developed and statistical predictions of runout were made, in collaboration with the Norwegian Geotechnical Institute.

Laboratory studies of acoustic emissions during slow shear failures were done. Data on avalanche impact forces, speeds, mass, runout and snow type were collected at Rogers Pass, B.C.

A series of tests for flowing snow from a test slide path (15 m long) was completed. The data include effects of mass, volume, temperature, flow depth and speed on the debris runout pattern.

Reports on 33 avalanche incidents involving persons or equipment received by the Avalanche Centre were analyzed and tabulated, and short notes on 7 fatal accidents were published. Case histories of 49 accidents that occurred between 1978 and 1984 were assembled and edited for publication.

Variability of the shovel shear strength observations obtained at Rogers Pass and in other ski areas was correlated with the shear frame index and the hardness of the snow.

## ICE PHYSICS/ENGINEERING

*EVALUATION OF HOVERCRAFT FOR SUPPORT OF BEAUFORT SEA PRODUCTION DEVELOPMENT FOR GULF CANADA CORPORATION*
(DF Dickins Associates Limited, Vancouver)
Existing hovercraft and new designs were evaluated for their ability to meet the year-round supply requirements of an offshore Beaufort Sea oil-production facility. Preliminary design drawings and specifications were developed for several new hovercraft with 75 to 300 tonnes payload capacity.

*CHUKCHI SEA TRANSPORTATION STUDY (ICE COMPONENT) FOR A U.S. INDUSTRY CLIENT*
(DF Dickins Associates Limited, Vancouver)
This study provided a detailed description of ice conditions along the marine transportation route from the Bering Sea to the planned Chukchi Sea lease-sale area. Available ice data were combined with selected satellite imagery

to provide the necessary design criteria for economic and technical evaluations of pipeline and tankers.

***ICEBREAKING WITH INCLINED INDENTORS***
(B. Michel, F. Picard, N. Cornelissen, CIVIL/LAVAL)
Tests have been completed to break ice with flat inclined indentors at various angles in the upwards and downwards breaking modes, in a laboratory tank 4 m × 5 m. This was done both in the brittle range and at very low rates of loading. The final results are being analyzed.

***CREEP OF ICE***
(B. Michel, CIVIL/LAVAL)
A computer model is being developed to determine the parameters characterizing the creep model that has been used in the Ice Mechanics Laboratory to represent primary, secondary and tertiary creep of uniaxial ice samples.

***SOLUTIONS TO THE NON-LINEAR MOMENTUM EQUATIONS OF SEA ICE***
(T.E. Keliher, MATH and STATISTICS/ MUN)
Attempts have been made to obtain analytic solutions to the full sea-ice momentum equations, including the non-linear advection and water-drag terms. The non-linear effects would be important at short time and length scales typical of the marginal ice zone. The equations do not possess the Painlevé property, which means the solutions have singularity properties which are difficult to handle. However, the solution to the one-dimensional case to lowest order exhibits a kink-type solitary wave. A solution has been obtained for the two-dimensional case, which shows a similar behaviour.

***INFLUENCE OF TRANSVERSE ANISOTROPY ON THE BEARING CAPACITY OF SEA ICE***
(J.R. Murat, T. Benissan, M. Lamy, CINEP/UofM)
Direct shear tests, under controlled strain rates, have been performed on sea-ice samples of various crystallographic orientations. The results are currently being used to develop anisotropic constitutive equations for the creep of sea ice.

***LONG-TERM BOREHOLE DILATOMETER TESTS IN ICE***
(J.R. Murat, Y. Lemoigne, J. Belhachemi, CINEP/UofM)
A number of laboratory experiments at low temperature in blocks of ice have been performed: long-term tests (up to 30 days) under constant pressure, and shorter-term tests (6 hours) under step loadings. The test results have been used to develop some new calibration and correction procedures, suited to the prevailing physical conditions. Computer simulation of the tests is presently underway to compare the relevance and accuracy of different constitutive equations and interpretation methods.

***CARBON-MONOXIDE CLATHRATE HYDRATE***
(M. Desando, S.R. Gough, Y.P. Handa, J.S. Tse, J.A. Ripmeester, CHEM/NRC)
The clathrate hydrate of carbon monoxide has been prepared and characterized. Its decomposition pressure at 0 °C is 128 bars, and, unlike other clathrate hydrates with small guests ($O_2$, $N_2$, Kr, Ar), it has the cubic type-I structure.

***A NEW CLATHRATE HYDRATE STRUCTURE***
(J.A. Ripmeester, C.I. Ratcliffe, J.S. Tse, CHEM/NRC; B.M. Powell, AECL)
Most clathrate hydrates belong to two structural types, referred to as types I and II, both of which have been found in nature. A new hexagonal structure has now been identified. The structure is stabilized by large, bulky guest molecules, such as branched and cyclic alkanes, in combination with small guests, such as methane and $H_2S$.

***CONCRETE ABRASION BY ICE***
(Arctec Canada Limited, Kanata)
A test procedure has been developed which enables the wear rate of concrete subjected to impact and abrasion by ice to be evaluated. Rotating concrete cylinders are subjected to impacts and abrasion by ice at freezing temperature. Parameters which may be varied include the concrete mixture proportions, ice type, and test temperatures, as well as ice impact force and frequency. The apparatus has been built and a series of tests carried out on concrete mixtures similar to those proposed for use at Hibernia.

***ICE-BUCKLING EVENTS***
(G.W. Timco, MECH/NRC; N.K. Sinha, IRC/NRC)
A short test series has been performed to investigate the buckling of thin freshwater ice sheets. The buckling loads were measured using a dynamometer platform, and an array of eight DCDTs was placed on the ice cover to record the deflections of the ice during the buckling event. Immediately prior to the ice failure, the maximum amplitude of the ice buckle was approximately one-half of the ice thickness. The measured buckling loads were slightly higher than those predicted using Sodhi's buckling model.

***GULF ICE-DYNAMICS PROJECT***
(B. Wright, H. Iyer, K. Woolner, Gulf Canada)
In the spring of 1986, Gulf Canada documented a series of multi-year ice interactions aboard the Molikpaq drilling platform in the Beaufort Sea. The Molikpaq, a bottom-founded steel drilling caisson with a sand core, was positioned on a berm performing delineation drilling at the

Amauligak I-65 location, when a large-scale intrusion of multi-year ice moved into the Beaufort Sea drill area and resulted in several interactions with multi-year ice ranging from 3 m to 12 m thick. These interactions, which occurred over periods ranging from several minutes to several hours, were characterized predominantly by pulverization of the multi-year ice against the near-vertical-sided caisson, and resulted in very high global ice forces. The response of the structure to this pulverized ice failure was highly dynamic and a variety of sensors, including accelerometers, strain gauges and piezometers, measured this response at frequencies up to 50 Hz.

Gulf Canada has initiated a Joint Industry Program to perform a detailed analysis of these dynamic events in first-year and multi-year ice. This analysis will include the simulation of the observed ice-pulverization failure mode, using a discrete element computer model. Also a fast Fourier Analysis will be conducted to extract forcing functions from structural response for various events. Ice interaction models will be developed and measured response used to verify them. The importance of key ice parameters to dynamic response, including failure mode, thickness and drift speed, will be investigated. One of the mandates of the project is to develop dynamic design spectra that can be used in future design of offshore structures.

### *MEASUREMENTS OF THE PROPERTIES OF ICE RUBBLE*

(K.R. Croasdale, Calgary, Alberta)

Ice rubble, both in the Arctic around a drilling island, and in a large outdoor test basin, was studied to measure refreezing rates and consolidation thicknesses. In addition, a large-scale vertical loading test was conducted on grounded ice rubble in the test basin. The test results were compared with analytical predictions.

### *ICE - PHYSICS, MECHANICS AND ENGINEERING*

(R. Frederking, V.R. Parameswaran, M. Sayed, N.K.Sinha, IRC/NRC)

Static forces and vibrations on the lightpier at Yamachiche bend, caused by floating ice on the St Lawrence Seaway, were measured and the results analyzed. Software and hardware for automatic recording of the forces and vibrations, using a micro-computer, have also been developed.

Forces developed during ice break-up in the Ottawa River were measured, using a special frame built on the Minto Bridge. Laboratory strength tests on multi-year ice were completed. Behaviour of the Ottawa/Rideau River ice cover under heavy loads during the Winterlude 1986 was studied.

A borehole jack has been designed and built for in-situ testing of ice covers. Field and laboratory tests and in-situ borehole jack tests were carried out in multi-year ridge ice and floe ice, which showed the same rate sensitivity of strength as first-year ice. Tensile tests of large ice samples were carried out on a close loop machine. First-year sea ice was tested in the laboratory as well as in situ, using a borehole jack.

An apparatus has been designed and built to test stiffness of the foundations of structures to resist ice forces. Experiments on ridge formation and rubble freezing were done in the ice tank in the Hydraulics Laboratory of NRCC. Mechanical properties of model ice rubble were studied.

Adfreezing strength of saline ice to wood piles was measured in the laboratory at $-10\,^{\circ}C$.

Field measurements of ice forces at Nanisivik were carried out.

Acoustic emission studies associated with deformation and fracture of first-year sea ice have been carried out.

Strength of multi-year ice as a function of temperature and strain rate has been studied under uniaxial and biaxial loading.

Theoretical and experimental investigations on the rate sensitivity of Poisson's ratio of isotropic and anisotropic freshwater and sea ice have been carried out.

### *IMD ICE TANK*

(S.J. Jones, IMD/NRCC)

After one year's operation we have successfully completed a number of projects. Some initial problems with the EG/AD/S model ice have been resolved, mostly by installing a water filtering system, and the ice properties are not consistently uniform and as described by Timco (1986) (*Cold Regions Science and Technology*, 12: 175-195).

### *LOUIS S. ST LAURENT MODEL TESTS*

(D. Spencer, IMD/NRCC)

An extensive set of model tests was undertaken for the Canadian Coast Guard with a 1:15 scale model of the *Louis S. St Laurent*. The original bow, plus two new proposed bow forms, were examined. Resistance tests in ice were completed in December 1986, self-propulsion tests will be conducted in March 1987.

### *EFFECT OF FRICTION ON ICE RESISTANCE*

(F.M. Williams, IMD/NRCC)

Model tests of the M.V. *Arctic* with different ice/hull friction coefficients were conducted in February 1987 for Melville Shipping Ltd. Three models were built, at a scale of 1:30, with different surface finishes. The effect of friction on ship resistance in ice will be determined.

### *ARCTIC FIELD TRIP*

(B. Parsons, IMD/NRCC)

A field trip to Resolute Bay, N.Y.T., is planned for April 1987 to examine the fracture properties of first year sea ice.

*DYNAMIC ANALYSIS OF THE MOLIKPAQ*
(J.P. Nadreau, C-CORE/MUN)
A preliminary study of the dynamic behaviour of Gulf's Mobile Arctic Caisson (the Molikpaq) was undertaken. The Molikpaq had been instrumented with various transducers in order to monitor the behaviour of the caisson and the berm continuously. The first task of the study was to identify interesting data sets from the huge amount of available data. Spectral analysis was performed on the selected data in order to provide the type of frequencies at which the structure would vibrate.

*INDENTATION TEST*
(J.P. Nadreau, C-CORE/MUN)
The program consisted of small-scale tests, for which indentors were driven into the ice. The tests were set so that the indentation would create a 3-D stress field without being influenced by the boundary conditions. The spherical indentors were kept under 10 cm in diameter and the speed of advance around 1 mm/s. Special attention was given to the behaviour of the ice, the crack patterns, the amount and the thickness of the layer of crushed ice and the eventual crystallographic modification of the ice.

*KAUBVIK CAISSON RETAINED ISLAND PROJECT - RUBBLE/STRUCTURE INTERACTION*
(I. Jordan, MUN; J.P. Nadreau, C-CORE/MUN)
The project focused on:
(a) monitoring ice loads on the caissons and foundation response;
(b) measuring the dissipation of ice pressures along a radial line within the grounded ice rubble;
(c) installing stress sensors outside the grounded rubble in the area of landfast ice and a strain meter in the rubble field;
(d) characterizing grounded rubble including freeze back (thickness of frozen layer), degree of grounding, ice strengths and temperature profiles;
(e) analyzing measured ice loads, including the influence of ice rubble on loads. This task includes development of analytical models and the comparison with the field results.

*HIGH-DENSITY AMORPHOUS ICE, NEUTRON DIFFRACTION*
(M.A. Floriano, E. Whalley, CHEM/NRCC; E.C. Svensson, V.F. Sears, NSSP/AECL)
The high-density amorphous ice that is made by "melting" ice I at 77 K and 10 kbar has been studied by neutron diffraction. The pair distribution closely resembles that of the liquid, except that it is sharper because of the lower temperature.

*ICE Ih AND Ic, NEUTRON DIFFRACTION*
(M.A. Floriano, D.D. Klug, E. Whalley, CHEM/NRCC; E.C. Svensson, V.F. Sears, NSSP/AECL)
The neutron powder diffraction pattern of $D_2O$ ice Ic and Ih, when converted to the structure factor and Fourier transformed to real space, shows directly for the first time that the actual O-D distance in ice I is 0.986 ± 0.003 or 0.004 Å. The standard crystallographic value of 1.01 or 1.02 Å is too big, because of the orientational disorder.

*HIGH-DENSITY AMORPHOUS ICE - RAMAN SPECTRUM*
(O. Mishima, D.D. Klug, E. Whalley, CHEM/NRCC)
The Raman spectrum of $H_2O$ and $D_2O$ high-density amorphous ice, each containing small amounts of HDO, and of the lower-density phases made by controlled heating, have been obtained. The spectra of uncoupled O-H and O-D groups have been used to learn about the distribution of hydrogen-bonded O--O distances of several phases.

*ICE I, DIPOLE-MOMENT DERIVATIVES*
(D.D. Klug, E. Whalley, CHEM/NRCC)
The relative absorption intensity of the coupled vibrations of an O-D---O-D pair isolated in $H_2O$ ice as measured by others, shows that the dipole-moment derivative is directed along the O-D--O bonds within the experimental uncertainty.

*ICE V AND VI, ORDERED FORMS*
(Y.P. Handa, D.D. Klug, E. Whalley, CHEM/NRCC)
Ice V and VI, with considerable order in the hydrogen positions, have been made by doping the ices with potassium hydroxide. The degree or order has been measured calorimetrically and the nature of the order is being elucidated.

*PROBABILITY-BASED DESIGN CRITERIA AGAINST ICE LOADS FOR FIXED STRUCTURES IN THE BEAUFORT SEA*
(M. Nessim, M. Maes, DnV(Canada) Limited)
The study considered winter, break-up and summer seasons, and the load scenarios included level first-year ice, first-year ridges, and multi-year floes/ridges with or without pressure from surrounding peak ice. A variety of input parameters probability distributions can be used and extremal analyses combined with ice- structure interaction models to give extreme annual load distributions. An interactive computer package (BOREAS) was developed to carry out the analysis.

*STATISTICAL ANALYSIS OF THE BEAUFORT SEA COMPUTERIZED ICE-SCOUR DATA BASE*
(M. Nessim, M. Maes, DnV (Canada) Limited)
This covered studies of individual scour parameters, as well as inter-relationships between parameters. The effect of environmental factors such as location, water depth and sediment type on scour parameters such as depth, width and orientation were

also assessed. Probabilistic and extremal modelling was undertaken to produce environmental descriptors applicable to engineering problems. Areas for future research were identified.

### *DAMAGE MECHANICS OF SEA ICE AND KINEMATICS OF CRUSHED POWDEROUS ICE*

(M. Nessim, M. Maes, DnV (Canada) Limited)
A constitutive model for the progressive damage of ice was developed. This model was implemented in the FE program Abaqus and is applicable to compressive stress states in which progressive microcracking causes isotropic shear stiffness degradation. The possibility of residual shear strains upon unloading was also included in order to represent combined microcracking and creep. An incompressible slow viscous-flow model was successfully used to model the behaviour of pulverized ice.

### *ICE/STRUCTURE INTERACTION WITH ICE CONTAINING FLAWS*

(G.W. Timco, MECH/NRC)
A test series has been carried out to investigate the effects which flaws or cracks in ice have in an ice/structure interaction event. The tests were performed using freshwater ice in the ice tank at NRC Ottawa. The results indicate that there can be significant reduction in the load imposed on a structure by ice containing even a few long flaws. The results are correlated using an elementary damage model.

## PERMAFROST/GROUND ICE/GAS HYDRATES

### *GROWTH OF NALEDS/FREEZING OF SOILS AND SLURRIES/ICE DAM*

(G.S.H. Lock, MECH/UofA)
A preliminary experiment on naled formation has been undertaken in cold-room facilities. Observations indicate a complex, three-dimensional formation and growth process depending upon substrate temperature, air temperature, water temperature, and water-flow rate.

A microscope has been fitted with a cryostage to study ice growth and decay in slurries. Preliminary observations reveal considerable movement in the interparticulate water during freezing, but it is too early to draw firm conclusions. Systematic study of soils will be undertaken for a range of cooling rates.

Work on the Built Ice Veil Assessment (BIVA) project continues. A preliminary study of cold-water flow through a row of closely spaced cylinders has been completed. Results indicate unusual flow behaviour brought about by instabilities with respect to certain flow regimes.

### *DEVELOPMENT OF FIELD-TESTING METHODS FOR MEASURING RHEOLOGICAL PROPERTIES OF FROZEN SOILS AND ICE*

(B. Ladanyi, J.R. Murat, P. Huneault, Ph. Talabard, CINEP/UofM)
This on-going project, which includes the improvement of existing field-testing methods in permafrost, and the development of new ones, has seen some important advances during the past year, both in theory and in practice. In the former, new theories for the interpretation of borehole dilatometer relaxation tests and deep cone penetration tests, respectively, have been developed. In the latter, a new borehole test for creep testing of ice and frozen soils has been developed and tested in the laboratory.

### *BEARING CAPACITY OF PILES IN FROZEN SOILS*

(B. Ladanyi, A. Foriero, A. Thériault, CINEP/UofM)
After completing the study of the behaviour under axial load of slurried shaped piles in permafrost, attention was turned to the problem of permanence of lateral adfreeze strength in driven piles, taking into account the variation of lateral ground stresses with time, and eventual healing of ice bond. In addition, a complete analytical solution for stress redistribution with time in long, axially loaded piles embedded in permafrost was obtained. An experimental and theoretical study of laterally loaded piles in permafrost is presently underway.

### *FREEZING/THAWING/FROST HEAVE*

(T.H.W. Baker, L.E. Goodrich, G.H. Johnston, J.H.L. Palmer, V.R. Parameswaran, O.J. Svec, IRC/NRCC)
Field measurements of the electrical potentials developed during freezing and thawing of ground were completed at Inuvik.

Electrodes and thermocouples were also installed in a pingo near Tuktoyaktuk, N.W.T., to study the fluctuations of the ice lens at the base of the pingo. (This work is being carried out in collaboration with Professor J. Ross Mackay of UBC.)

Laboratory studies on frost heave are continuing in order better to understand the complex processes of heat and moisture migration during heaving. These results are used in the development of an advanced design of road beds for avoiding damage due to frost heave. A project to evaluate the potential use of oil to reduce frost heaving has begun.

### *PILES IN FROZEN SOILS*

(T.H.W. Baker, L.E. Goodrich, G.H. Johnston, J.H.L. Palmer, V.R. Parameswaran, O.J. Svec, IRC/NRCC)
Equipment has been built to conduct pull-out tests on small-scale piles in the laboratory in frozen soils and ice. Four full-scale pipe piles have been installed on NRC property to study

their modes of vibration under impact and alternating loads. Static and dynamic tests on piles frozen in sands and clays were studied, and the effect of dynamic loads in accelerating creep was demonstrated. Automatic logging of data from ongoing tests in the laboratory, using a desk-top computer, was developed. Penetration tests have been done in frozen soils and ice, using small-scale penetrometers.

***FOUNDATION TEMPERATURE MONITORING***

(T.H.W. Baker, L.E. Goodrich, G.H. Johnston, J.H.L. Palmer, V.R. Parameswaran, O.J. Svec, IRC/NRCC0

Ground- temperature measurements and observations were continued in a naturally vented duct-cooled foundation of the water-treatment plant and the main supply building in Alert, N.W.T. Instrumentation was installed in the new firehall at Alert to monitor the performance of its foundation, which is cooled by heat pipes. Advice and assistance were provided to the Department of National Defence in the preparation of specifications for construction of foundations for satellite dishes at eight sites along the DEW line, and in installing test piles for proof-loading.

Evaluation of monitoring data obtained for the foundation (maintained at subzero temperatures by thermosiphons) of a maintenance garage at Baker Lake, N.W.T., is being carried out for the Ministry of Transport. Installation of ground-coupled heat pumps to cool the foundations of some future buildings to be constructed in permafrost areas is also being planned. Evaluation of several new devices for measuring thermal conductivity of soils has begun and development of a new finite-element procedure for phase-change problems is underway.

Studies on the use of wood chips as insulation material to protect slopes in permafrost areas are underway along the Norman Wells to Zama oil pipeline. Instrumentation was placed in the wood-chip insulation on a slope at Canyon Creek to monitor the long-term thermal performance.

The projects on weekly ground-temperature measurements at the Inuvik Airstrip, and an insulated road along the Mackenzie Highway (NWT), Dempster Highway (YT) and Eagle River Bridge foundation, have been terminated and monitoring of all instrumentation discontinued. The data collected from these studies are currently being analyzed.

## ANY OTHER GLACIOLOGICAL WORK

***HIGH RUNOFF FJORDS - SUITABILITY FOR SALMON NET PEN FARMING, B.C.***

In 1986, the success of Norwegian salmon farming created an "avalanche" of applications for salmon net pen farm sites along the similar fjord-indented coastline of British Columbia. The most critical fjords are the Portland Canal – Observatory Inlet area to the north of Prince Rupert, and the Dean–Burke Channel system to the west of Bella Coola. Both areas have large icefields at their heads and both are periodically disrupted by jokulhlaups emanating from Summit and Ape Lakes, respectively. With the Portland Canal system the scant oceanographic data, coupled with the spotty river hydrograph records, were examined to determine the possible duration, steadiness, and depth of the dilute zone. Until further measurements are carried out, it is recommended that salmon farming should not be undertaken as a commercial venture.

In the case of the Burke–Dean Channel area, the Ape Lake jökulhlaup was monitored by aerial photography (black-and-white), but because the event occurred during the high-runoff season this technique was not totally successful. Further, for days after the event, up-inlet winds tended to hold up the down-inlet diffusion of diluted, turbid water. Future work is still in the planning stages.

***ICE-DAMMED LAKES - YUKON TERRITORY***

(J. Schmok, G.K.C. Clarke, GPHYS/UBC)

In 1984 and 1985 J. Schmok visited 23 small lakes and ponds situated within the basin of the formerly glacier-dammed Lake Alsek. Cores from these lakes contain a record of past fillings and outburst floods from Lake Alsek. From the sedimentology of these cores, three distinct environments can be recognized: (1) Lake Alsek phase (varved silts and clays); (2) Lake Alsek flood deposits (sands and gravels); (3) Normal (organic horizons). This sequence is repeated many times within a single core. Schmok has recently completed an MSc thesis on the sedimentology of these cores and the implied lake-filling chronology.

***ASPEN - ARCTIC SHIPPING PROBABILITY EVALUATION NETWORK***

(Arctec Canada Limited, Kanata)

ASPEN is a risk model for Arctic shipping. Environmental, navigational, routing and structural factors are combined to calculate the probability of structural damage to a ship due to collision with floating ice in the Canadian Arctic. The system makes use of a large database and algorithms developed over many years of field trials and numerical modelling. The program is used by the Coast Guard as part of the regulatory decision-and review-process.

J-P Nadreau

# UK

## BRITISH ANTARCTIC SURVEY, 1986-87

### *ICE CORES AND CLIMATE*

Studies on ice cores drilled from the Antarctic Peninsula region are developing the geochemical record of past climate preserved in the ice sheet. Dr D.A. Peel has studied the isotopic record of two cores spanning the past 50 years, one from Dolleman Island and the other from Palmer Land. The samples were prepared by B.M. Davison and analysed by the Geophysical Isotope Laboratory of the University of Copenhagen. The records have improved our knowledge of the relationship between the stable-isotope composition and air temperature. Such studies take advantage both of the lengthy instrumental records available locally, and ice-core profiles which can be dated easily. The results have highlighted the problems associated with isotopically deduced temperatures, which can only be derived for periods of snowfall. A correction factor of the order 40% is indicated; a similar correction may be required to interpret ice-core records from large areas of West Antarctica.

Future plans include proposals to drill deeper at sites chosen to represent the principal climatic zones. J.C. Moore undertook shallow drilling to 40 m depth and a reconnaissance site survey at two potential drilling sites on the Palmer Land plateau. It is hoped to identify a site suitable for drilling to around 500 m depth, where a record up to 2000 years long can be expected. Subject to US funding, an important collaborative BAS/USAP project is destined to undertake the drilling, detailed site survey and ice-core analysis.

### *TEMPERATE ICE SHELVES*

The effect of global warming on the ice shelves fringing the Antarctic continent is one of the most important aspects of the study of the potential impact of climatic change. A warming climate (dramatically evident over the last five years in the Antarctic Peninsula) has its greatest glaciological effect where summer temperatures exceed 0 °C. This is because summer melting leads to albedo changes which then encourage further melting. When melting is sufficient to warm a floating ice shelf to around 0 °C it may become warmer than the sea water in which it is floating. Dr J.G. Paren and S. Cooper are investigating the thermal regime of such a temperate ice shelf: the northern part of George VI Ice Shelf to the west of the Antarctic Peninsula. Dr K.W. Nicholls and M.H. Talbot are studying the sea beneath the ice shelf and the oceanography of the surrounding waters. Both glaciological and oceanographic inputs are needed in the modelling of the region. The aim is to produce estimates of the melt rates over the entire ice shelf, and an understanding of the physics of the processes which control them.

### *DYNAMICS OF THE ANTARCTIC ICE-SHEET SYSTEM*

One of the important consequences of increased melting of the Antarctic ice shelves would be an increase in the discharge of grounded ice into the sea, thus raising sea level. Understanding how the forces which restrain ice-sheet flow would react to changing boundary conditions and what implications this would have for the total ice volume is a problem of global significance. Dr C.S.M. Doake has led the group investigating all the active elements in the ice-sheet system (the inland ice sheet, outlet glaciers and floating ice shelves) to produce a coherent account of the interactions between the different parts.

Survey stations have been established on the Ronne Ice Shelf and the Rutford Ice Stream by A. Jenkins, R.M. Frolich and D.G. Vaughan. The velocity and strain-rate data obtained from this network are being analysed with the help of D.R. Mantripp to see how the various forces acting both to drive and restrain Rutford Ice Stream vary with distance from the ice-shelf junction. D.G. Vaughan and H. Corr radio-echo sounded the Rutford Ice Stream and are using the data in conjunction with surface topography obtained from satellite images to decipher the physical mechanisms that control the movement of a fast-flowing glacier over its bed.

### *DIELECTRIC STUDIES AND CHEMICAL STUDIES ON THE DOLLEMAN ISLAND ICE CORES*

J.C. Moore has developed a system for the rapid dielectric profiling of ice cores in the range 20 Hz – 300 kHz. He has acquired a continuous dielectric record for the 113 m long Dolleman Island ice core at a discrimination better than five samples a year. The data, after extrapolation to higher frequencies, show variations in permittivity and conductivity which intimately determine the propagation, absorption and reflection of radio-echo pulses at the site. Chemical and isotopic analysis is being undertaken to establish correlations between the dielectric behaviour and other stratigraphic parameters.

Dr R. Mulvaney has analysed the ice core for the major anions, $Cl^-$, $NO_3^-$, and $SO_4^{2-}$, to assess their potential as indicators of past climate. Chloride, which is almost entirely associated with sea salt, shows a clear annual cycle with a maximum concentration in the later summer/autumn snow. Sulphate too shows a particularly clear seasonal cycle, with a maximum concentration during the late summer. This finding, together with the observation by A. Reid that most of the sulphate is present as un-neutralized sulphuric acid, suggests that a significant part of this

species is derived from photochemical oxydation of sulphurous gases derived from biological decay in the ocean. The clear cycle in sulphate will allow its future use as a reliable stratigraphic marker for precise dating of ice cores from the region.

*GLOBAL POLLUTION*

Highly refined techniques developed by E.W. Wolff have allowed the first reliable measurements of a range of heavy-metal elements in modern Antarctic snow. The measurements suggest that pollution may be responsible for up to 90% of the present lead content of Antarctic snow. Measurements made on snow collected by D.A. Peel in Greenland show much higher levels of cadmium, copper, lead and zinc than are found in Antarctic snow. This reflects the predominance of pollutant emissions in the Northern Hemisphere. Pioneering studies by Dr A.L. Dick in the Antarctic Peninsula have also investigated the processes involved in the scavenging and deposition of chemical components of the atmospheric aerosol. There is evidence that marine components are preferentially deposited compared with crustal dusts and that removal of the sulphate aerosol is least efficient.

J.G. Paren

# USSR

## SOVIET GLACIOLOGICAL RESEARCH IN 1986

In 1986 glaciological research was carried out in the Caucasus, Central Asia, the Khibiny Mountains, Siberia and the Far East, Kamchatka, and in the Arctic and the Antarctic.

In 1986, at the meeting of the editorial board, the final version of the *World Atlas of Snow and Ice Resources* was confirmed, and the material for the *Atlas* was passed on to a map enterprise in Kiev to be prepared for publication. At the **Institute of Geography of the USSR Academy of Sciences** a systematic approach was applied during work upon the *Atlas* which made it possible to work out the principles of drawing maps of nival-glacial systems situated in different latitude zones. New information about seasonal and multi-year ice in different regions of the globe was obtained.

A hydrodynamic model of "sea" glacial cover was created which describes the instability of glaciation of such a kind with regard to the dynamic interaction of its components, first of all "sea" shields and shelf ice. An original idea of self-organization of ice movement in the ice sheets was put forward which made it possible to explain the origin of their glacial flows and to describe their thermal regime.

At **Kazan University**, jointly with the **Arctic and Antarctic Institute**, numerical modelling of quasi-stationary processes of heat-mass transfer in the ice sheets of East Antarctica over the main sectors of ice flow was carried out. Changes in such characteristics as ice flow at the bed, the distribution of ice-flow speeds and the temperature regime were analysed. The influence of glacier mass balance interacting with the sea upon its dynamics at different relief of bedrock was studied. The existence of unstable transitional processes was shown. Together with the **Institute of Geography of the USSR Academy of Sciences** and **Tashkent University** the dynamics of the Golubin and the Abramov glaciers were modelled numerically. Special attention was paid to the reconstruction of the relief of the bed of the Golubin Glacier and the analysis of the movement of Abramov Glacier, of which the period of pulsation is estimated at 25 years.

**The Institute of Mechanics of Moscow University** worked out a one-dimensional model of radio-locating heat physics of snow and ice which makes it possible to describe the peculiarities of the temperature regime of these media, taking into account their optical characteristics. A model explaining the heat physics of stratified freshwater–salt lakes of the Antarctic oases was created.

At the **Khabarovsk Complex Scientific Research Institute** of the **Far East Scientific Centre of the USSR** theoretical principles of glaciochemistry – the theory of cryogen metamorphization of the chemical composition of natural waters and the theory of the formation of the chemical composition of snow and glaciers – were worked out. Information about distribution of soluble matter while melting was summarized. Mathematical models of distribution of matter between ice and water while melting were worked out. The role of ice formation and melting in geochemical processes and the cycle of matter on the Earth was estimated.

**The State Hydrological Institute** suggested methods for the determination of the physical parameters of snow while using different means of snow retention. A model of the processes of snowmelt, water yield from snow and infiltration of water into the soil was worked out.

*STUDY OF GLACIERS*

The **Institute of Geography of the USSR Academy of Sciences** investigated the stability and instability of the global mass exchange of glaciers. The probable analysis of the results of measurements at the base glaciers of the Earth showed that the cause of glacier runoff fluctuations and glacier mass budget is of macrosynoptic origin, which is the cause of redistribution of the volume of water flow

between the outer area, i.e. into the ocean (119 mln km$^2$), and the inner closed drainage area (30 mln km$^2$). In connection with such asynchronism the glacier runoff, in contrast to the river runoff, has a regulating capacity on a global scale which makes special demands on monitoring as well as on conservation of the snow–ice resources of the Earth.

No clear-cut pattern of mass changes was determined in different parts of glaciers subject to the same weather conditions in the continental climate with the summer peak of precipitation which is typical for the whole inner and east Tyan'-Shan', the Himalayas and Alaska. In the summer months a speeded-up increase of the mass of glaciers takes place in the upper parts, while the lower parts are melting intensively. On the Sary-Top glacier some peculiarities of superimposed ice formations were exposed during the period of ablation. The results of many years' work on the glaciers of the Polar Urals were summarized, the great changeability of their mass exchange being connected with instability of macrosynoptic processes in the small range of altitudes where they are situated.

The **Institute of Geography of the KazSSR Academy of Sciences** analysed the data on the fixed mountain-glacial basin Tuyuksu in the Zailiyskiy Alatau. The maps of the components of the outer mass exchange of the Middle Tuyuksu glacier were drawn up, and the water–ice balance was estimated from indexes compiled over many years. Ice resources at the Dzhungarskiy Alatau were calculated on the basis of materials from aero- and surface radio-sounding. According to the field computer processed observation maps of the components of the outer mass exchange of the Shumskiy glacier were drawn up. Maps of the quasi-stationary characteristics of the inner mass exchange of the Shumskiy and Muravlev glaciers were drawn up using the computer.

The **Tyan'-Shan' Physical-Geographical Station** continued research in the basin of the Akshiyrak river, where the lack of moisture has a negative influence on the glacier mass balance. In 1986, as well as in previous years, the mass balance of the glacier under investigation was negative and the directed retreat of the glacier tongue and the expansion of non snow-covered areas in the basin are evidence of it. The volume of glacier runoff of the Sary-Dzhaz river basin, equal to 1.6 milliard m$^3$, was calculated. It was established that despite the steady reduction of glaciation the total runoff of the Issyk-Kul' region rivers and the central Tyan'-Shan' is not decreasing at present.

In the Altay, **Tomsk University** applied for the first time the method of radio-sounding in winter conditions. They showed the bed profiles of the tongues of the Malyy, Pravyy and Levyy Aktru glaciers and the areas of alimentation of the latter glacier, where a maximum thickness of ice equal to 160 m was established. The thickness of the tongue of the Pravyy Aktru glacier below icefall is 101 m. In the Aktru basin precipitation deficit was noted in the period of accumulation, while during the ablation period the amount of precipitation was considerably more than the norm; here the volume of runoff was 30 mln m$^3$, and the part of the glacier runoff which equals 42% corresponds to the average multiannual data. The temperature regime was also near the average multiannual one. The mass balance of the glaciers of the basin has been positive since 1983.

In the Caucasus the **Institute of Geography of the USSR Academy of Sciences** carried out research in order to provide a comprehensive analysis of the interconnection of glaciers with the lithosphere and atmosphere. Concrete information was obtained about different aspects of the mountain glaciers' existence which makes it possible to establish different connections between glaciers and the atmosphere.

The **Institute of Geography of the USSR Academy of Sciences** carried out meteorological and hydrological research on the Adish glacier, on the south slope of the central Caucasus. A structural–tectonic and moraine survey of the glacier was carried out, and the velocity of deformation of glacial ice was studied. A repeated phototheodolite survey of the glacier surface was made at the beginning and end of the period of ablation.

At Kamchatka the **Institute of Volcanology of the Far East Scientific Centre of the USSR Academy of Sciences** sudied the glaciers of the Klyuchevskoy volcano, the calderas and summit craters of the Dal'niy Ploskiy (Ushakovskiy) volcano, the Erman and the Bilchenok glaciers, and the glaciation of the north slope of the Ploskiy Tolbachik volcano. According to the stratigraphical and isotope-chemical analysis, a temperature anomaly was found at the top of the Ushakovskiy volcano, confirming the considerable influence on the temperature regime of the region of a series of phreatic explosions in the Krestovyy groove on 2 December 1985. While investigating the glacier cover in the Gorshkov crater and its contact with the edge of the crater, the values of the velocity of the horizontal flow of ice were determined, the ice discharge of caldera-valley glaciers was evaluated and also the bottom ablation due to volcanic heat. Heat-balance at the top of the volcano was analysed, the specific heat-emission power with regard to solfatara activities and the consumption of power for the evaporation of snow-melt water were evaluated. The possible mechanisms of the influence of heat from the Kluchevskoy volcano on the dynamics of the glacier cover formed on it were isolated. Preliminary evaluations showed that the heightened phone heat flow on the slopes of volcanic structures plays the main part in these processes. It can determine the maximum thickness of ice cover, the intensity character of the erosion

activities of glaciers, as well as the regions of "downfall" of glaciers from the volcano slopes. Investigation of glaciers on the north-west slope of the Ostryy Tolbachik volcano showed their active state, which is apparently connected with present climatic conditions.

### *OBSERVATIONS ON FLUCTUATIONS OF GLACIERS*

The **Airspace Methods Laboratory of Moscow State University**, using photosurvey methods, has established a change in the state of the El'brus glaciers: after continuous retreat, with the highest intensity registered in the '60s, the Kukurtlu Glacier was found to be advancing in the middle of the '70s. A marked drop has been found in the rate of retreat of the Dzhankuat Glacier as compared with 1968-74. The field of annual velocity of ice movement on the surface of the Dzhankuat Glacier over 1985-86 was obtained using the photogrammetric method.

The **North Caucasian Board of Hydrometeorology and Environmental Control** identified the annual value of fluctuations of 32 glaciers on the northern slope of the central and western Caucasus. Twenty-nine glaciers retreated at a speed of 0.6-40.8 m per year, whereas 3 glaciers advanced 6-9 m per year. During the period of accumulation in 1985/86 the precipitation was less than usual, whereas the temperature during the period of ablation was 6-10% above the normal, as a result of which the glacier mass balance was altogether negative.

The **Institute of Geography of the USSR Academy of Sciences** continued to study and catalogue the fluctuating glaciers of the Pamirs. Two cycles of observation of the velocity of movement, and the morphology and structure of the surface, were carried out at the Medvezhiy Glacier, which showed that in the near future this glacier is not expected to surge.

The **Tadzhik Board of Hydrometeorology and Environmental Control** continued observations on the fluctuations of 19 glaciers. The change in the state of the ends of the glaciers and of their surfaces was assessed. It was proved that the glaciers were in a state of degradation or in a stationary condition.

The **Tyan'-Shan' Physical and Geographical Station of the Kirgiz SSR** continued observations on the Karabatkak Glacier. Despite the favourable humidification conditions as compared with the major part of the glacier of the Sary-Dzhaz basin it continues to reduce at a rate of 4-6 m per year. The glacier mass balance is steadily negative; in 1981-86 its value changed within the limits of 45–114 g/cm$^2$.

**Altay University** carried out observations on the condition of glaciers at Katunskiy, the northern and southern Chuysk mountain ridges and the Mongun-Tayga massif. The Altay glaciers continue to retreat even though the velocity of degradation has slowed down, and some high-altitude glaciers were in a stationary condition. Cirque-valley glaciers retreated 5–6 m during a year, whereas the velocity of retreat of the glaciers exposed to the south was much higher. For instance, in 1985 and 1986 the Gebler Glacier retreated 45 m. In the central mountain area the increment in the areas of the snow patches has been registered for the past five years.

**Tomsk University** measured the surface velocity of the movement of the Malyy Aktru glacier. In 1986 on average it was 0.2 cm/day more than in the preceding year, but at the end of the tongue it was twice less. Linear reduction of 9 glaciers at a speed of 9–25.6 m/year was established.

The **Institute of Geography of the KazSSR Academy of Sciences** carried out observations in Zailiyskiy Alatau on the fluctuations in the state of the front of the Bogatyr' Glacier, which is in a state of active pulsation. The data on the movement and fluctuation of the height of the surface of the right-hand branch of the Shokal'skiy Glacier, which is approaching the next surge, were analysed.

### *STUDY OF SNOW COVER, AVALANCHES AND GLACIAL MUD FLOWS*

**The Kazakh Board of Hydrometeorology and Environmental Control** carried out regime observations on snow cover and avalanches in the mountains of Zailiyskiy and Dzhungarskiy Alatau and in the western Altay. In the Zailiyskiy Alatau in winter months operative maps were compiled of the snow-cover thickness distribution and snow reserve values for comparison with the perennial ones. Efforts were made to unify the methods of forecasting the freshly fallen snow avalanches, avalanche hazard forecast maps were prepared and the territorial limits for using a forecasting formula were identified. The research revealed that for the purpose of unifying methods of forecasting avalanches of other genetic types it is expedient to follow a uniform methodological pattern in various regions of the country. Methods of background avalanche forecasting in mountainous areas of Kazakhstan, on the basis of a rated forecast formula, were tested using current meteorological data and their operative computer processing.

The **Institute of Geography of the Kazakh SSR Academy of Sciences** unified a statistical series of data on glacial mud flows in Zailiysky Alatau over 1930–1986. The basic factors of their origin were identified and a model of factor-causation of the glacial mud flows was developed. Direct research was done in representative basins of Dzhungarskiy Alatau and northern Tyan'-Shan'. The possibility of a quantitative inventory of the effect of local natural factors on the distribution of snow cover in the mountains was explored, and investigatory work was begun to assess the possibilities of using methods of identification of images (using computers) with a view to identifying the characteristics of snow capacity in the less

well-studied mountainous areas. The automated system for monitoring and forecasting glacial mud flows in the mountains of Zailiyskiy Alatau was introduced and charts of rivers liable to mud flow and arrangements for the protection of inhabited places against mud flow were prepared. A methodological manual on background forecasting of glacial mud flows was also prepared, and a map of specific expenditures for mud-flow protection arrangements was drawn up.

The **Novosibirsk Institute of Railway Transport** continued developing measures for the protection of roads under design, construction and operation in Siberia, Kazakhstan, the Far East, Far North and Central Asia against snow-drifts, avalanches, mud flows and wash-outs. Work was started on mathematical modelling of snow stability on the flat slope for the Baykal-Amur railway, and the effects of the snow–ice waves on structures were studied. New designs of snow-retention fences, filled with waste from the tyre-manufacturing industry, were developed and tested.

Recommendations were prepared for protection against snow drifts at a number of stations and the Urengoy-Yamburg railway.

The **Snow Avalanches and Mud Flow Problems Laboratory of Moscow State University** improved scientific and methodological principles for assessing avalanche and mud-flow hazards and for the selection of optimum protection arrangements. The complex of natural and technogenic factors determining the efficiency of avalanche-protection arrangements and structures was specified. The indices and methodology of quantitative assessment of the engineering-cum-geographic and economic efficiency of avalanche-protection arrangements and structures were improved. The relationship between the distance of ejection of water and snow floes and the morphology of the basin was studied. The results of registering seismic and electro-magnetic signals from the avalanches in the El'brus region and Hibin were summarized. A series of experiments in physical modelling of the air wave was carried out. The dependence of the recrystallization of snow on the density of water-vapour flow was studied both in the laboratory and in the field, and the role of stratigraphic heterogeneities in forming loosening and condensation strata. The adjusted models of heat and mass transfer in the snow mass were elaborated and put into practice numerically; the results of modelling agree well with the data of direct observations. The statistical inter-relation between the average density of the snow cover, the average perennial wind velocity and the number of days of snow was substantiated. A mathematical model of the social and economic development of a mountainous area, taking into account unfavourable and hazardous natural factors, was proposed.

The **Central Asia Institute** carried out snow-avalanche studies in the western Tyan'-Shan', the mountainous areas of Kamchatka, the Baykal-Amur and Amur-Yakutsk railway, and in the Magadan area. Methods for the daily forecast of avalanches of various types were elaborated for these areas. Experiments in the deformation of various types of snow were staged and rated characteristics obtained. A model of a reference book on snow cover in the mountains of the USSR, in which statistical characteristics of snow cover citing the Chirchik-Akhangaran basin as an example, was prepared.

At the **"Priroda" State Centre** maps on snow cover and avalanches in Kirgiziya, and mud flows in Kirgiziya and Uzbekistan, were prepared on the basis of data from space. They show the main passages of mud flows and the scale of their manifestation. In Uzbekistan about 5500 sections liable to mud flows, occupying 12% of the total area of the Republic, were identified. In Kirgiziya 80% of the territory is liable to mud flows, whereas 54.3% is liable to avalanches.

The **High-Mountain Geophysical Institute** elaborated methods for active influencing of snow-avalanche processes, and for forecasting avalanche hazards in the northern Caucasus. The conditions for the formation of snow-avalanches were studied on the basis of the information obtained by new technical means. The principles of snow stability on the slopes were specified, and an acoustic distance method of indicating the limits of loosening of snow cover was elaborated. A power unit was built to study mechanical and acoustic properties of snow.

The **Institute of Geography of the USSR Academy of Sciences (Siberian Department)** identified patterns of snow-cover distribution on the slopes of the Baykal and Barguzin ridges, and Khamar-Daban. Basic indices of avalanche activity were compiled with regard to altitude zones, taking slope orientation into account. Reasons and conditions for the formation of glacial mud flows were studied. Results of anthropogenic effects on the downfall and activation of snow collapse were assessed.

The **"Apatit" Combine** improved the imitation model of snow stability on the slopes. The relationship between the probability of avalanche formation and the length of the slope, its longitudinal curvature, and the parameters of the physical and mechanical properties of snow cover were assessed. Experiments were staged to search for people in avalanche deposits using biolocation methods.

### *PALAEOGLACIOLOGY*

At the **Institute of Geography of the USSR Academy of Sciences** the form, volume and outer mass-exchange of the glacial cover of

the Late Pleistocene in the north-east of the USSR and Central Asia was reconstructed. On the basis of bioindication methods the peculiarities of the regime and the dynamics of the glaciers of northern Tyan'-Shan' for the past thousand years were reconstructed. It was found that the limit of glacier alimentation during the minor glacial period was reduced by only 25–30 m.

**Tomsk University** improved methods of photoindication, which made it possible to elaborate a basic scheme of reconstructing the snow capacity of the Gornyy Altay and changes in it in the Late Pleistocene and Holocene. **Khar'kov University**, with the **Institute of Geography of the Kazakhstan Academy of Sciences**, studied the use of dendroindication methods in glaciological research. The methodology of reconstructing the level of the firn line with regard to annual tree-rings was elaborated, on the basis of which the levels of the firn line over 1549–1979 were calculated; the calculated values proved to be close to the actual ones.

The **Geocryology Institute of the USSR Academy of Sciences (Siberian Department)** prepared a chart of the cryogenic structure of Upper and Middle Pleistocene sediments of high-mountain Tyan'-Shan'. The data confirmed the assumption about the stability of geocryological conditions in the area in the Holocene and the considerable warming up during the latest Interglacial.

The **Institute of Geology of the USSR Academy of Sciences, Moscow State University** and the **Productional Scientific Research Institute of Engineering Constructions** studied the palaeoclimatic and palaeocryological regimes of western and north-eastern Siberia. The principles of stratigraphic partition and comparison on the basis of variations of $\delta^{18}O$ in stratum and polygonal ice-veins were worked out. The inter-relationship of the Late Holocene glaciation in Spitsbergen and changes in the glacioclimatic conditions of forming glaciers was studied.

### *STUDIES OF RIVER AND SUBTERRANEAN ICE AND ICINGS*

The **Institute of Geography of the USSR Academy of Sciences (Siberian Department)** summarized the materials of field research into the effects of icing and icing processes upon the structure and dynamics of vegetation cover. It was proved that icing phenomena play an active ecological role. Not only do they change the floristic structure of plants, but they result in the change of vegetation communities to the extent of their complete annihilation. The photoindication characteristics of ice-massif development which were found, were recommended for assessing the hazard of icing when carrying out surveys for the construction of routes of linear structures. While conducting complex research into the peculiarities of ice-forming and the winter regime of the rivers of eastern Sayan, the patterns of formation of the ice cover of mountain waterways were discovered, and the nature of the relationship of this process with hydrometeorological conditions, the hydrographic structure of the river network and the hydraulic-morphometric peculiarities of a river channel.

The **Mechanics Institute of Moscow State University** completed the computation of the geocryological regime of western Siberian soils. Programmes for the calculation of the soil-heat condition using computers were introduced, which are used to make recommendations when conducting surveys for construction in the northern parts of western Siberia.

The **Productional Scientific Research Institute of Engineering Constructions**, with the participation of **Moscow State University**, the **All-Union State Institute of Geology** and the **Moscow Geological Prospecting Institute** prepared maps showing the spread of the processes of heaving, thermokarst, thermal erosion, solifluction, icings and perennially frozen grounds in the territories of the USSR. An assessment of territory is also provided according to the extent of the hazard of each enumerated phenomenon, as well as the temperature at the depth of base of bed of its annual fluctuations and distribution over the area.

At the **Cryology Institute of the USSR Academy of Sciences (Siberian Department)** new data were obtained on the occurrence, morphology and temperature of perennially frozen rocks in Siberia. Subterranean ice complexes were discovered in the zone of the future water reservoir in northern Yakutiya.

The **State Hydrological Institute** studied ice dam and jam formations, the distribution of ice thickness at the lower Ob', the lower Irtysh, regulated sections of the western Dvina and the Volga rivers, and Kazakhstan rivers and the BAM zone. The methodology of calculation and the forecasting of maximum dam and jam water levels was elaborated. The fourth edition of the *Icing Catalogue of the BAM Zone*, providing detailed information on 3000 icings of subterranean waters, is ready for publication.

### *THE ARCTIC*

The **Arctic and Antarctic Institute** continued meteorological and glaciological observations in the accumulation zone of the Vavilov Ice Dome on Severnaya Zemlya. Snow observations were carried out, and the accumulation of snow along the flow-line ice divide–outlet glacier was identified. On Kotel'nyy Island (the Novosibirsk Islands) samples were taken for oxygen-isotope analysis from polygonal vein ices of the Late Pleistocene and Holocene as well as from ice schlieren perennial frozen rocks.

**Leningrad University**, the **Institute of Geography of the USSR Academy of Sciences**, and the **Arctic and Antarctic Institute** carried out investigations at the ice dome of the Academy of Sciences on Komsomolets Island

of Severnaya Zemlya. In the upper part of the ice dome a borehole 560 m deep was drilled, actinometric and meteorological observations were conducted, and ice-forming processes and the temperature regime of the glacier were studied. It was proved that the transformation of firn into ice is being completed at a depth of 35–40 m. A considerable negative gradient was found in the glacier mass, the temperature goes down from -11.2 to -14.8 °C at a depth of 160 m. An isothermal 40 m layer is found at a deeper level, while at a depth of 560 m the temperature goes up to -10.3 °C. According to preliminary evaluation the age of the lower part of the drill core is two-and-a-half to three-and-a-half thousand years. All this time at the glacier cold firn ice was forming. During the past two centuries it was getting warmer, and at certain periods firn-ice formation was prevalent but the horizontal snow-melt water-flow was absent.

The **Institute of Geography of the USSR Academy of Sciences**, on the basis of a complex analysis of relic peat bogs from the central part of West Spitsbergen Island, reconstructed the palaeoclimatic conditions of the Sub-Boreal. A conclusion was reached about the changing of glacier size at various stages of the Sub-Boreal. The measurements of the mass balance of three standard Spitsbergen glaciers continued.

*ANTARCTICA*

The **Institute of Geography of the USSR Academy of Sciences** carried out investigations at the Filchner and Ronne shelf glaciers, and Druzhnaya-1 and Druzhnaya-2 bases. The temperature, snow and firn density were measured, and samples were taken for oxygen-isotope analysis. For the first time data on temperature distribution over the whole mass of the Filchner Glacier were obtained. Thermal physical analysis of this curve showed that in the marginal glacier zone, at its lower surface, melting at a rate exceeding 1 m/year takes place. The conclusion was reached that the shelf ice of Filchner Glacier receives alimentation mainly by accretion of ice from the internal areas of the Antarctic continent, while quick change of ice within the glacier mass, active movement of the front and recurrent large breaks at the edges take place. According to aerovisual investigations and interpreted images from space of the barriers of the Filchner and Ronne shelf glaciers, it became possible to ascertain the unusually strong deformations where these glaciers had fractured and to corroborate the previous prognosis of the possibility of their destruction. Cartographic and satellite data for the last 90 years on the location of the edge of shelf outlet glaciers of the Antarctic were analysed and for the first time the general picture of their fluctuations was obtained.

Palaeoglaciological reconstructions of the territory of the Amery mountain oasis were made. A unique profile of ancient moraines discovered in the cliffs above Lake Radok in the Prince Charles Mountains was described. It was established that the profile consists of ancient material extraordinarily seldom met with in the naturally occurring sediments of the Early Glaciation of the Antarctic, formed about 20,000,000 years ago in considerably different glaciogeomorphological conditions.

The **Institute of Geography of the USSR Academy of Sciences** and the **Arctic and Antarctic Institute** continued joint Soviet–French analysis of an ice-core sample from a borehole from Vostok Station, which made it possible to reconstruct variations in the thermal regime of East Antarctica for the whole climatic cycle. For the last 150,000 years fluctuations of average annual temperatures up to 10 °C were registered. Underlying the analysis of the thermal data there was a supposition that the epoch of the last glaciation began about 115,000 years ago in the high latitudes of the northern and southern hemispheres, while within the intertropical zone a fall of temperature only 70–80,000 years ago is registered. During the epochs of the fall in temperature the surface of central Antarctica was lower than at present by 200–300 m, because the rate of atmospheric alimentation decreased twice. It was proved in experiments that the general circulation of the atmosphere was more intensive in cold epochs, which resulted in the intensified accumulation of aerosol particles in Antarctic ice. The genetic relationship between the climatic changes and $CO_2$ content in the atmosphere was identified.

The **Arctic and Antarctic Institute** at Vostok Station carried out observations on impulse noises in a range of 250–1000 mH, and absorption in a glacier of the impulse signal with echo duration 10 for the purpose of studying the possibility of detecting radio measurements of nuclear and electromagnetic cascades in the continental ice of the Antarctic (the "Dumont" project). The technique of radio-location sounding of glaciers and measurements of annual snow layers are being improved. Data on the weakening of the radio-location signal when measuring the thickness of a glacier from the air at a height of 100–1000 m were received. The data from natural measurements of the velocity of electromagnetic waves passing in the snow were summarized.

In the area of Mirnyy Station observations were carried out on the content of 10 chemical ingredients of basic salt composition in atmospheric precipitation samples and snow cover from the surface. A short ecological description of the area was compiled. Measures for nature conservation now carried out in the Antarctic were examined. In the area of Molodezhnaya Station an experimental ice wharf was made by forming ice by freezing sea water, applying the method of water jets. The relationship between the

wharf and the atmosphere and the ocean was studied.

The **Leningrad Mining Institute** carried out work aimed at improving technical methods and drilling technology. The design of a borehole-sample cutter for taking ice samples for microbiological research directly from boreholes was improved. At the station a $CO_2$ sample was taken from a borehole 205 m deep in order to identify the absolute age of the ice mass, using the radiocarbon method.

The **Institute of Geology of the Estonian SSR Academy of Sciences** studied $\delta^{18}O$ variations in a glacier core sample 801 m long, covering nearly 4,000 years, from a borehole at Novolazarevskaya Station. A relatively stable climatic regime over that time period was identified. Seasonal $\delta^{18}O$ variations were well preserved along the whole core sample, which make it possible to define the average accumulation velocity as about 20 cm.

V.M. Kotlyakov
M.Yu. Gnedovskaya

## PROFILE

### THE POLAR SCIENCE CENTER UNIVERSITY OF WASHINGTON

Legend has it that Sidney Chapman visited the University of Washington in the mid-1950s to describe plans for the forthcoming International Geophysical Year. His talk apparently stimulated P. Church, in the Meteorology and Climatology Department, to initiate a project in polar meteorology. It may also have played a role in attracting R. Hubley away from the University to the nation's capital, where he was to have a hand in managing the U.S. arctic glaciology component of IGY. Church had had an interest in cold climates before this. He and R. Fleagle had worked on predicting minimum temperatures for Alaska, and Church had studied mountain drainage winds early in the '50s.

In fact, the University's interest in arctic work can be traced back two decades further. In the 1930s C. Barnes made oceanographic measurements in the Bering and Chukchi Seas. After serving in the North Atlantic ice patrol during the war, he returned to the University in the late '40s and continued his oceanographic exploration of the Chukchi, at times operating with dog sleds out of Point Barrow. When the Coast Guard ice breakers were establishing and maintaining the early warning radar sites in the '50s, Barnes was aboard making measurements. During the '60s, he and L. Coachman collected measurements from the East Siberian, Kara, Barents, and Laptev Seas.

The emphasis in sea ice studies can be dated to the start of the IGY with the establishment of a year-round meteorological program at Point Barrow. A research station on drifting sea ice was established as part of the IGY, and the University was represented there by F. Badgley, W. Campbell, A. Hanson, and others, including N. Untersteiner, who came from Innsbruck to participate.

An outpouring of scientific papers followed IGY which set the agenda for arctic research until the present day. Church and others began to accumulate an arctic climatology; Badgley wrote about the surface heat balance over ice and over water, and about aerodynamic drag. R. Reed and Campbell examined the wind driven drift of sea ice, and Campbell put forth a model to account for the mean drift pattern, in which he modelled the ice as a viscous material. At about the same time, Untersteiner documented the seasonal cycle of ice growth, and opened the way for the subsequent analysis he and G. Maykut wrote together.

In 1969 the University received an institutional grant from the National Science Foundation for science development. This grant supported the growth of the Quaternary Research Center, under A.L. Washburn's direction, and the establishment of an academic program in glaciology. Untersteiner had returned to the UW after IGY, and taken charge of Church's original Project Husky, which had been renamed Air-sea-interaction. He was one of the leaders in the new glaciology program. E. LaChapelle and C. Raymond joined the faculty at that time. Raymond has led this program for the past ten years or so. It has produced about a dozen PhDs and a similar number of MS degrees.

By the end of the 1960s there was a consensus in the small community of people interested in these things that the time was right for a major effort to improve the state of knowledge about the dynamics of sea ice. This was a time when there was increasing awareness of the importance of sea ice in the world climate, in part because of J. Fletcher's work, and of the likelihood that economic pressures might soon make routine transportation and operation necessary in a sea ice environment. It was also a time when scientific and logistic capabilities were expanding rapidly, making it possible to contemplate much more ambitious field experiments than had been possible a decade earlier. The development of aircraft with long range, and short take-off and landing capability, the proven ability to land cargo planes on sea ice, the use of helicopters in

the Arctic, a decade's experience with the operation of ice camps, improved arctic communications, all encouraged a new initiative in arctic research. Satellite navigation systems had been tested on Fletcher's Ice Island by K. Hunkins and shown to be capable of providing fixes more frequently and more accurately than had been possible before. The development of sonic anemometers, a new generation of instrumentation for current and hydrographic measurements in the ocean, the anticipated appearance of automated data acquisition systems which could operate unattended at remote sites for long periods of time, of satellite data links; all these promised a handsome scientific return on investment.

Out of this general optimism grew the Arctic Ice Dynamics Joint Experiment. The original stimulus came from W. Wittman at the Naval Oceanographic Office, who invited Untersteiner and Hunkins to draft a plan for a new arctic initiative. As enthusiam for the plan spread, Fletcher left the RAND corporation and came to the University to head the AIDJEX Project Office with support from the National Science Foundation. The Project Office was responsible for coordinating the planning and execution of the field experiments, and for the interpretation of the field data. The present Polar Science Center is traceable to the group which Untersteiner and Fletcher began to assemble for AIDJEX.

The University's glaciology program gave Untersteiner a pool of scientific talent to tap. The Science Development grant included support for visiting scientists. In the formative days of AIDJEX, J. Glen spent a year at the University, then W. Budd, and then J. Nye. Nye returned to the AIDJEX office several times over the next five years. Faculty from other University departments were attracted to the project. R.J. Evans, from Civil Engineering, had had a hand in S. Colbeck's thesis work on the Blue Glacier, and had collaborated with Untersteiner on the problem of thermal cracking in a floating ice sheet. M. Coon, also a civil engineer, had done a thesis on the bearing capacity of sea ice. Evans and Coon enlisted R. Parmerter from Aeronautical Engineering. E. Leavitt, R.A. Brown, and M. Albright, recent graduates of the Atmospheric Sciences Department, joined the group to work on the wind drag over sea ice. J.D. Smith, W. Criminale, L. Coachman, J. Newton, and M. McPhee from Oceanography, began or continued their work on ice-ocean problems.

Fletcher was sensitive to the logistic challenge of an experiment which eventually was to involve hundreds of field personnel, and half a dozen research stations, over a period of several years. He stole R. Bjornet and A. Heiberg from the Boeing Company to develop the logistic support for the experiment. R. Trowbridge came from within the University to provide administrative support.

P. Martin joined the project around 1970 to coordinate two crticial parts of the field experiment, the satellite navigation for monitoring the motion of drifting stations, and the automatic data buoys which were used to measure the atmospheric pressure field in the region of the experiment.

D. Rothrock, a fluid dynamicist, trained at Cambridge, in need of a job after a year teaching in India, signed up in 1971. A year or so later . Ling joined the group to beef up the theoretical work. R. Pritchard came from the University of New Mexico to coordinate the assembly of a new numerical model. R. Colony brought from Boeing his expertise as a numerical analyst.

The news of a new project spread fast through the Arctic community. Hanson, who had been on the ice in IGY, and on every ice camp since, showed up. A radio operator from Australia, a jumper from New Zealand, jacks of all trades from Norway, Sweden, Denmark, materialized when needed to expedite the field experiment.

Putting the experiment into the field presented many challenges. One has only to imagine the consternation of the customs officer who arrived in Barrow to find a fully loaded C-130 ready to take off, and an export declaration to sign for "4 ea. drifting ice stations for support of 15,000 man/days scientific research, valued at $2,200,000", or the helicopter pilot who realized too late that he was homing on a beacon in Tuktoyaktuk, not Barrow. There were other close calls: a helicopter burned up on the landing pad at ice station Blue Fox; the runway at Big Bear disintegrated, but just after the Twin Otter had taken off; heroes and novices got unexpected dunkings; a couple of cooks cracked up. But one cannot look back at the AIDJEX field experiments without wondering how so much was accomplished in such an environment without loss of life or serious accident. Blind luck surely was on their side, but the luck had been earned through years of arctic experience on the part of the personnel at the Naval Arctic Research Lab in Barrow, the Canadian Polar Continental Shelf Project, and many of the scientists.

During the same period, theoretical work was underway in the AIDJEX group, leading to the development of a new ice model. Although I do not recall anyone saying so in so many words, the modelling effort was strongly influenced by Campbell's thesis and by the W. Wittman and J. Schule compilation of data from the Bird's Eye ice reconnaissance flights which the Navy had been flying during the previous decade. The idea was to model the entire ice pack as a continuum, as Campbell had done, but with a more appropriate rheology, and to include in the model, as state variables for the ice, quantitites which could be compared with the Wittman and Schule data, such as ice

concentration, or pressure ridge counts. The conceptual developments of this period led to a new generation of ice models. The main contributions here were by Coon, who proposed a plastic rheology; by Parmerter and Coon, who modelled the formation of pressure ridges; by Rothrock, Maykut, and A. Thorndike, who characterised the ice in terms of its thickness, and showed how the distribution of thickness might evolve in time; and by Rothrock, who pointed out the energetic constraints which link the thickness distribution theory to the ice rheology. Pritchard, Colony, and D. Thomas shaped these ideas into a numerical model tailored to the data products coming out of the field experiment.

In the earliest stages of the AIDJEX planning it became clear that a critical component of the experiment would be the ability to infer the wind stress on the ice from the surface atmospheric pressure field. "We tried it in Australia and we tried it in Kansas, and it doesn't work", we were told by those who had. But it did work, spectacularly, in the Beaufort Sea, a coup for Martin, D. Bell, Albright, W. Brown and others who made and analysed these measurements.

New oceanographic measurements were made in AIDJEX. High resolution current meters made it possible for Smith and McPhee to measure the turbulent structure through the entire planetary boundary layer. They succeeded in relating turbulent fluxes to the mean profile at a time when comparable efforts in the atmosphere were limited to the near surface logarithmic layer.

In the period 1972-75, Martin, together with B. Buck, W. Brown, M. Hall, and D. Haugen developed several automatic data platforms which could make observations, store or transmit data, and, exploiting satellites, report their own positions. These early data buoys, as they were called, collected vital data during AIDJEX. From them, evolved the air droppable buoy which has, over the last decade, greatly extended our ability to monitor conditions in the Arctic.

AIDJEX had been sold as a project with a definite termination date. To the relief of the supporting agencies, and to the consternation of the team of scientists and support staff in the AIDJEX Office, that date arrived in about 1978. Changing the group's name to Polar Science Center was only one sign of the wholesale changes going on. Untersteiner was called to duty at the Office of Naval Resarch, and then at NOAA. Coon, Pritchard, and Thomas went to industry, and later into private consulting. McPhee left to wrok at CRREL for a few years before returning to the family farm and private consulting. NASA got F. Carsey. Martin turned to fisherman.

The group that remained in 1979 consisted of Brown, Maykut, Rothrock, Colony, R. Hall, Heiberg, Thorndike, and staff. Since then, Brown and Thorndike have moved on, while J. Morison and R. Moritz have joined, and Thomas and Untersteiner have rejoined the group. In 1982 the Polar Science Center became a unit of the Applied Physics Laboratory of the University of Washington.

As a contribution to the First Global Atmospheric Research Experiment (1979), the Polar Science Center initiated a program to monitor the ice motion and atmospheric pressure and temperature over the Arctic Ocean. The Arctic Buoy Program, now under Colony's direction, has been in operation for 8 years, and has amassed an unparalleled set of data for a region otherwise poor in data. It has led to improved climatology for the region, and better understanding of the interactions between the ice, air, and ocean.

Optical properties of snow and ice have been studied by Maykut in collaboration with T. Grenfell. Their measurements in the visible range have been important in Maykut's ongoing investigations of the surface radiation balance over sea ice. More recent measurements in the microwave bands are being used to improve the interpretation of satellite observations of the microwave emissions from the ice.

Morison has worked to improve our understanding of the upper Arctic Ocean. He has developed new systems for measurements of the temperature and salinity structure, including the profiler in the figure, and unmanned buoys with strings of sensors suspended below the ice. He will have eight buoys in the field in 1987-88, continuously monitoring the structure of the upper ocean.

Morison is also interested in the dynamics of the upper ocean. He was one of the architects of the 1985 Arctic Internal Wave Experiment, and has plans for follow-up field work in 1988. He is exploring the hypothesis that the ice cover dissipates internal wave energy, thus keeping the energy level below what it is in other oceans.

When Rothrock's works from the period 1975-90 are published, the theme that will emerge is one of trying to make quantitative use of unruly data sets. Taking a hint from Nye, he has used Landsat data to study the evolution of the thickness distribution. He has explored ways to use submarine profiles of the ice, aerial photomosaics, and satellite radar data to characterize the geometry of the ice pack and to describe its modes of motion. In his work, new ideas have been introduced to face up to the granular nature of the ice and the way it moves. He is developing an image processing center to further his work with satellite images. He will be one of the main users of satellite Synthetic Aperture Radar data over sea ice, when it becomes available in a few years.

R. Moritz joined the Polar Science Center in 1981, adding his interest in the dynamics of the climate system. He has studied the predictability of climate variables, and the

N. Untersteiner's historic first simultaneous measurements of the surface divergence and depth of the Arctic Ocean

effect of persistent large-scale features, such as persistent high pressure systems, on predictability. His dissertation is a step towards establishing an ice balance for the Greenland Sea.

Sea ice motion has been a focus of interest among this group of scientists. In AIDJEX, acoustic techniques were used to attain positioning accuracies of meters and sampling intervals of minutes. Satellite techniques gave accuracies of order 100 meters and one hour sampling intervals, at several different locations. The buoy program extended the coverage to the full Arctic Ocean and Greenland Sea. The forthcoming satellite radar will permit much denser sampling in space. Papers by Colony, McPhee, Moritz, Rothrock, and Thorndike have all tried to make sense out of these kinematic data. As a result, we have now a better understanding of the mean motion, of the statistical properties of the time and space fluctuations, and of the relation between the ice motion and the geometry of the ice pack. A satisfactory understanding of the deformation of this irregular ensemble of discrete floes has not yet emerged, and no doubt will continue to attract interest.

Neither the University nor any government agency makes any committment to the Polar Science Center. The group survives on the merits of the scientific work it accomplishes. In an arena where past successes, of which there have been many, are no guarantee of future support, one would be a fool to predict what will become of the Polar Science Center in even a few years' time. One finds reasons for optimism, however. There is a healthy mix of successful ongoing programs, such as the arctic buoys, and the arctic upper ocean studies, and expansion into new areas, such as interpretation of satellite imagery and climate modelling. There is a general interest in the group, and within the international arctic community, for a new sea ice initiative in the Greenland Sea. The group has also begun work on Antarctic sea ice. New ideas have been proposed for monitoring ice thickness, ocean heat flux, and upper ocean structure.

Of the many branches of government which have supported scientific work at the Polar Science Center, the Office of Naval Research has reason for particular pride. Since IGY it has taken the lead in polar oceanography, and sea ice geophysics. It was the foresight of that agency that preserved the experience in arctic logistics, gained during AIDJEX, and drew on that experience in the field programs of the past decade in the Fram Strait and in the marginal ice zones.

The work coming out of the Polar Science Center is characterized by two traits: the emphasis is on sea ice geophysics, and the approach is via data collection and interpretation. What is the extent of the ice? How does it respond to the atmosphere and the ocean? How does it affect its environment? A substantial effort was made during AIDJEX to theorize about the dynamics of sea ice. After AIDJEX, the Polar Science Center opted for observations of the long-term and large-scale ice behavior, as in the Buoy Program, and detailed processes studies, as in the internal wave studies, or the work on optical properties. Proposed future work likewise emphasizes data collection. One is struck by the difficulty in interpreting many kinds of sea ice data. The satellite microwave, Landsat, and synthetic aperture radar images for example, all contain vast amounts of information, in the abstract sense, but to extract geophysical knowledge from these kinds of data has not proven easy. The same can be said of the profiles of the ice surface, the vertical profiles of temperature and salinity in the ocean, and the trajectories of ice floes. With the technological developments of the past twenty years, our ability to observe has raced ahead of our understanding: we are now limited by our ability to interpret, not by our ability to observe. It is by the application of our wits to the observations within our reach that new understanding will be achieved. Drop into Polar Science any time, and you will see people painfully applying their wits to observations of sea ice.

Alan S. Thorndike

# INTERNATIONAL GLACIOLOGICAL SOCIETY

## SYMPOSIUM ON SNOW AND GLACIER RESEARCH RELATING TO HUMAN LIVING CONDITIONS

Lom, Norway, 4 – 9 September 1988

*CO-SPONSORED BY*

Norwegian Geotechnical Institute
Norwegian Water Resources and Energy Administration
Norwegian State Power Board
Norwegian Polar Research Institute
Norwegian Highway Department
Royal Norwegian Council for Scientific and Industrial Research

**SECOND CIRCULAR**
May 1987

SYMPOSIUM ORGANIZATION:
H. Richardson

PAPERS COMMITTEE:
B. Wold (Chairman)
(other members to be appointed in September 1987)

LOCAL ARRANGEMENTS COMMITTEE
K. Lied (Chairman)
H. Norem (Deputy Chairman)
O. Orheim
B. Wold

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INFORMATION ABOUT THE SYMPOSIUM MAY BE OBTAINED FROM:
Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, England
Tel: Cambridge (code from outside U.K. = 223) 355974 Fax: Cambridge 336543

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The Society will hold a symposium on Snow and glacier research relating to human living conditions, in Lom, Norway in 1988. Registration will take place on Sunday 4 September and sessions will be from Monday 5 to Friday 9 September. A mid-symposium half-day tour and two post-symposium four-day tours will take place.

PARTICIPATION
This circular includes a booking form, which should be sent to the Secretary General before 1 May 1988. Payments should be made in £ sterling, as indicated on the booking form, to I.G.S. in Cambridge, England. (Norwegian participants may make payments to the I.G.S. bank account in Oslo, as indicated on the booking form.)

*Participants'* registration fees cover organization costs, distribution of preprints of summaries, Icebreaker, ½-day tour, and a copy of the Proceedings Volume.
*Accompanying persons'* registration fees include organization costs, Icebreaker, and ½-day tour. *There is an administration surcharge for participants who are not members of I.G.S.

Registration Fees:

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|---|---|
| Participant | £100 |
| *Participant (who is not a member of I.G.S.) | £130 |
| Junior Member (under 26 years of age) | £70 |
| Accompanying person aged 18 or over | £40 |

There is no fee for those under the age of 18.

TOPICS

The Symposium will be concerned with science and engineering aspects of the following topics:

1. AVALANCHES OF SNOW, ICE & MIXED SNOW AND WATER -
   a) release mechanisms and flow dynamics,
   b) control and protection measures,
   c) forecasting, risk levels, cost-benefit analyses.
2. DRIFTING SNOW -
   a) processes of snow drifting,
   b) liquid water storage and movement within the snowpack,
   c) impact of snow drifting on human activity.
3. GLACIER & SNOW HYDROLOLGY -
   a) glacier and snow hydrology processes,
   b) water resources and discharge forecasting,
   c) catastrophic floods,
   d) glacier advances and retreats impinging directly upon human actions,
   e) sediment transport in glacial streams.

PROGRAMME

A detailed programme will be given in the Third Circular. Various local tours and visits will be available for accompanying persons, and may be booked when registering on Sunday 4 September.

*Workshops* may be organized, if some topics receive particular attention in the summaries submitted.

PAPERS

(i) SUBMISSION OF PAPERS

Those participants who would like to contribute to the Symposium should first submit a summary of their proposed paper in English; this summary should contain sufficient detail to enable the Papers Committee to form a judgement on the likely merit of the proposed paper, but should not exceed two pages of typescript, on international size paper A4 (210 × 297 mm). References and illustrations are not required at this stage. Summaries should be sent to: Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER. England. Place the title and authors' names and addresses at the top of the first page of your summary and not on a separate sheet.

LAST DATE FOR SUBMISSION OF SUMMARIES: 1 December 1987

(ii) SELECTION OF PAPERS

Each summary will be assessed by the members of the Papers Committee, acting independently of each other, taking into account scientific quality and relevance to the topics of the Symposium. The Papers Committee will then invite a strictly limited number of papers for presentation and thorough discussion at the Symposium (not necessarily confining themselves to authors who have submitted summaries). It is hoped to notify authors of papers during March 1988 about acceptance (or otherwise).

(iii) DISTRIBUTION OF SUMMARIES

The summaries of the accepted papers will be distributed to all registered participants before the Symposium.

(iv) SUBMISSION OF FINAL PAPERS AND PUBLICATION

Papers presented at the Symposium will be considered for publication in the proceedings volume (Annals of Glaciology Vol. 13). Final typescripts of these papers should be submitted to the Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, England, by 1 June 1988. They should be written in English and prepared in accordance with the instructions that will be sent to authors when they are notified about acceptance of papers for the Symposium. Authors will be told the maximum length for their papers when they receive notice of acceptance of their summaries. The papers will be refereed according to the usual standards of the Society before being accepted for publication. Speedy publication of the proceedings will depend upon strict adherence to deadlines.

**Acceptance of a summary implies that the paper based on that summary will be submitted to the proceedings volume and not to another publication.**

LAST DATE FOR SUBMISSION OF FINAL PAPERS: 1 June 1988

ACCOMMODATION

Lom is located 350 km north of Oslo, and is a small village of 700 inhabitants. Accommodation and meals will be at Fossheim Hotel, which has an interesting selection of old houses and Norwegian handicraft. All rooms are with toilet and shower/bath. Prices per night per person will be as follows:

Shared accommodation with full board – Nkr 350 per person.
Single accommodation with full board – Nkr 430.

These prices also include coffee served during the meetings, the cost of the Banquet and all taxes. If wanted, some cheaper accommodation may be available in nearby guest-houses, with lunches and dinners served at Fossheim hotel. If we take all the rooms in the hotel, the committee reserves the right to book late registrants at the neighbouring guest houses.

A deposit of £15 (Nkr 150 for people resident in Norway) must be paid when booking accommodation. This deposit is returnable if notice of cancellation is received before 1 July 1988.

TRANSPORTATION

The recommended transportation is by train to Otta on the Oslo-Trondheim railway, and then by connecting buses to Lom. There are three trains a day leaving Oslo, at 0800, 1010, and 1513. The fares will be approximately Nkr 300. We have made a block reservation on the train at 1513 on 4 September, arriving Lom at 2000. The Icebreaker and dinner will be served shortly after arrival. One can also easily drive from Oslo to Lom.

CLIMATE

The climate in Lom is arid, with a yearly precipitation rate of only 400 mm. The temperature in September may vary within 5° and 15°C, with 10° as an average temperature in the middle of the day. However, the field trips will be arranged to the mountains and fjord districts, and in these areas the climate in September may be cold and moist. Participants are therefore advised to bring warm clothes, raincoats and waterproof boots.

SOCIAL EVENTS

Several social events are planned, including a WELCOME PARTY on the evening of Sunday, 4 September when there will be an Icebreaker, and a BANQUET on Thursday 8 September.

ACCOMPANYING PERSONS' PROGRAMME

Lom is situated north of the Jotunheimen mountain area, and along one of the main roads connecting Eastern and Western Norway. It thus has easy access to some of the most spectacular parts of the mountain and fjord districts of Norway.

Lom and the surrounding area is well-known for old timbered farm houses, some of them dating back to the 16th and 17th century. Close to the hotel, a more than 700 years-old stave church can be visited.

Belonging to the hotel is a "stone centre" with one of Norway's best collections of rocks and minerals, and displays of the development of the local geology. They also make jewellery based on silver and local stones.

Several arrangements for accompanying persons will be offered:
- A one-day trip to Heidal village visiting a farm having several preserved houses, the local dairy, and an opportunity to hike in the mountains.
- Visits to the stave church and the local museum in Lom.
- A two-days' course in grinding jewellery-stones and making your own decorations.
- If weather permits, a hike to the highest peak of Norway (Galdhøpiggen – 2469 m) will be arranged. Vertical hiking elevations 600 m, roughly estimated as 5-hr walk.

## EXCURSIONS

### MID-SYMPOSIUM TOUR

On Wednesday 7th or Thursday 8th there will be an excursion to the Stryn Mountain area, approximately 1 hour's bus drive from Lom. The field trip will concentrate on:
- The avalanche research station run by NGI, 10 minutes' walk from the road.
- Research facilities for measuring snow-creep pressure on a retaining structure, tubes and the base of a high-voltage transmission tower.
- The experimental set-ups for the Ryggfonn project, full scale experiment for measuring avalanche impacts on constructions, cables and a dam.
- The all-seasons mountain road connecting Eastern and Western Norway.
- Studies of glacial-hydrological problems and late- and post-glacial processes around Jostedalen glacier.

### POST-SYMPOSIUM TOURS

Two four-day post-symposium tours will be arranged, one concentrating on snow avalanches and one on glaciers. Both tours will pass scenic mountain roads and the most spectacular fjords of Western Norway. The transportation will mainly be by bus, ferry boats and railway. The fourth day is common to both tours.
The cost of the post-symposium tours is approximately Nkr 2500, which includes transportation, accommodation with full board, maps and field guides.

### (A) SNOW AVALANCHE EXCURSION

*Saturday, September 10*
Avalanche events and recently made avalanche hazard evaluations in Geiranger village.
1½ hours by boat on the famous Geiranger Fjord.
Bus to Sæbø through some of the most avalanche-exposed parts of Norway.

*Sunday, September 11*
Visit a local road in the Hjørunfjord area, showing several different protective measures.
Bus to Ørsta where information will be given about the surveying of avalanche evidence back to 1750. Guide to living areas exposed to avalanche hazard and to a newly protected area where 11 houses were destroyed in 1979.

*Monday, September 12*
Loen valley by bus, a narrow valley with steep mountain sides, now an abandoned area after two huge rock avalanches in 1905 and 1936, which killed 61 and 73 persons respectively. The wave created by the avalanche was up to 74 m high.
Bus to Fjærland, where we join the glacier excursion and where we have an end of excursion party at the Hotel Mundal.

*Tuesday, September 13*
5-hour boat trip on Sognefjord to Flåm, and then by train to Finse. The Flåm railway is the steepest railway in Europe and has severe rock- and icefall problems. Finse is the highest railway station in Norway, 1222 m a.s.l. and approx. 300 m above the tree line. The most severe winter problems are caused by drifting snow. The train will be allowed to stop at all places having special tourist or scientific interest.
The excursions will end at Finse, and you may return to either Oslo or Bergen in the evening. Fare approximately Nkr 250.

(B) GLACIER EXCURSION

*Saturday, September 10*
Study glacio-hydrological processes around the northern end of Jostedalsbreen, where large-scale hydro electric development is under way. Sites to be visited depend both on weather and the stage of the construction work. We hope to include the glacier Austdalsbreen which calves into a lake, and where the projected dam and the raised lake level is expected to cause a "mini-surge" and increase calving by an order of magnitude.

*Sunday, September 11*
Visit to Loen valley, to see 1) avalanche phenomena described under Monday for excursion (A), 2) studies of various glacial geologic phenomena along the western side of Jostedalsbreen, and 3) hydrologic aspects of Jøstervatnet.
Through the new tunnel under the glacier to Fjærland, passing through classic late glacial moraine landscape in the Bøya Valley. Stay at Hotel Mundal for two nights.

*Monday, September 12*
Full-day hike to Flatbreen, studying 1) Supphellebreen, a regenerated glacier, 2) a glacier-damned lake which empties each autumn and 3) numerous active glacier processes.
Excursion A joins us in the evening and we have an "end of excursion" party.

A bus tour to the front of the glacier will be arranged for people that do not want to take part in the full-day hike.

*Tuesday, September 13*
See excursion A.

***If one of the excursions does not attract sufficient numbers to make it viable financially, we will arrange a joint excursion, featuring the highlights of both tours.***

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*Your copy*

I.G.S. SYMPOSIUM in Lom, Norway, September 1988

The following fees were paid and the form sent to the Secretary General in Cambridge, England on ...../ ...../ 198 .
(day) (month)

REGISTRATION FEES

(i) Participant £.....
(ii) Participant who is not a member of IGS £.....
(iii) Junior member IGS £.....
(iv) Accompanying person £.....

ACCOMMODATION DEPOSIT
£15 per person .....£.....

POST-SYMPOSIUM TOURS DEPOSIT
£ 20 PER PERSON £.....

TOTAL fees sent £..... (Nkr ..... for Norwegian participants only)

REGISTRATION, ACCOMMODATION
SYMPOSIUM ON SNOW AND GLACIER RESEARCH
RELATING TO HUMAN LIVING CONDITIONS

4 – 9 September 1988

Mail to: Secretary General, International Glaciological Society, Cambridge CB2 1ER, England - BEFORE 1 MAY 1988.

REGISTRATION (please type or print in black ink)
Name of participant:

..... .....
(family name) (initials)

Address .....

.....

.....

Accompanied by (indicate age if under 18)

Name ..... Name .....

I send registration fees as follows:

(i) Participant (£100 each) £ .....

(ii) Participant (not IGS member) (£130 each) £ .....

(iii) Junior member (£70 each) £ .....

(iv) Accompanying person (£40 each) £ .....
(There is no registration fee for accompanying persons under the age of 18)

Total Registration fees/s £ .....

ACCOMMODATION
I send £15 deposit per person for accommodation for .... people £ .....

POST-SYMPOSIUM TOUR
I send £20 deposit per person for *TOUR A/*TOUR B £ .....
*delete as applicable.

TOTAL FEES & DEPOSITS .....£

METHODS OF MAKING PAYMENT

- by **sterling cheque** payable to: International Glaciological Society and sent to the Secretary General at the Society's address;
- by **sterling Bank transfer** to: International Glaciological Society, Account No. 08102112 and sent to the National Westminster Bank plc., 56 St. Andrew's Street, Cambridge CB2 1ER, England.

*For people resident in Norway by equivalent payment in Nkr to:*
- Norges Geoteckniske Institutt, NGI-Konto 1416, Boks 40, Tåsen, 0801 Oslo 8, Norway. Bank Giro: 5096.05.01281

# INTERNATIONAL GLACIOLOGICAL SOCIETY

## SYMPOSIUM ON ICE AND CLIMATE

**Seattle, Washington, U.S.A.**

**21 – 25 August 1989**

**FIRST CIRCULAR**

May 1987

The Society will hold a symposium on ice and climate in Seattle, Washington, USA in 1989. Registration will take place on Sunday 20 August and sessions will be from Monday 21 August to Friday 25 August in the University of Washington.

TOPICS

The symposium will be concerned with natural forms of ice on land and sea, with focus on (1) information obtained from ice about past climates, (2) physical processes by which ice influences climate change, and (3) practical means by which ice effects can be incorporated into large-scale climate models.

Topics will include:

Deduction of paleoclimate from ice properties.

Advance and retreat of glaciers and ice sheets.

Climate effects of sea ice-ocean-atmosphere interaction.

Implications of seasonal snow cover feedbacks for long-term climate change.

PAPERS

Details about submission of summaries and final papers will be given in the Second Circular, to be published in May 1988. Dates for submissions are firm ones and must be adhered to. The Papers Committee will decide on acceptance of sumbitted summaries and may invite review papers on major themes if submitted contributions do not give sufficient coverage.

PUBLICATION

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

SESSIONS

Sessions will be held on four full days and one half-day. An excursion will be held during the week.

POST-SYMPOSIUM TOUR

We are planning a post-symposium tour to Alaska.

ACCOMMODATION

Accommodation will be available in various price categories: details will be given in the Second Circular.

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, England.

SYMPOSIUM ORGANIZATION

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

LOCAL ARRANGEMENTS COMMITTEE

C.F. Raymond (Chairman)

P. Grootes — S. Hodge

B. Hallet — S. Warren

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INTERNATIONAL GLACIOLOGICAL SOCIETY
SYMPOSIUM ON ICE & CLIMATE, 1989

Family Name .....

First Name .....

Address .....

.....

.....

*I hope to participate in the symposium in 1989 [ ]

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

**without obligation*

TO BE SENT AS SOON AS POSSIBLE TO:

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

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

# INTERNATIONAL GLACIOLOGICAL SOCIETY

## JOURNAL OF GLACIOLOGY

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

G.K.C. Clarke:
A short history of scientific investigations on glaciers.

G. de Q. Robin & C.W.M. Swithinbank:
Fifty years of progress in understanding ice sheets.

E.L. Lewis:
Fifty years of progress in understanding sea ice.

H.J. Zwally:
Technology in the advancement of glaciology.

D.M. Cole:
Strain-rate and grain-size effects in ice.

D.R. Lindstrom & D.R. MacAyeal:
Environmental constraints on West Antarctic ice-sheet formation.

K.A. Echelmayer & R. Butterfield:
Some observations on a recent surge of Peters Glacier, Alaska, USA.

G. Brand, V. Pohjola & R. LeB. Hooke:
Evidence of a till layer beneath Storglaciären, Sweden, based on electrical resistivity measurements.

K. Echelmeyer & B. Kamb:
Glacier flow in a curving channel.

R.W. Jacob & S.K. Anderson:
Interpretation of radio-echo returns from internal water bodies in Variegated Glacier, Alaska, USA.

S. Hastenrath:
On the relation of net balance, ice flow, and surface lowering of Lewis Glacier, Mount Kenya, East Africa, 1982-86.

C-S. Man & Q-X. Sun:
On the significance of normal stress effects in the flow of glaciers.

A.C. Fowler:
Sliding with cavity formation.

D.E. Sugden, C.M. Clapperton, P.G. Knight & J.G. Gemmell:
Stable isotopes and debris in basal glacier ice, South Georgia, Southern Ocean.

S.A. Arcone & A.J. Delaney:
Airborne river-ice thickness profiling with helicopter-borne UHF short-pulse radar.

T.J. Chinn:
Victoria Lower Glacier, Dry Valleys area, South Victoria Land, Antarctica.

T.J. Chinn & A. Dillon:
Observations on a debris-covered polar glacier "Whisky Glacier", James Ross Island, Antarctic Peninsula, Antarctica.

A.J. Aristarain, J.F. Pinglot & M. Pourchet:
Accumulation of temperature measurements on the James Ross Island ice cap, Antarctic Peninsula, Antarctica.

# FUTURE MEETINGS (of other organizations)

### INTERNATIONAL ASSOCIATION FOR HYDRAULIC RESEARCH

### 9th IAHR SYMPOSIUM ON ICE

23 - 27 August 1988, Sapporo, Japan

A Symposium on ice engineering for rivers, lakes and seas will be held in Sapporo, Japan, from 23-27 August 1988. It is organised by the International Association for Hydraulic Research (IAHR).

Topics will include: thermal regime of waters in cold regions; ice initiation, growth and deterioration process; ice mechanics and ice properties; instrumentation and remote sensing in ice engineering; modelling of ice phenomena; hydraulics of ice covered waters; ice jam process; ice and wave interaction; ice control/management; structures and vessels in ice-covered water; ice piling and ridging; spray and atmospheric icing.

The deadline is 15 November 1987 for 300-400-word abstract (three copies).

For further information contact Prof. Hiroshi Saeki, Department of Civil Engineering, Hokkaido University, N-13, W-8, Kita-ku, Sapporo, 060 Japan.

### 8th INTERNATIONAL CONFERENCE ON GEOSCIENCE AND REMOTE SENSING

13 - 16 September 1988, Edinburgh, Scotland

The 8th International Conference on Geoscience and Remote Sensing is being held from 13-16 September 1988 at the University of Edinburgh. IGARSS'88 is jointly sponsored by the Geoscience and Remote Sensing Society of the IEEE and the Remote Sensing Society, under the presidency of Sir Herman Bondi FRS.

As in previous years sessions will be devoted to the remote sensing of both sea and land ice and kindred glaciological topics.

Abstracts of papers should be sent to Dr J.B. Montcreiff IGARSS'88 office, Dept. of Geography, University of Edinburgh, EH 9XP, who will send further details and the full call for paper on request.

# GLACIOLOGICAL DIARY

** IGS Symposia
* Co-sponsored by IGS

**1987**

7-11 December
American Geophysical Union: Snow, ice and permafrost sessions. San Francisco, USA. Heat and mass transfer processes in frozen ground and permafrost. (Conveners A.H. Lachenbruch, U.S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025, Ph. (415)-323-8111; T.E. Osterkamp, Geophysical Institute, University of Alaska, Fairbanks, AK 99775-0800, Ph. (907)-474-7548) Snow physics and avalanche dynamics. (Conveners T.W. Tesche, Alpine Geophysics, Inc., 5360 Spring circle, Placerville, CA 95667-0321, Ph. (916)-677-7550; Jeff Dozier, Center for Remote Sensing and Environmental Optics, Department of Geography, University of California, Santa Barbara, CA 93106, Ph. (805)-961-2309; R.L. Brown, Department of Civil Engineering and Engineering Mechanics, Montana State University, Bozeman, MT 59717, Ph. (406)-994-6122) Climate and ice: global interactions. (Convenors M.F. Meier, INSTAAR, Campus Box 450, University of Colorado, Boulder, CO 80309, Ph. (303)-492-7909; R.G. Barry, CIRES, Campus Box 449, University of Colorado, Boulder, CO 80309, Ph. (303)-492-5488)

**1988**

14-19 February
** Symposium on Ice dynamics. Hobart. Australia. (Secretary General, IGS, Lensfield Road, Cambridge CB2 1ER, UK)

11-15 April
Sixth International Congress on Numerical methods in geomechanics, Innsbruck, Austria. (G.A. Swoboda, University of Innsbruck, Technikerstr. 13, A-6020 Innsbruck, Austria)

4-8 July
Sixth International Congress on Protection of habitat from floods, debris flows and avalanches. Graz, Styria, Austria. (INTERPRAEVENT 1988, Postfach 43, A-8010 Graz, Austria)

2-5 August
Fifth International Conference on Permafrost, Trondheim, Norway. (c/o The Norwegian Institute of Technology, Studies Administration, N-7034 Trondheim-NTH, Norway.)

2 August
(in conjunction with the above conference) Workshop on Permafrost data and information. (R.G. Barry, Director, WDC-A for Glaciology, Boulder, Colorado, U.S.A.)

23-27 August
Ninth International Symposium on Ice. Hokkaido University, Sapporo, Japan. (Hiroshi Saeki, Department of Civil Engineering, Hokkaido Univeristy, Kita-13, Nishi-8, Kita-ku, Sapporo, 060, Japan)

4-9 September
** Symposium on Snow and glacier research relating to human living conditions. Lom, Norway. (Secretary General, IGS, Lensfield Road, Cambridge CB2 1ER, UK)

**1989**

9-19 July
28th International Geological Congress, Washington, D.C., U.S.A. (B.B. Hanshaw, Secretary General, 28th International Geological Congress, P.O. Box 1001, Herndon, VA 22070-1001, U.S.A.)

21-25 August
23rd IAHR Biennial Congress. Ottawa, Ontario, Canada. (T.M. Dick, NWRI, CCIW, P.O.Box 5050, 867 Lakeshore Road, Burlington, Ontario, L7R 4A6, Canada)

21-25 August
** Symposium on Ice and climate. Seattle, Washington, U.S.A. (Secretary General, IGS, Lensfield Road, Cambridge CB2 1ER, UK)

# NEWS

## NEW CHAIR

The Regents of the University of Wisconsin have established the Albert P. Crary Professorshp of Geophysics, in honor of one of the outstanding pioneers in polar geophysics and glaciology.

Crary was born in Pierrepont, N.Y. on July 25, 1911. He graduated *magna cum laude* from St Lawrence University (B.S. in chemistry) in 1931, and received an M.S. in physics from Lehigh University in 1933. That same year, he began geophysical research with Maurice Ewing, with whom he published papers on various topics in seismology, electrical resistivity of rocks, and submarine geophysics, including the first of the landmark series of papers on "Geological investigations in the emerged and submerged Atlantic coastal plain".

From 1935 to 1945 Crary worked on geophysical oil-prospecting in Colombia, Venezuela, and England, with interruptions for antisubmarine research during 1941-42 at Woods Hole Oceanographic Institution, and for a short period of oil exploration in the Persian Gulf. His research on upper air acoustics for the U.S. Air Force resulted in a series of papers on upper atmosphere winds and temperatures.

Crary made contact with polar glaciology, his primary concern for the next 25 years, in 1951. From 1951 to 1955 he worked on an assortment of problems dealing with sea ice, ice islands and the ocean. When ice island T-3 ("Fletcher's Ice Island") in the Arctic Ocean was occupied in 1952, Crary became chief scientist for Air Force work on the island, continuing until T-3 was abandoned in 1955. It was while working on T-3 that he discovered and explained "Crary waves", an unusual type of guided, elastic-plate wave, and also flew to, and landed at, the North Pole.

In 1955 he set up the Glaciological Headquarters for the U.S. National Committee for the International Geophysical Year, and organized the U.S. Antarctic work in glaciology, including oversnow traverses. In 1957 he went to Antarctica as Deputy Leader of the U.S. scientific efforts and scientific leader at the Little America Station. He remained in Antarctica until 1959, leading the summer traverses on the Ross Ice Shelf and Victoria Land. In 1960-61 he returned to lead the McMurdo–South Pole traverse. When he arrived at the South Pole he became the first person to set foot on both Poles. In 1966 he returned to the Antarctic again aboard the research vessel *Eltanin*.

Although he ceased active work in Antarctica thereafter, he continued to play a vital role in the organization, direction, and support of Antarctic research through his successive positions in the National Science Foundation as Chief Scientist of the U.S. Antarctic Research Program, and Deputy Director and then Director of the Division of Environmental Sciences. At the same time, he continued to publish the results and analyses of his own Antarctic work.

His output of research work is as versatile as it is large and he is regarded as one of the outstanding scientists in his field. Recognition of his work has come in the form of many awards: the U.S. Department of Defence Distinguished Civilian Service Award, the Cullum Geographical Medal of the American Geographical Society, the Patron's Medal of the Royal Geographical Society, the U.S. Department of Navy Distinguished Public Service Award, the Vega Medal of the Swedish Society of Anthropology and Geography, a medal from the Soviet Academy of Sciences commemorating 100 years of international geophysics, and an Honorary D.Sc. degree from St Lawrence University.

He retired in 1976, and now lives in Bethesda, MD, with his wife Mildred and their son Frank.

**Charles R. Bentley**, a beneficiary of Crary's leadership, will hold the Chair.

**Note:** Dr Crary is an Honorary Member of the International Glaciological Society. He was the main stimulus in the early 1960s to those of us involved in the transformation of the Society from a British organisation to an international one.

## PUBLICATIONS

The *Bulletin of Glacier Research* nos 4 and 5 was published in March 1987 by the Data Center for Glacier Research, Japanese Society of Snow and Ice. The Data Center has previously issued three publications, but with different titles. Forthcoming issues will be published under the title of *Bulletin of Glacier Research*.

No 4 (p.175) contains 22 papers, which report on the activities and scientific results of glaciological studies carried out by Japanese and Chilean workers in 1985 and 1986, mainly in the Northern Patagonia Icefield. Glacier studies in Asian highland regions in 1985 and 1986 are reported in No 5 (p.128), with 18 papers by Japanese, Nepalese and Chinese researchers. The research areas covered are the Langtang Valley, central Nepal, and the West Kunlun Mountains, western China.

These publications may be ordered from the Data Center for Glacier Research, Japanese Society of Snow and Ice, Bancho Haim 308, 1-2 Nibancho, Chiyoda-ku, Tokyo 102 Japan, for ¥2000 each, including postage.

Masayoshi Nakawo

## INTERNATIONAL FOUNDATION

## HIGH ALPINE RESEARCH STATIONS JUNGFRAUJOCH AND GORNERGRAT, SWITZERLAND

The International Foundation "High Alpine Research Stations Jungfraujoch and Gornergrat" (HFSJG) is a foundation in accordance with Article 80 ff of the Swiss Civil Statute Book.

Members of the Foundation are:

| *COUNTRY* | *REPRESENTED BY* |
|---|---|
| Austria | Akademie der Wissenschaften |
| Belgium | Fonds National de la Recherche Scientifique |
| France | Centre National de la Recherche Scientifique |
| Germany (FRG) | Max-Planck-Gesellschaft zur Förderung der Wissenschaften |
| Italy | Consiglio Nazionale delle Richerche |
| Netherlands | Nederlandse Akademie van Wetenschappen |
| Switzerland | Schweizerische Naturforschende Gesellschaft |
| | Jungfraubahn-Gesellschaft |
| | Gornergrat-Gesellschaft |
| United Kingdom | The Royal Society |

The aim of the Foundation is to make possible scientific investigation, which must be carried out at high altitude or in a high alpine climate. The research station and Sphinx observatory at the Jungfraujoch, together with the two astronomical observatories, Gornergrat South and Gornergrat North, are run for this purpose. Scientists from universities, institutes of technology and other research institutes of the member countries can carry out time-limited research experiments in these buildings.

The Jungfraujoch and Gornergrat scientific stations both lie far from large cities and industrial centres. With a prevalent atmospheric pressure of 655 mb, the Jungfraujoch scientific station lies above the lower third of the earth's atmosphere where about 95% of the aerosols are suspended. The precipitable water vapour content of the atmosphere above Jungfraujoch varies from a few millimetres down to 0.25 mm during clear weather, while that value averages about 5 cm at sea level for the same latitude. These conditions make the site very favourable for all types of research which require a high atmospheric transparency over a wide spectral range and/or the absence of local sources of pollution. Astronomy was the first discipline to take advantage of these properties. The site, however, has considerable potential value for studies of the higher atmosphere and for environmental research related to the global component of atmospheric pollution. The Gornergrat site has the same advantages as the Jungfraujoch and is at present dedicated to observational astronomy. Both stations are accessible all the year round by narrow gauge railways capable of transporting heavy equipment.

Further information may be obtained from:

Administration of the International Foundation HFSJG, Hochalpine Forschnungs-station, Jungfraujoch und Gornergrat, Sidler-strasse 5, CH-3012 Bern, Switzerland

Telephone: (031) 65 40 52

# NEW MEMBERS

X. Bosch i Marti, C/. Toledo 37 (Mira-sol), 08190 Sant Cugat del Valles, Barcelona, Spain.

E.J. Crick, Dendermonde Straat 48, 1880 Merchtem, Belgium.

J. Determann, Institut für Geophysik, Correnstr. 24, 4400 Münster, Federal Republic of Germany.

G.M. Holton, Box 82631, Fairbanks, AK 99708, U.S.A.

Y. Pages, Le Vallon Fleuri, Bât. C, 73490 La Ravoire, France.

R.F. Svendsen, Lab. Hydraulics, Hydrologie und Glaziologie, Gloriastrasse 37/39, ETH Zentrum, 8092 Zürich, Switzerland.

## TAILPIECE

### *CREATING AN ICE AGE*

An enthusiastic glaciologist was showing off his new computerized word-processing system to a visitor. "If you make a mistake" the glaciologist said, "the system can find and correct the error. For example, I am now telling the computer to find and replace all "accumulations" in this report with "ablations". He pressed a key, the letters of the display screen shivered for a moment and the miracle happened - "And now I just change it back".

He gave the instruction, but there was an unexpected result. The computer did exactly what it had been told. All the "ablations" were now "accumulations" again - including those that had been "ablations" in the first place.

Henrik Hoejmark Thomsen

# INTERNATIONAL GLACIOLOGICAL SOCIETY

Founded by G. Seligman

c/o SCOTT POLAR RESEARCH INSTITUTE, Lensfield Road, Cambridge CB2 1ER, England
Secretary General: H. Richardson

## COUNCIL MEMBERS

| | | | Date first elected to the Council (in present term of office) |
|---|---|---|---|
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| VICE-PRESIDENTS | G.K.C. Clarke | 1987-90 | 1987 |
| | H. Kohnen | 1985-88 | 1984 |
| | P. Schwerdtfeger | 1984-87 | 1984 |
| IMMEDIATE PAST PRESIDENT | H. Röthlisberger | 1987-90 | 1978 |
| TREASURER | J.A. Heap | 1986-89 | 1980 |
| ELECTIVE MEMBERS | * K. Higuchi | 1985-88 | 1985 |
| | * C. Jaccard | 1985-88 | 1985 |
| | * Shi Yafeng | 1985-88 | 1985 |
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| | * R. Hooke | 1986-89 | 1986 |
| | * N. Maeno | 1986-89 | 1986 |
| | * R. Perla | 1986-89 | 1986 |
| | * D. Sugden | 1986-89 | 1986 |
| | * C. Hammer | 1987-90 | 1987 |
| | M. Kuhn | 1987-90 | 1987 |
| | * E.L. Lewis | 1987-90 | 1987 |
| | * H.J. Zwally | 1987-90 | 1987 |

* first term of service on the Council

## CORRESPONDENTS

| | | | |
|---|---|---|---|
| AUSTRALIA | N. Young | JAPAN | N. Maeno |
| AUSTRIA | M. Kuhn | NEW ZEALAND | T. Chinn |
| BELGIUM | R.A. Souchez | NORWAY | H. Norem |
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| ICELAND | H. Björnsson | USA (Western) | A. Fountain |
| ITALY | G. Zanon | USA (Alaska) | L. Mayo |

## SELIGMAN CRYSTAL AWARD RECIPIENTS

| | | | |
|---|---|---|---|
| 1963 | G. Seligman | 1976 | W. Dansgaard |
| 1967 | H. Bader | 1977 | W. Kamb |
| 1969 | J.F. Nye | 1982 | M. de Quervain |
| 1972 | J.W. Glen | 1983 | W.O. Field |
| 1972 | B.L. Hansen | 1983 | J. Weertman |
| 1974 | S. Evans | 1985 | M.F. Meier |
| | | 1986 | G. de Q. Robin |

## HONORARY MEMBERS

| | |
|---|---|
| A.P. Crary | M.F. Meier |
| W.O. Field | M. de Quervain |
| R.P. Goldthwait | H. Richardson |
| P. Kasser | R.P. Sharp |
| R.F. Legget | A.L. Washburn |
| L. Lliboutry | Z. Yosida |

**The Society is registered as a charity in the United Kingdom with the Charity Comissioners – number 231043**

# INTERNATIONAL GLACIOLOGICAL SOCIETY

## 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 1988

| | |
|---|---|
| Private members | Sterling £27.00 |
| Junior members | Sterling £13.50 |
| Institutions, libraries | Sterling £75.00 for Volume 34 (Nos.116,117,118) |

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

Note: Payments from countries other than Britain should be calculated at the exchange rate in force at the time of payment. Please ensure that sufficient money is included to cover the bank charges. The Society needs the full payment, so bank charges should be paid by you. Thank you.

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## ICE

Editor: H. Richardson
Assisted by 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.

Annual cost for libraries, etc., and for individuals who are not members of the Society:

Sterling £9.00

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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.