Number 100 *3rd Issue 1992*

ICE

NEWS BULLETIN OF THE INTERNATIONAL GLACIOLOGICAL SOCIETY

INTERNATIONAL GLACIOLOGICAL SOCIETY

International Workshop
on
Glacier Hydrology
including
Soirée Richardson

8 - 10 September 1993

Jesus College
Cambridge
UK

see p. 28, this issue of ICE

ISSN 0019–1043

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CONTENTS

COVER PHOTOGRAPH by E. R. LaChapelle, from his *Field Guide to Snow Crystals* in the new edition published by IGS 1992 (ISBN 0 946417 13 X)

CANADA

GENERAL

For key to abbreviations see ICE No.97 (1991), p.17-18

CRYSYS

(R. Simard, K. Fadaie, J. Cihlar, M. Manore and T. Fisher, CCRS/EMR)
A C-band airborne SAR image of a Schefferville (Québec) transect (discontinuous permafrost zone) was obtained, analyzed and processed. It was registered with a digital elevation model of the area and integrated with existing ground-truth data. Textural analysis is focusing on understanding remotely detected signals and their relation to surficial permafrost features. Some progress was made in assessing the usefulness of SAR for monitoring snowpacks.

A joint CCRS/Manitoba Hydro/MacPlan project for evaluating SAR data for monitoring ice formation and break-up was successfully completed.

Advancement of northern scholarship

(ACUNS, 1915-130 Albert Str., Ottawa, K1P 5G4)
The Association of Canadian Universities for Northern Studies advances northern scholarship through education and research, including research and teaching about ice and snow, and the sponsoring of conferences. The Proceedings of the Third National Student Conference on Northern Studies will appear as a special issue of *The Musk-Ox*.

GLACIERS – GENERAL

Measurement of ice cores

(E. W. Blake, Icefield Instruments Inc., Box 5567, Whitehorse, Y1A 5H4, and D. A. Fisher, TSD/GSC)
A portable instrument capable of measuring frozen and liquid conductivity, pH, particulates, and selected specific ions in ice cores is being developed. It will be used in the field while the ice core is fresh. Field testing will begin on the Agassiz Ice Cap, Ellesmere Island in 1993.

Glacier fracture mechanisms

(H.H. Schloessin, GPHYS/WEST, and W.C. Mahaney, GEOG/YORKA)
Elastic inhomogeneity stresses can trigger the propagation of pre-existing fractures in minerals and rocks.

Subglacial sedimentology

(J. Menzies and graduate student, GEOG/GEOL/Brock Univ., St. Catharine's, L2S 3A1)
Strong evidence supports the idea that wide areas of the southern Laurentide Ice Sheet were underlain by deformable beds.

Quaternary in southern Québec

(J.-M. M. Dubois, A. Larocque and G. Larocque, CARTEL/Sherbrooke)
For the eastern townships, a detailed model of deglaciation is being developed and related to proglacial lakes. In the case of the Magdalen Islands, the mode of deglaciation and its relation to the marine level have been established.

GLACIERS – ARCTIC AND YUKON

Canadian Arctic Archipelago

(D. A. Fisher, R. M. Koerner, B. Alt and J. C. Bourgeois, TSD/GSC)
A new drill, based on the Danish shallow model, will be used primarily for sampling stable isotopes and chemistry of the last 1000 years. Mass balance results for the Queen Elizabeth Islands show no trend to date, but winter balances exhibit a slight increase. Modelling of vapour transport and stable isotopes is being undertaken to establish transfer functions for the ice cores. Five stages of the Laurentide Ice Sheet are being reconstructed using a plastic model; a dynamic model is planned. Pollen concentrations have been obtained from the Agassiz Ice Cap 1987 core; a new pollen lab is being set-up. Polar climatology during the last century is being assessed in collaboration with other circumpolar countries. Automatic weather stations are being placed on all major ice caps in the Canadian Arctic.

Axel Heiberg Island

(W. P. Adams and M. A. Ecclestone, GEOG/TRENT)
Mass balance measurements continued on White and Baby glaciers in conjunction with a study of equilibrium line processes on the latter. The mass balance record of White Glacier now extends over 30 years. A study is under way to determine the value of remotely-sensed albedo measurements in high arctic mass-balance work.

(J. G. Cogley and F. Jung-Rothenhaeusler, GEOG/TRENT)
White Glacier, for which large-scale maps are available, is the base for a study using LANDSAT imagery and a digital elevation model. The DEM provides the spatial framework for a model to estimate mass balance.

Bylot Island

(F. A. Michel, ES/CARL, and W.W. Shilts, TSD/GSC)
A study has been initiated on the transport of sediment within active glaciers on Bylot Island and the distribution of ground ice associated with glaciers as they retreat.

Baffin Island

(J. D. Jacobs, GEOG/MUN)
Data from remote automated climate stations, have been used, with optimal interpolation techniques, to improve mapping of climatological fields in the Baffin Island interior. The results reveal positive anomalies in summer temperatures and set limits on the extent of winter snowfall events.

Inventory of Yukon glaciers

(C. S. L. Ommanney, NHRI/EC)
Preliminary data compiled so far suggest that the areal extent of Yukon permanent snow and ice may be as much as 20% greater than published estimates.

Cause and mechanics of glacier surging

(G. K. C. Clarke with E. W. Blake, D. B. Stone, T. Murray, U. H. Fischer, B. S. Waddington, J. P. Schmok and S. J. Marshall, GA/UBC)
Trapridge Glacier, Yukon, lies on an unlithified bed. Sediment deformation contributes substantially to the total flow and may lead to complex interactions with the subglacial water system that might be the cause of flow instability.

Ice-core climate and atmospheric chemistry

(G. Holdsworth and others, AINA/CAL)
Trace gas measurements in the Mount Logan core, spanning the last 200 years, show increases in CH_4, CO_2 and N_2O that follow similar trajectories to those in published curves, although there are some differences which are still being interpreted.

GLACIERS – CORDILLERA

Iskut River basin, B.C.

(O. Mokievsky-Zubok, GCS/Ottawa)
For the 1990–91 hydrological year, all three control glaciers again showed a negative balance: Andrei Glacier's specific loss was –0.12 m H_2O, Yuri's –0.27 m H_2O, and Alexander's –0.17 m H_2O. From September 1990 to September 1991 Andrei Glacier retreated another 48 m. During the 10 years studied, Andrei Glacier had two years of positive balance, while Yuri and Alexander Glaciers only had one.

Homathko River basin, B.C.

(O. Mokievsky-Zubok and A. Chichagov, GCS/Ottawa)
The two glaciers chosen as controls each showed a negative balance for the 1990–91 balance year: Tiedemann Glacier –0.16 m H_2O and Bench Glacier –0.25 m H_2O. Of the nine years studied, Tiedemann Glacier had only one positive balance year and Bench Glacier had none.

Glacier hydrometeorology

(M. M. Brugman (NHRI/EC)
Measurements of winter, summer and net mass balance were made at Sentinel, Place and Helm glaciers in the Coast Mountains and at Peyto Glacier, in the Rockies. Detailed surveys, using a total station, will assess volumetric change. Ground-truthing before, during and after a remote-sensing overflight of the Wapta Icefield and Peyto Lake by the NASA/JPL aircraft, included temperature, snow pit, roughness and dielectric observations. Preliminary analysis of the SAR polarimeter data is complete.

Wedgemount and Overlord glaciers, B.C.

(K. Ricker, RICK and W. Tupper, Survey Dept/BCIT)
Wedgemount Glacier is in accelerating retreat, while Overlord Glacier's snout is oscillating, having advanced slightly between August 1989 and August 1990. There was no field work in 1991.

Climate/glacier/streamflow relationships

(R. D. Moore, GEOG/Simon Fraser Univ., Burnaby, V5A 1S6)
A study has been completed of the relationship between the variability of annual runoff and glacier cover in the B.C. Coast Mountains. A conceptual streamflow model incorporating glacier melt and storage routines is being calibrated with data from the Lillooet River. The model will be used to investigate the effect of varying glacier cover on streamflow and the influence of climatic variations on basin water balance.

Jøkulhlaups, icebergs and Neoglacial history

(W. H. Mathews, GEOL/UBC, and J. J. Clague, GSC/Vancouver)
Jøkulhlaups and icebergs at Summit Lake, and the sedimentary record and Neoglacial history of Tide Lake are being investigated.

Glacier influences on aquaculture sites

(K. E. Ricker, RICK, and Axys Group, Sidney, BC)
Plans are underway to initiate a study on the influence of glacier-fed, high runoff fiords on the Burke Channel system related to its suitability or limitations as a salmon "grow-out" site.

Quaternary history, east-central B.C.

(D. H. Huntley and B. E. Broster, GEOL.UNB, Box 4400, Fredericton, E3B 5A3)
Two principal depositional environments are recognized: upland and plateau areas; Fraser and associated valleys. Each has distinct facies associations and styles of glacigenic deformation, related to the advance and retreat of the Fraser Ice Sheet. The deformation is partly controlled by the depositional environment. Some units may be crudely correlated on a regional basis.

Paleoglaciology

(L. E. Jackson, Jr, GSC, 100 West Pender Street, Vancouver, V6B 1R8)
The results of paleoglaciological investigations in western Canada have implications for contemporary glaciers.

Small Glacier, Rockies, B.C.

(C. C. Smart, GEOG/WEST)
About 90% of the accumulation zone is captured by subglacial karst to major springs. The proglacial stream drains only an ablation zone. Each discharge point has a characteristic hydrograph. Basal drainage runs through dendritic/low pressure (atmospheric) axes linking cavities with tributary high-pressure areas. Basal water residence time varies from $\ll$1 h to $\sim$1 day depending on the system.

Dendrochronological studies, Rockies

(B. H. Luckman, GEOG/WEST)
Tree-ring chronologies (using living trees and snag material) provide high-resolution (annual) proxy climate data for the Canadian Rockies. Sites include those adjacent to glaciers (Athabasca, Cavell, Peyto, Robson, Bennington, etc.). Advances at Robson (1142–1350 AD) and Peyto (1246–1324 AD) glaciers were dated through kill dates for trees. A mid-Neoglacial advance occurred at Peyto Glacier ca. 3100–2500 years BP (with Holdsworth and Osborn).

Rae Glacier, Alberta

(D. J. Smith, C. Lawby and C. Larocque, GEOG/SASK)
The 40 stakes installed on Rae Glacier in 1990 were surveyed regularly to a permanent benchmark using an electronic total station. Annual surface velocities are relatively slow, averaging 3.4 m a^{-1} (from 1.2 m a^{-1} near the snout to 4.5 m a^{-1} near the ELA). Deformation rates are <1 cm d^{-1}, with basal slip contributing a substantial component of overall flow during the ablation season. Ablation is quite variable with volumetric loss in the surveyed area ranging from >86 257 m^3 in 1990 to 29 680 m^3 in 1991.

The maximum ice depth measured with a mono-pulse radar unit was 53 m. Observations suggest ice losses at Rae Glacier since the Little Ice Age total ca. 2.91×10^7 m^3; a volumetric loss of 85%.

SNOW – GENERAL

Snowfall in Canada

(J. M. M. Frappier, National Atlas/EMR and R. Crowe, CCC/AES)
The 5th edition of the National Atlas of Canada main map (1 : 12 500 000) shows mean annual snowfall in Canada. Six other maps (1 : 25 000 000), illustrate the distribution of median snow depth on 15 November, 31 December, 15 February and 31 March, the median dates of snow cover loss and formation, and the maximum snow depth.

Optical properties of falling snow

(D. L. Hutt, Electro-Optics Division/DREV)
Commercial forward scatter-meters can be used to estimate visibility in snow with appropriate calibration. Extinction of visible and IR beams by falling snow can be modelled by taking into account multuple scattering effects. A multiple field-of-view lidar can remotely detect ice crystals suspended in stratus clouds.

SNOW – ARCTIC

Mass and energy transfer in seasonal snow

(M. R. Albert, CRREL, with J. P. Hardy and R. S. Bradley, GEOG/Univ. Massachusetts, Amherst, MA 01003, USA)
The influence of wind pumping on polar snow temperature regimes and the behaviour of snowmelt flow paths through a very cold snowpack is being studied in northern Ellesmere Island. A 3-D physically based numerical flow model will simulate heat and mass transfer in the snow.

Mountain hydro-meteorology

(D. R. Hardy and R. S. Bradley, GEOG/Univ. Mass., Amherst, MA 01003, USA)
The winter snowpack in northern Ellesmere Island is being assessed and characterized, to determine heat inputs controlling meltwater production and streamflow, and to delineate rainfall runoff from snowmelt using stable isotopes. Solar and terrestrial radiation measurements at sea-level and 520 m should determine the influence of altitude on the radiation balance at the snow surface.

Snow–atmosphere interaction

(H. G. Jones, INRS/Québec)
Experiments on the concentration changes of NO_3 in surface snow on the Agassiz Ice Cap have shown that the transfer of NO_3 at the snow–atmosphere interface is influenced by solar radiation. The results suggest that photochemical processes on snow grain surfaces could be a factor in the control of NO_x and/or HNO_3 fluxes between the atmosphere and snowcover.

Isotopic composition of precipitation

(F. A. Michel, ES/CARL with R. Drimmie, GEOG/WATER)
Precipitation from across the Canadian Arctic is being collected and analyzed to determine the isotopic directions occurring in the precipitation.

High Arctic wetland basin hydrochemistry

(J. M. Buttle, K. E. Fraser, M. A. Ecclestone and W. P. Adams, GEOG/TRENT)
Ca^{2+} dominated the ionic load in the premelt snowpack. H^+ was retained on hill slopes during snowmelt, while there was net export of Ca^{2+}, Mg^{2+}, Na^+, K^+ and Cl^- to the wetland. Differences in active layer thickness have an important control on contact time between infiltrating meltwater and the soil; these differences in turn accounted for spatial variations in net ionic export from slopes. The wetland retained H^+, Na^+, K^+ and Cl^-, while there was a net export of Ca^{2+} and Mg^{2+} from the basin as a result of cation exchange.

Spatial variability of snow

(M.-K. Woo and Zhaojun Xia, GEOG/McM)
Meso-scale variations of snowmelt are related to the uneven aeolian deposition of dust in the arctic winter. Field measurements and experiments were made to study the spatial variability.

Contaminants in arctic ecosystems

(D. J. Gregor, C. Teixeira, R. Rowsell and R. Semkin, NWRI/EC)
Median winter deposition of PCBs in 1986 and 1987 was 70 $\mu g\, m^2$. Subsequent work is quantifying deposition on a weekly basis. At Moult Bay total PCB deposition from late October 1990 to March 1991 was about 2 $ng\, m^2 d^{-1}$, but increased to 11 $ng\, m^2 d^{-1}$ during one week in January 1991. This is thought to be due to increased scavenging of atmospheric pollutants during a snowfall event.

SNOW – WESTERN CANADA

Ground snow loads, western Canada

(H. Auld, D. A. Etkin and W. Dnes, CCC/AES)
Ground snow-load estimates, provided for mountainous areas for the National Building Code of Canada, are being re-examined.

Snow survey bulletin

(G. B. Atkinson, AES/Winnipeg, R3C 3V4)
A report on snow depth and the water content in the Prairies and Arctic is published weekly.

Snow water-equivalent and ice maps

(F. Thirkettle, Ph.D. Associates Inc., 100–3553, 31 Street N.W., Calgary, T2L 2K7)
Operational campaigns are in effect for prairie hydrometeorological stations (government) and private sector groups to produce near real-time satellite operational snow water-equivalent and ice maps.

Passive microwave studies of prairie snow

(A. E. Walker and B. E. Goddison, CCC/AES)
During wet snow conditions the current passive microwave snow water-equivalent algorithms produce false zero values; misinterpreting wet (melting) areas as snow-free land and underestimating snowcover extent. A wet snow indicator derived from SSM/I 37 GHz dual-polarization data discriminates wet snow areas from snow-free land and allows a more accurate representation of snowcover extent during short-term winter melt events or throughout the spring melt period.

WMO solid precipitation intercomparison

(B. E. Goddison and J. R. Metcalfe, CCC/AES, K. Jones, Scientific Services Division/AESR)
The correction factor to estimate true precipitation from winter precipitation measurements can be over 3.0 for unshielded gauges. Systematic under-measurement, due to wetting losses and trace observations, is significant with manual gauges like the Canadian Nipher shield snow gauge. Corrections for wind-related errors, associated with various gauge configurations, are being developed in relation to the WMO reference standard — an octagonal, vertical, double-fence shield surrounding a Tretyakov precipitation gauge (DFIR). The Regina airport testing site will be dismantled in the spring 1992 and a summary report covering 15 years of testing various snow gauges prepared. A long-term precipitation reference station has been established near Barrie, Ontario.

Regional snow-melt model

(R. Hopkinson, Scientific Services Division/AESR)
Considerable success has been achieved in modelling the snowpack using standard climatological data at Regina, but the results are *not* universally applicable across the Canadian Prairies.

Snow cover prediction from topography

(L. W. Martz and D. R. Lapen, GEOG/SASK)
Correlations between individual topographic variables and snowcover properties were weak, but landform units defined in terms of topographic variables had distinctly different snowcover properties. This functional classification forms the basis for an empirical predictive model which reveals the most important factors governing snow redistribution in prairie landscapes.

Snow management

(H. Steppuhn, SCRS/AC)
Some prairie soils have a chemical imbalance, which when amended with calcium, require increased water inputs for reclamation; this can be achieved through snow management. Water accumulated in snow-fenced plots was seven times greater (76 to 11 mm) than unfenced plots. Upon melting, 41% more water was supplied to depths up to 60 cm within the soil profile.

Snow–atmosphere exchange

(J. W. Pomeroy, P. Marsh and T. D. Prowse, NHRI/EC, H. G. Jones, INRS-Eau, D. J. Gregor, NWRI, D. M. Gray and D. H. Male, ENG/SASK, N. E. Peters and R. A. Schmidt, USA, T. A. Davies, East Anglia, UK and M. Tranter, Southampton, UK)
Initial results form sites near Inuvik and Tuktoyuktuk show snow water-equivalent and most major ion loadings at the tundra/forest ecotone are about ten times those in snow over adjacent open tundra, and concentrations of ions deposited as aerosols are as much as 60 times higher over these sites than over open tundra.

An experiment near Radville (Saskatchewan) to measure blowing-snow transport and sublimation and the efficiency of tall snow fences for accumulating snow in artificial ponds showed a dramatic increase in snow accumulation in the pond.

Measurements in Prince Albert National Park, Saskatchewan and near Inuvik, showed many light snowfall events are intercepted with 50% efficiency by dense black spruce and jack pine canopies; this intercepted snow scavanges sulphates and nitrates, and after sublimation the highly concentrated remnant is released to the ground during warm weather. Snowpacks under dense spruce and pine forests contain 50% to 60% of the water equivalent found under aspen forests, however most snowpack chemical concentrations are higher under the coniferous trees. Open spruce and pine forests show these effects to a much lesser degree.

The Prairie Blowing Snow Model can now use mean monthly climate data. Operational blowing snow transport and sublimation equations can calculate the snow redistribution/sublimation budget in regions of incomplete meteorological measurements.

Snow cover and boreal mammals

(W. O. Pruitt, Jr, ZOO/MAN)
Comparison of more than 2000 hardness vs density measurements in northern Saskatchewan, southeastern Manitoba and northeastern Finland revealed no consistent correlation. The same applied to comparisons of horizontal and vertical hardness; therefore one measure cannot be substituted for the other. Increases in snow thickness and hardness in burned uplands have apparently led to the abandonment of some late-winter habitat by caribou in southeastern Manotiba.

SNOW – CENTRAL AND EASTERN CANADA

Snow-hedge design guidelines

(M. S. Perchanok, R&D Branch/Ministry of Transportation, 1201 Wilson Ave., Downsview, M3M 1J8 (MINT))
Preliminary findings suggest that the set-back of a snowhedge from the road can be reduced from 25 times the height which is not standard. The relationship between hedge type, height and density, and required set-back are being investigated.

Snow fence specification

(M. S. Perchanok, R & D Branch/MINT)
Operational trials of a variety of fence fabrics provided qualitative performance criteria. Engineering laboratory tests were used to define tensile and elongation criteria applicable to any fabric intended to be used as a snow fence.

Snowdrift model

(M. S. Perchanok, R & D Branch/MINT, D. G. McGillvray and J. Smith (MEP Co.), H. B. Granberg, CARTEL/Sherbrooke)
A numerical simulation model for highway designers to test the severity of snow drifting and accumulation at any highway site in Ontario, and to compare the effectiveness of mitigative treatments prior to highway construction, is being developed.

Highway de-icer research

(M. S. Perchanok, D. G. Manning, J. J. Armstrong and R. Raven, R & D Branch/MINT)
Calcium magnesium acetate (CMA) holds the greatest potential as an alternative to salt by virtue of reduced negative impacts on highway structures, motor vehicles and the environment. However, it is more costly and less effective than salt.

Suburban snowmelt runoff

(J. M. Buttle, A. Vonk and C. H. Taylor, GEOG/TRENT)
Suburban areas have higher snowmelt rates than open fields and forests. Their catchments respond faster than rural ones to snowmelt and rain-on-snow. Progressive development has led to a six-fold increase in spring quickflow response and more snowmelt events that generate quickflow. Stormflow during rain-on-snow is dominated by event water runoff from artificial surfaces, although pre-event water contributions are significant during snowmelt. Cl^- export patterns during snowmelt and rain-on-snow differ due to changes in contributing areas.

Snowpack and chemistry

(B. D. La Zerte, Dorset Research Centre–OME/Box 39, Dorset, Ontario, P0A 1E0)
Processes have been described in an investigation of snow accumulation and loss, and snowpack chemical accumulation and loss, as part of a study to model accumulation and loss of major ions in the snowpack.

Hydrochemical fluxes during snowmelt

(J. M. Buttle, K. Sami and S. Steele, GEOG/TRENT)
Ground-water contributions to streamflow during snowmelt were attributed to expansion of a ground-water mound under a central wetland and its extentions down the stream channel, rather than to ground-water ridging mechanisms operating under adjacent hill slopes. SO_4^{2-} fluxes in streamflow during snowmelt exceeded contributions from the snowpack and precipitation, as a result of pronounced desorption of SO_4^{2-} from the basin's soils during ground-water recharge.

Chemistry and microbiology of snowmelt

(H. G. Jones, INRS/Québec)
Experiments on the concentration changes of NO_3 in snow meltwaters have shown that microbiological activity can reduce the amount of total nitrogen by 30% during the transfer of solutes from the snowcover to the soil during snowmelt. Snow algal assimilation of NO_3 appears to be the dominant overall process for the loss of this nutrient species.

Snowcover and climate, Grand Lake, Newfoundland

(C. E. Banfield, GEOG/MUN)
Local to meso-scale variability in individual event snowfalls over Grand Lake basin is regulated by proximity to open water, elevation and topographic situation with respect to airflow direction during precipitation events.

AVALANCHES

Avalanche Research Group

(D. M. McClung, GEOG/UBC)
Analysis of avalanche runout distances from the Coast Range using terrain variables was completed. The data were compared with a similar analysis of 500 avalanche paths from five other mountain ranges using extreme value statistics. Work is in progress on a computer-assisted avalanche prediction scheme using snow, avalanche and weather data. The system features Bayesian statistics coupled to parametric discriminant analysis, including cluster techniques, to analyze past avalanche occurrences. The text for *The avalanche handbook* was delivered to a publisher. It is a sequel to Perla and Martinelli's (1976) book of the same name.

Snow stability and avalanche hazards

(C. D. Johnston and J. B. Jamieson, Civil ENG/CAL)
Shear frame tests show strength is reduced by decreasing distance between fins or increasing area. Under rapid loading, the ratio of tensile to shear strength of low-density snow approximates 1. Most natural dry slab avalanches occur when the ratio of shear strength (of weak layer) to vertical overburden stress is less than 1.5.

Rutschblock tests indicate most natural dry slab avalanches occur when the Rutschblock score is <5. In the 25–40° range, median scores increase by 1 for a 10° decrease in slope angle. Rutschblock scores correlate with the Swiss S' stability index when the load is <400 Pa.

Influence of avalanches on snowmelt runoff

(F. de Scally, GEOG/Okanagan College, 1000, KLO Rd, Kelwna, V1Y 4X8)
Research in Pakistan showed a significant delay in melting of avalanche-transported snow compared to undisturbed snow. Even in a large basin (Himalayas, 2500 km^2) avalanche snow can represent 6% of the annual runoff in severe avalanche years.

PERMAFROST – GENERAL

Canadian permafrost map

(M.-A. Dubreuil, National Atlas/EMR, and J. A. Heginbottom, GSC, TSD/GSC)
The fifth edition of the National Atlas of Canada map will show the extent of permafrost (continuous, extensive, sporadic, isolated patches and subsea) and relative content of ground ice. Other information includes: relative abundance of massive ice bodies, ice wedges and pingos, mean annual ground temperature, thickness of permafrost, and depth to the top and bottom of subsea permafrost. The sheet includes temperature profiles at selected locations, a brief text describing the general nature and characteristics of permafrost and ground-ice conditions in Canada as well as methodology, and a glossary of permafrost terms. A 1 : 30 000 000 inset map illustrates the distribution of permafrost temperature.

Multi-lingual index for permafrost glossary

(R. O. van Everdingen, AINA/CAL)
A set of internationally accepted permafrost terms for use in science and engineering, with equivalents in French, German, Russian and Spanish, is being developed.

Permafrost hydrological models

(M.-K. Woo and Zhaojun Xia, GEOG/McM)
A stochastic model was completed to simulate climatic inputs for snowfall and river ice calculations under climatic change scenarios. Hydrological models are being developed to estimate frost table and water table positions in a continuous permafrost environment.

Processes in freezing soils

(B. Ladanyi and M. Shen, Génie civil/EP)
The newly developed conceptual model and numerical solution, involving a combination of the finite-difference and finite-element methods, was successfully validated against laboratory test results published by Penner (1986), and against measurements made during a large-scale test on a buried chilled pipeline (in Caen, France). The method makes it possible to predict the stresses acting on a buried chilled pipeline under any given longitudinal pipeline rigidity conditions.

(P. J. Williams and M. W. Smith, GEOG/CARL)
The passage of a buried chilled gas pipeline across the boundary between permafrost and unfrozen, frost-susceptible ground, is simulated in a large controlled-environment laboratory in Caen, France. Frost heave of the ground surface, stresses in the ground and soil displacement are monitored. High stresses develop within the frozen soil and deformation of the pipe is characterized by a sharp inflection at the interface between the permafrost body and adjacent soil.

Freezing kinetics of saline soils

(M. K. Seguin and A. Frolov, GEOL/LAVAL)
Using electro-acoustic conversion and dielectric spectroscopy, the freezing kinetics of saline soils in a porous medium can be quantified in the temperature range from 0° to –35°C.

Frost penetration and ground temperatures

(G. McCormick, EBA Engineering Consultants Ltd, 14535 – 118 Avenue, Edmonton, T5L 2M7)
Frost penetration records from Canadian airports are being reviewed.

Monitoring thawing front movement

(M.-K. Seguin and R. Fortier, GEOL/LAVAL)
The variations of potential difference in a hole with time are correlated with those of temperature variations. Polarity and intensity of self-potential are used to characterize the nature of the active layer/permafrost boundary.

Bedrock frost heaving in permafrost

(Y. Michaud, Cen. Géoscientifique, 2700 rue Einstein, C.P. 7500, Sainte-Foy, G1V 4C7, and L. D. Dyke, GEOL/Queen's Univ., Kingston, K7L 3N6)
Results from freezing tests confirmed pore-water expulsion mechanism as the most likely mechanism at the origin of forces producing heave displacement. Shear test results demonstrated that the main resistance to heave is provided by the ice-filling in bedrock fractures. Data suggest a shear stress at failure in the ice-filling on the order of 0.3 MPa. Finally, bedrock frost heaving occurs through the ductile deformation of fracture ice-filling.

Piles under axial and lateral loads

(B. Ladanyi and A. Foriero, Génie civil/EP)
Complete analytical and numerical solutions for stress redistribution with load and time in short and long, rigid and flexible, axially and laterally loaded piles, embedded in permafrost, have been obtained and compared with laboratory and field test results.

(D. H. Shields and L. Domaschuk, Civil ENG/MAN)
Lateral movement and bending moments continue to increase with time, making "new" demands on the structure.

Examination of massive ground ice using ground penetrating radar

(B. J. Moorman, ES/CARL)
GPR is being used to characterize ground ice of different origins.

Infrastructure for cold climates

(L. W. Goodrich and T. H. W. Baker, Inst. for Res. in Construction/NRC)
Slab-on-grade foundations, chilled using conventional heat-pump technology, are technically an economically effective foundation on permafrost; three demonstration projects have been completed. Passive insulation, incorporating variable thermal conductivity, is a potentially effective means of cooling embankments on permafrost.

Borehole dilatometer creep and relaxation

(B. Ladanyi, Génie civil/EP)
Both in situ tests, at two permafrost sites (CRREL Permafrost Tunnel, Alaska; Longyearbyen, Svalbard), and a series of full-scale tests, were carried out under well-controlled cold room conditions. The results were interpreted by ageing creep, reference stress, and isochronous curves methods. The values of creep parameters determined from the Borehole Dilatometer Relaxation Tests were found to agree well with those determined by some other testing methods, such as triaxial compression and borehole creep tests.

In situ creep properties determination

(B. Ladanyi, P. Talabard and J. Sgaoula, Génie civil/EP)
This method consists in pushing a smooth low-angle cone into a predrilled conical portion of the borehole. Creep properties are determined by applying a constant axial load to the cone, and by observing its time-dependent axial displacement, tending to enlarge the hole. Results in ice and frozen sand under cold-room conditions show that reasonably consistent values of creep parameters, comparable to some pertinent published data, can be obtained by this type of test.

Cone penetration testing

(B. Ladanyi, Génie civil/EP, T. Lunne, Norway, P. Vergobbi and B. Lhuiller, France)
The field tests carried out in frozen silt (1988), in frozen silty sand (1990) and in sea ice (1990) have confirmed previous findings that, in a given frozen material, at a constant temperature, there is a unique relationship between the cone resistance and the cone penetration rate. This makes it possible to carry out either continuous frozen soil strength profiling down to a given depth, or to determine the frozen soil or ice strength vs strain rate behaviour within a selected soil layer.

PERMAFROST – ARCTIC AND YUKON

Permafrost and climate

(J. B. Maxwell, A. N. Headley and B. Peters, CCC/AES)
Primary field sites being monitored and evaluated for the effect of a changing arctic environment on permafrost include: Hot Weather Creek (Ellesmere Island); the Mackenzie Corridor from Norman Wells to Richards Island on the Beaufort Sea coast; the Barnes Ice Cap, Amadjuak and Nettilling lakes on Baffin Island; Mayo, Churchill and Schefferville.

Thermal and hydrological investigations

(C. R. Burn, GEOG/CARL)
The response of permafrost to climate change, the hydrology of frozen soil, and $\delta^{18}O:\delta D$ relations are being investigated in northwest Canada.

Properties, distribution and testing

(P. J. Kurfurst, TSD/GSC)
Nearshore areas of the southern Beaufort Sea show considerable variability in lithology, material properties and geothermal regime in the temporal and spatial sense. Major stratigraphic units have been identified as well as major factors controlling the geotechnical properties.

Thermal stability of gas hydrates

(A. S. Judge, GSC and J. A. Majorowicz, Northern Geothermal/Edmonton, T6H 4L6)
Connection between deep gas fields and documented occurrences of gas hydrates above in the Beaufort–Mackenzie area. An ongoing release of methane from gas hydrates as a result of change of surface environmental conditions is predicted.

Massive ground ice, Fosheim Peninsula

(S. D. Robinson, GEOG/Queen's Univ., Kingston, K7L 3N6)
Reconnaissance field work began on mapping the distribution and determining the geomorphological processes associated with massive ground ice in the Fosheim Peninsula area of Ellesmere Island, using geophysical techniques such as ground-penetrating radar.

Electromagnetic studies, Mackenzie Delta

(B. J. Todd, S. E. Pullan and J. A. M. Hunter, TSD/GSC)
The permafrost base deepens very rapidly from tens of metres under "young" delta deposits to hundreds of metres beneath "old" delta deposits. Some shallow lakes appear to have thaw zones beneath them, as does the Mackenzie River.

Active layer monitoring, Mackenzie Valley

(F. M. Nixon and P. Eggington, Minerals and Continental Geology/GSC)
A program to monitor regional variability of the active layer and its changes over time, as a response to environmental change, is in the initial phase of site installations.

Electrical freezing potentials

(J. R. Mackay, GEOG/UBC, and V. R. Parameswaran, Inst. for Aerospace Res./NRC)
The growth of a pingo ice-core has been monitored for six years by measuring the freezing potential generated on an electrode located at the freezing front. The rate of growth is about $15\,\mathrm{cm\,a^{-1}}$.

Thermal structure of permafrost, Taglu

(A. S. Judge, GSC, and J. A. Majorowicz, Northern Geothermal/Edmonton, T6H 4L6)
Unfrozen zones within permafrost in the Taglu area (Beaufort–Mackenzie) were interpreted from well logs.

Soil temperature regimes, Mackenzie Valley

(H. N. Hayhoe and C. Tarnocai, LRRC/AC)
The effect of site disturbance on the active layer along the Norman Wells pipeline near Fort Simpson has been quantified.

Icings and springs, Mackenzie Valley

(G. W. Hollingshead, Thurber Engineering Ltd, 3 Coronation Drive, Box 1317, Yellowknife, X1A 2N9, Jack D. Mollard and R. O. van Everdingen, AINA/CAL)
There are over 100 icings or potential icings within a possible pipeline corridor in the Mackenzie Valley downstream of Norman Wells. Some cover up to a hectare and are over 1 m thick.

Permafrost and active layer depth, southwest Y.T.

(D. R. Peddie, GEOG/OTT)
Using a new evidential reasoning classifier, the occurrence of permafrost was classified with accuracies of 85% and 82% from field data and digital remote-sensing imagery, respectively, in a $100\,\mathrm{km}^2$ area of discontinuous permafrost near Aishihik Lake, Ruby Range. In a second experiment, four active-layer classes were classified with an accuracy of 79% from image data. It may well be possible to estimate regional permafrost occurrence and active-layer depth from digital remote-sensing data alone.

PERMAFROST – ELSEWHERE

Alpine permafrost

(S. A. Harris, W. MacDonald and J. Pederson, GEOG/CAL, with Institute of Glaciology and Geocryology, Lanzhou, China)

The distribution of alpine permafrost, the nature and processes occurring in its associated landforms, and the effects of climate change on them are being investigated.

Blanc Sablon region, Québec

(M. K. Seguin and J.-C. Dionne, GEOL/LAVAL)
Geomorpholoical, geophysical and geothermal studies of pemrafrosted palsa fields were undertaken in the Blanc Sablon area. Recent thermal recordings and atmospheric temperatures suggest that the marginal patches of permafrost are in thermal equilibrium.

Qinghai-Xizang (Tibet) Plateau

(M.-K. Seguin and Y. Huang, GEOL/LAVAL)
The axial distribution and thickness of alpine permafrost in continuous and discontinuous zones is being delineated using electrical resistivity, induced polarisation soundings and some calibration with drill-hole information.

High ice-content permafrost table, Qinghai-Xizang highway

(M.-K. Seguin and Z. Zeng, GEOL/LAVAL)
The variation of the permafrost table, active layer and the occurrence of ice lenses which are highly damaging to the highway have been detected and characterized with the help of a continuous recording ground-probing radar survey.

PHYSICS OF ICE

Physics and chemistry of ice

(Edward Whalley, SIMS/NRC)
Laboratory studies were carried out on ice and related materials.

Supramolecular science – ice and clathrates

(J. A. Ripmeester, C. I. Ratcliffe, D. D. Klug, John S. Tse and G. E. McLaurin, SIMS/NRC)
^{119}Xe NMR shows that there is a short-range ordering of water around the Xe atoms before crystalline order sets in amorphous co-deposits of water and Xenon.

Structure H hydrate readily forms in light hydrocarbon fractions such as gasoline.

(J. A. Ripmeester, C. I. Ratcliffe, D. D. Klug, John S. Tse, SIMS/NRC)
^{2}H NMR at 77 K shows that there is a considerable lengthening of O–O distances (nearest neighbour) in high density amorphous ice as compared to ice Ih. Spin-lattice relaxation measurements suggest that these may be used to distinguish amorphous ices.

Supramolecular chemistry – ice and clathrates

(J. A. Ripmeester and G. E. McLaurin, SIMS/NRC)
R 141-b (CH_3CCl_2F) is a clathrate hydrate former suitable for cool energy storage.

ATMOSPHERIC ICING

Atmospheric icing of structures

(J. A. Druez and others, Sciences Appliquées/UQAC)
A data base on atmospheric icing (glaze and in-cloud icing, frequency and duration of events, ice loads, ice accretion and shedding rates, statistical modelling of accretion and shedding) has been developed. Research on icing of electrical lines includes studies of static and dynamic loads, accretion, shedding and vibrations. Other investigations include those into the mechanical strength of glaze, rime and spray-ice (adhesion, tension, compression, torsion) as a function of strain rate, temperature, wind velocity, droplets diameter and liquid water content.

(T.-C. Yip, CCC/AES)
Different icing models are being compared with observation data to select one for glaze ice simulation. So far, the simple empricial model developed by Chaine and Skeates, seems to be the best.

Atmospheric ice accretions

(J.-L. Laforte, GRIEA/Sciences Appliquées/UQAC)
Grain size and porosity of ice accreted on the surface of insulators in DC+, DC– and AC show no significant change compared to features in non-energized conditions. Morphology and porosity of icicles grown under DC+ and AC have shown some differences when compared to those formed under DC– and in non-energized conditions. The effects of polarity are mainly seen at the top of the icicle where the pendant drop is deformed and elongated under the enhanced electric field, producing discharge activity.

Flashover and vibration of high voltage conductors

(M. Farzaneh and 10 researchers, Science Appliquées/UQAC)
Studies on the influence of snow, ice and rain have revealed: the minimum flashover voltage of ice-covered insulators; the effects of voltage polarity on the rate of ice accretion deposited on conductors and insulators; mechanisms of corona-induced vibration under wet snow and rain conditions; the grain texture of ice and icicles grown on H.V. insulators; and the ionic wind velocity near ice asperities.

De- and anti-icing of grounded aircraft

(J.-L. Laforte, P. Louchez and G. Bouchard, GRIAE/Sciences appliquées/UQAC)
During the last three years, a research infrastructure has been set up by GRIEA to investigate, under various icing conditions, the behaviour of de-icing and anti-icing products used on grounded aircraft. Four testing procedures have been developed and marketed. Two, in a climate chamber, measure the holdover times of de-icing and anti-icing under cold conditions simulating freezing rain and frost deposition. Of the other two, in a cold tunnel, the first uses a 2-D small-scale model, and the second a flat plate, both covered with a film of fluid and submitted to a simulated take-off. The UQAC facility is the only private laboratory in North America able to evaluate de- and anti-icing products and certify them for commercial use.

MARINE ICING

Marine icing

(E. P. Lozowski, W. P. Zakrzewski, K. Szilder, R. Blackmore and V. Chung, MET/GEOL/ALTA)
A 3-D, time-dependent model of ship icing has been completed. A simple model of the overall iceload on a ship has also been developed and successfully tested using a Russian ship-icing data set.

(R. E. Gagnon, IMD/NRC)
Marine icing is being modelled on computers and simulated in marine icing wind tunnels.

Compressibility of spray ice

(L. Domaschuk, Civil ENG/MAN)
Creep plays a dominant role in compressibility. Increasing particle size increases compressibility. Increasing initial density from about 0.5 to 0.6 $g\,cm^{-3}$ reduces compressibility by about 50%. Compressibility under an isotropic state of stress was best represented by a hyperbolic function.

LAKE ICE

Early Canadian glaciology

(W. P. Adams, GEOG/TRENT)
Studies and observations of various types of ice appeared in journals published by the Royal Canadian Institute throughout the last half of the 19th century and well into the 20th. They do not appear to have fed into the mainstream of glaciology. One on lake ice expansion and contraction, undertaken in the 1850s, and on J. B. Tyrrell's observations of lake ice, will appear shortly. The journals are still available at very low cost.

Colour Lake, Axel Heiberg Island

(M. C. English, GEOG/WLU, with W. P. Adams, J. M. Buttle and M. A. Ecclestone, GEOG/TRENT)
Work on the amount and type of ice on Colour Lake and on the roles of ice growth and decay in lake and downstream chemistry continues. This is a naturally acid lake.

Passive microwave monitoring of lake freeze-up and break-up

(A. E. Walker and M. R. Davey, CCC/AES)
Preliminary results from SSM/I data of Great Slave and Great Bear lakes indicate it may be possible to discriminate between areas of ice-covered and open water using the 85 GHz channels, and therefore monitor ice formation and break-up over the two lakes. Coincident ground observations of lake-ice conditions are necessary to evaluate fully the potential of the SSM/I data for lake-ice monitoring.

Ice processes in Lake Ontario

(Robert Gilbert, GEOG/Queen's Univ., Kingston, Ontario, K7L 3N6)
The action of ice on the shores of northeastern Lake Ontario and its relation to the weather and limnological conditions that control it is being investigated at present and since glaciation.

Ice in lake systems, Schefferville

(O. Choulik, W. P. Adams and M. A. Ecclestone, GEOG/TRENT)
Winter oxygen depletion was studied in Knob and Pease lakes.

Thermal expansion of ice in reservoirs

(B. Michel, LMG/LAVAL)
The first year of study on two reservoirs on the St Maurice River showed the major damping effect of snowfalls.

RIVER ICE

Rivers and ice regimes

(H. R. Kivisild, HRK Consultants Ltd, 1420 Premier Way S.W., Calgary, T2T 1L9)
By defining ice rubble as a friction material, active and passive states of rubble mounds were found to express arresting and stable states of rubble. Large ice-covered areas were found to influence ice production and motion.

Ice jams: theory and control

(B. Michel, LMG/LAVAL)
There is a limit equilibrium on the levels that can be attained with ice jams. New jam-control methods are being developed.

Ice-jam occurrence and severity

(S. Beltaos, NWRI/EC)
The previously developed numerical model, RIVJAM, which calculates the longitudinal variation of thickness and water levels along an ice jam, was applied to several sets of field data. It reproduced the measurements adequately while values of the coefficients were consistent with values determined analytically in the past.

Flow through the voids of ice jams

(S. Beltaos, NWRI/EC)
Values deduced from numerical modelling exceed those expected from extrapolated test results. Direct field measurements are possible when grounded jams form at ice retention structures. Pertinent measurements were carried out at such a structure, in the Credit River at Mississauga, during a winter break-up event in February 1992. After the other surveys under open-water conditons, it will be possible to deduce the first field values of flow through an ice jam.

Characterization of ice break-ups and ice jams

(S. Sarraf, Génie civil/CONC and N. El-Jabi, ENG/MONCTON)
Characterizing ice break-ups and ice jams through statistical approaches and theoretical analyses has been relatively successful. The ultimate objective is to be able to predict these phenomena with measured certainties.

Ice cover and ice-jam formation modelling

(S. Sarraf, Génie civil/CONC)
A 2-D model based on the depth-averaged hydro- and thermo-dynamic equations has been developed to simulate the transient behaviour of ice-jam formation and release

conditions. Heat exchanges with the atmosphere are computed for varying meteorological conditions. The movement and deposition of a fragmented ice cover are now being investigated.

Computer simulation of motion of broken ice

(O. G. Vinogradov, P. Wierzba and W. A. J. Springer, Mechanical ENG/CAL)
A mathematical model and corresponding computer code for simulating the flow of disks random in size and with random distribution on the water surface was developed.

Heat transfer through a brash-ice cover

(S. Sarraf, Génie civil/CONC and V. H. Chu, Civil ENG/McG)
Small-scale features on the rough ice/water interface were found to play a prominent role in heat transfer across the interface. The roughness, created by preferential melting around the rugged ice elements, was responsible to an increase in heat flux from water to ice.

Frazil and anchor ice

(Gee Tsang, NHRI/EC)
An empirical equation for the distribution of frazil in a flow was found and parameters determining the formation of anchor ice were ascertained.

River channel ice regimes, Mackenzie Delta and Hay River

(D. A. Sherstone, Scientific Services/NWT Science Institute, Box 1617, Yellowknife, X1A 2P2)
Ten winters monitoring in the Mackenzie Delta confirms that maximum thickness is achieved in late April or early May. Delta ice is consistently thinner in channels on the east side than the west. Central Channel shows greater year-to-year variations, thought to be due to freeze-up events and timing in Middle and Oniak channels. At Hay River, maximum thickness is reached in the first two weeks of April. Ice can thin by as much as 50% prior to break-up. Weather conditions are the prime factor in determining the timing and magnitude of break-up events.

Restigouche River ice, New Brunswick

(S. Beltaos, NWRI and B. C. Burrell, Environment/NB)
The configuration of the ice jam near the toe of the Restigouche River can be predicted using a numerical algorithm that solves appropriate differential equations.

ICE PROPERTIES

River ice cover cracking

(K. S. Davar, J. L Dawe and A. K. Abdel-Zaher, Civil ENG/UNB, Box 4400, Fredericton, E3B 5A3)
On the basis of a finite-element model (FEM1), longitudinal cracking was found to coincide with the positions of maximum bending stress for all river categories and varieties of boundary conditions. The experimental program indicated very good agreement between FEM1 predictions and measured values both for cracking positions and deflections.

Stable macrocracking, dynamic unloading and brittle fracture

(R. W. Marcellus, C.M.E.L. Enterprises Ltd, Box 220, Spencerville, K0E 1X0 [CMEL])
2-D boundary element analysis was used to evaluate load situations causing macrocrack propagation at the leading edge of an ice sheet; both lateral loading and wedge loading scenarios were investigated. The latter can explain the variability in local ice loads observed from both large- and small-scale measurements. The analysis shows why stable macrocracking occurs and provides a straightforward explanation of the occurrence of different failure modes in ice.

Characteristics of crack formation in ice

(L. W. Gold, LTL, (now Cold Regions Lab)/NRC)
Strain and stress for initiation of the first crack in columnar-grain ice under nominal constant strain rate compressive loading was found to agree with that found for granular ice under the same conditions of loading: the ratio of transgranular to grain boundary cracks depends on strain rate; for strain rates greater than about $5 \times 10^{-5}\ s^{-1}$, most of the cracks form in the grain boundaries; the crack width has log-normal distribution; the crack population depends on strain rate, grain size and temperature.

Large-scale fracture modelling

(R. W. Marcellus, CMEL)
A macrocrack propagated from the corners of an ice-pressure panel due to poor bonding with the ice and high stress concentrations at the panel corners. Analysis showed how the crack propagated in three distinct phases and the utility of the boundary element technique for its analysis.

Mechanism and law of creep of ice bicrystals

(B. Michel, B. Doyon and P. Barrette, LMG/LAVAL)
For monocrystals, the creep law depends essentially on the reduced shear stress on the basal plane, but only for orientations of basal planes ranging from 30 to 60 to the load axis. The creep curve of a bicrystalline sample shows strain hardening and anelastic behaviour.

Ice/structure interaction

(L. W. Gold, LTL/NRC)
A theoretical description has been completed of edge loading an ice body by a rigid rectangular indenter: the maximum in the indentation force is associated with the time dependence of Poisson's ratio; the total force of indentation is inversely proportional to the square root of the width of the indenter.

Field studies of ice forces on structures

(R. M. W. Frederking and M. Sayed, LTL/NRC)
LTL participated in a study on the influence of the Northumberland Strait Crossing on ice breakup. A statistical analysis was done of past measurements of ice pressures on light piers in the St Lawrence Seaway; measurement of ice forces on light piers continued.

Stranded-ice features, Slims River, Yukon

(J. D. Mollard, J D Mollard & Associates Ltd/810-2002 Victoria Avenue, Regina, S4P 0R7)
What are thought to be stranded-ice landform features have been observed on the Slims River "elevated"

floodplain surface. They are similar to features seen elsewhere in Canada on till and glaciolacustrine landscapes. From the air, they appear as nested, deformed, doughnut-shaped low ridges, possibly up to 1 m in height.

MARINE ICE – GENERAL

Canadian sea-ice map

(M.-A. Dubreuil, National Atlas/EMR, and W. E. Markham, Canadian Offshore Data Analysts)
The 5th edition of the National Atlas of Canada sheet illustrates ice conditions on February 28 and August 26. The frequency of ice occurrence, the maximum and minimum ice limits, the nature of the ice cover and the predominant direction of ice drift are given for both dates. Notes provide information on ice types, conditions and motion for regions of particular interest. Two other maps show the retreat and advance of the ice cover at two-week intervals. A brief text describes rationale and methodology, and includes a short glossary of sea-ice terms.

Habbakuk

(L. W. Gold, LTL/NRC)
A report on a wartime feasibility study to build ships from ice and the history of NRC involvement in the project has been completed.

Ice data collection

(G. W. Timco, LTL/NRC)
Canatec Consultants are collecting and collating all the techniques currently used for characterizing ice properties. The assessment includes the time/expense of the collection procedure, and the usefulness of the final result. P. Spencer & Assoc. are evaluating geophysical borehole logging techniques for detailing basic ice properties of temperature, density, and salinity. The resulting data would be used as input to the Timco/Frederking model of ice sheet compressive strength, as an index of ice strength.

STAR-2 operations

(E. M. Krakowski, Intera Information Technologies, 2500, 101 - 6th Avenue SW, Calgary, T2P 3P4 [INTERA])
SAR imagery was provided to the Canadian Coast Guard and Ice Centre (AES) for forecasting and modelling.

AES ice research and development

(René O. Ramseier, AES/ICE R&D Group, Box 100, Stittsville, K2S 1A2)
Work continues on improving regional and global microwave data access for mapping and disseminating derived geophysical parameters, and developing forecast products for AES observational units.

Remote sensing of sea ice

(J. Sutton, INTERA)
Work centres on collecting, analyzing, and reporting on the relationship between remotely-sensed data and sea ice.

MARINE ICE – TECHNOLOGY

Airborne sea-ice and snow thickness sensors

(J. R. Rossiter and L. A. Lalumiere, CANPOLAR), J. S. Holladay, Aerodat Ltd, 3883 Nashua Drive, Mississauga, L4V 1R3, S. J. Prinsenberg, Phys. & Chem. Sci./BIO)
During 1991 the pre-production prototype ice- and snow-thickness sensors were assembled and successfully tested in the Canadian Arctic. The results are being compared with those collected by IOS using an underwater vehicle. Accuracies are 0.1 m over flat ice, improving over ice ridges. First- and multi-year ice can be distinguished through sensing of apparent ice conductivity. In collaboration with BIO, the sensors were deployed over pack ice in the Strait of Belle Isle region at Piscolet Bay and St. Anthony and at Hare Bay on the Newfoundland Shelf to validate ERS-1 SAR data. Using EM and laser sensors, the data could be partitioned into snow and ice thicknesses. Real-time output compared well with on-ice measurements. The data will also provide information on floe sizes and surface roughness.

Ice radar

(K. Iizuka, Electrical ENG/TOR)
Improvement in the thickness resolution of the ice radar to the ultimate was attempted. It now has a resolution of a few micrometres and can even be used for finding a fault in the optical waveguide or a crack in an iceberg.

Automatic ice-melt measurement system

(G. B. Crocker, C-CORE/MUN)
A prototype automatic ice-melt measurement system has been constructed for measuring the basal ablation of ice floes in the Labrador Ice Margin

Ice growth in Turton Bay, Igloolik Island

(J. MacDonald, G. Qulaut and M. Arnatsiaq, Igloolik Res. Cen., NWT Science Institute, Box 210, Igloolik, X0A 0L0)
Monofilament line (dia. 2 to 3 mm) was used successfully for ice measuring gauges through at least 2 m of salt-water ice, obviating the need to bore holes through the ice to determine thickness.

Through-ice bathymetry system (TIBS)

(J. S. Holladay, Aerodat Ltd/Mississauga)
The TIBS successfully completed a first "production" survey of sea-water depth through ice in Pelly Bay, N.W.T. Accuracies are 0.3 m up to 30 m over a smooth bottom with flat-lying ice.

Detection of growlers using X-band coherent radars

(T. J. Nohara and S. Haykin, Raytheon Canada Ltd, 400 Phillip Street, Waterloo, N2J 4K6)
Significant improvements in growler detection can be achieved by using medium-dwell-time coherent processors on received radar echoes. Long-dwell-time techniques (integration for periods > 1 s) are required to meet stringent PD and PFA requirements.

Non-linear acoustic imaging of ice properties

(G. B. Crocker, J. Guigne and V. Chin, C-CORE/MUN)
Impulse response analysis of acoustic data reveals that different ice types (columnar freshwater, freshwater snow-ice, and saline ice) have distinct acoustic signatures in their frequency dependent transmission and reflection coefficients.

MARINE ICE – REMOTE SENSING

SAR studies of sea ice

(M. E. Shokr, Met. Services Res. Br./AES)
Textural information in synthetic aperture radar images has potential for discriminating ice types. Combining textural and tonal information improves the classification.

(T. Carrieres, Ice Centre/AES, Ottawa, K1A 0H3)
SAR signatures of level and rough first-year and multi-year ice were documented. The evolution of the temperature profile through a multi-year ice floe during the melt season was also studied.

(J. S. Patterson, INTERA)
Sea-ice roughness is being investigated as reflected to SAR backscatter.

Sea-ice remote sensing

(N. K. Sinha, LTL/NRC)
LTL participated in the Sea Ice Monitoring Site (SIMS) project at Resolute in June 1991 to validate SAR imagery.

Ice-movement from remote-sensing imagery

(J. R. Marko and N. McAleese, Arctic Sciences Ltd, 1986 Mills Road, RR1, Sidney, V8L 3S1)
An operational TRACKER II motion-extraction algorithm was installed on image processors in Sidney, B.C. and St. John's, Newfoundland, and showed excellent performance on a wide range and quality of sea-ice imagery. A geometry extraction program ICEPIC was tested on artificial binary ice images. Its application requires further development of methodologies for binarizing ice images.

Thermal infrared and microwave imagery

(M. J. Press and R. Blais, PHYS/Royal Roads Military College, FMO, Victoria, V0S 1B0)
There exists a strong correlation between the amount of open water in the North Water polynya of Baffin Bay and the prevailing winds.

MARINE ICE – MODELS

Sea-ice model verification

(B. Dixit, PFL Inc. Consultants, 608-7th Street SW, Suite 305, Calgary, T2P 1Z2)
Two 10-day input and output model verification data sets were produced for the Beaufort Sea and waters off the east coast of Labrador and Newfoundland, and several verification procedures tested. Sensitivity analysis was performed on input data sets, selected parameters, and variations to the wind and current driving fields.

(T. Carrieres, Ice Centre/AES, Ottawa, K1A 0H3, D. B. Fissel, Arctic Sciences Ltd., T. Yao, ASA Consulting, and T. Brown, BERCHA)
Forecasts, prepared at the Ice Centre (EC), use a regional sea-ice model (multi-ice category Hibler model) for daily assessments of sea-ice conditions. The verification data sets and procedures were found to be adequate for characterizing many aspects of the operational sea-ice model's performance. Their application showed the present model has some significant limitations, including the adequacy of the ocean current forcing input. More thorough investigations will be possible when less expensive, but more accurate, observation techniques provide better data sets.

Sea ice model verification

(R. W. Marcellus and M. Sander, CMEL)
The Regional Ice Model (RIM), used by AES for 48-hour ice drift predictions in the Beaufort Sea, Davis Strait, Baffin Bay, Labrador Sea, Grand Banks and Gulf of St. Lawrence, is being evaluated using data sets from the Beaufort Sea and the East Coast. Based on the results, the RIM will be modified to ensure more accurate predictions of ice movements.

MARINE ICE – ARCTIC OCEAN

Arctic sea-ice/climate studies

(J.B. Maxwell, T. A. Agnew and A. Silis, CCC/AES)
Considerable effort has gone into developing and collecting regional, hemispheric, and global sea-ice data bases for trend analysis and monitoring. This includes studies of sea ice and atmospheric circulation anomalies and sea-ice/climate relationships. Satellite remote-sensing data are incorporated into data analysis and monitoring work, linked to the sea-ice ground-truth field work.

Climate change and Arctic Ocean ice cover

(G. H. Fleming, PHYS/Royal Roads Military College, Victoria, V0S 1B0)
The impact of projected changes in arctic climate on the ice cover and acoustics of the Arctic Ocean is being examined using current CO_2 and 2 x CO_2 scenarios

Beaufort Sea ice model verification

(B. Dixit, PFL Inc. Consultants/Calgary)
Several procedures have been developed to test ice velocity, total and partial ice concentration, ice edge, and ice pressure.

Interannual variability of arctic sea ice

(D. M. Holland, L. A. Mysak and J. Oberhuber, MET/McG)
A thorough sensitivity study of a sea-ice model (uncoupled to an ocean model) has been carried out.

Small-scale ice–ocean interaction

(D. R. Topham and H. D. Pite, IOS)
The combination of ocean density stratification and heavily ridged pack ice gives rise to hydraulically controlled flows generated by the larger ice keels. This leads to very large increases in local drag force, about five times that in unstratified slow.

Meso-scale ice deformation and limit stresses

(D. R. Topham and H. D. Pite, IOS)
Data sets have been obtained of stress and large-scale

(50 km) ice motion over a six-week period, April-May 1991, in the southern Beaufort Sea. A detailed survey of the top and bottom topography of a first-year ice ridge/keel structure has been completed.

Pack ice driving forces

(R. M. W. Frederking, LTL/NRC)
The pack ice driving forces in the Beaufort Sea were measured from March to May 1991, with the aid of a contractor.

Ice regime data base – western access

(B. Dixit, PFL Inc. Consultants/Calgary)
Ice regime information is being extracted from SAR, SLAR, and NOAA imagery, and ground-truth data, for a surface vessel transit simulation model.

Beaufort Sea oceanography

(E. C. Carmack, PHYS/IOS)
The Mackenzie Canyon plays a major role in the exchange of material between the Beaufort Shelf and Arctic Ocean interior through eddy formation and amplified upwelling. New production in the Arctic can be estimated from a knowledge of water age, oxygen, and nutrients.

Sea-ice scouring, eastern Beaufort Sea

(A. Héquette, GEOG/LAVAL)
A strong cross-shelf gradient in seabed sediment disturbance by ice scouring has been shown using sidescan sonar and echo-sounder data. The density and magnitude of ice scours is strongly controlled by water depth between 5 and 20 m. The 10 m isobath corresponds to a landward limit of intense ice scouring.

Ship interaction with complex ice

(R. M. W. Frederking and M. Sayed, LTL/NRC)
An aerial survey was conducted of the Beaufort Sea ice cover in April 1991. The data were analyzed, in collaboration with McGill University, to determine the size and distribution of the ridges.

MARINE ICE – EAST COAST

Implications of global warming

(J. R. Marko and David B. Fissel, Arctic Sciences Ltd/Sidney, with P. Wadhams, J. A. Dowdeswell, P. M. Kelly, W. C. Thompson and R. D. Brown, Ice Centre/AES, Ottawa, K1A 0H3)
Sea-ice extents are the dominant controlling factor in determining annual iceberg severities off Newfoundland. Control is exerted both through ice modulation of shallow-water berg entrapment and reflotation rates and by ice-related suppression of floating berg deterioration and mass loss. Hence, the upper limits of annual berg severities are proportional to spring ice extents off Labrador; in turn proportional to winter ice extents in the upstream Davis Strait area. Historical data indicate the past two decades of apparent global warming have produced greater ice and iceberg severities off eastern Canada.

East Coast ice and climate change

(R. D. Brown, Ice Centre/AES, Ottawa, K1A 0H3)
Simplified "box" models are being applied to investigate the growth and advection of ice onto the Labrador Shelf from Baffin Bay/Davis Strait and connecting side channels for various years with high and low upstream ice extent. Ice motion data, from satellite imagery and buoys, will verify the regional ice models. The simplified model results will be compared to a Hibler-type ice-ocean coupled model to investigate the role of internal ice dynamics.

Sea ice over the Labrador Shelf

(M. Ikeda, Phys. & Chem. Sci./BIO)
Ice floe movements in the Labrador Sea are mainly determined by winds with a secondary contribution from ocean currents. Ice cover is mostly controlled by air temperature and modified by winds.

Wave attenuation in the marginal ice zone

(P. Larouche, Maurice Lamontage Inst./FOC, C.P. 100, Mont-Joli, G5H 3Z4)
SAR images allow greater spatial resolution of physical processes within the ice pack that affect wave attenuation. Evidence of refraction was observed as waves penetrating the marginal ice zone off Newfoundland encountered an area of different ice compaction.

SAR observation of waves in ice, LIMEX '89

(P. W. Vachon, A. S. Bhogal, C. E. Livingstone and R. K. Raney, CCRS/EMR)
Synthetic aperture radar observations were made of ocean wave evolution in the marginal ice zone, including wave attenuation and wave refraction. Attenuation rates were related to the bulk ice properties; providing an indirect means of deducing certain properties of the ice cover using remote sensing techniques. Waves in ice can provide insight to SAR imaging mechanisms for ocean waves.

Modelling waves and ice dynamics

(W. Perrie, BIO/FOC)
Field data from LIMEX '87 and '89 have been analyzed and models developed for ice drift and movement. The latter are being improved with coupling to surface winds, surface currents and ice movement.

Sea-ice response to wind forcing

(D. B. Fissel, Arctic Sciences Ltd/Sidney, and C. L. Tang, Phys. & Chem. Sci./BIO)
The response of an ensemble of sea ice floes to wind forcing was measured in the late winter of 1988 and 1989, using satellite-tracked platforms deployed onto the ice. Some of the platforms were equipped with anemometers. The response of sea ice wind drift to wind forcing ranged from 2.6 to 5.4% of the local wind over much of the inner continental shelf off the east coast of Newfoundland. Differences in the response factor were analyzed and modelled as effects due to proximity to the coastline, duration and steadiness of the wind field and the roughness and area concentration of the sea ice. Ice melt plays an important role near the ice edge in ice motion.

Satellite data for sea-ice forecasting

(V. R. Neralla and R. O. Ramseier, Ice Centre/AES, Ottawa, K1A 0H3)
The applicability of SSM/I data for obtaining simulations with the numerical sea-ice prediction model for the East Coast was successfully demonstrated.

Newfoundland sea ice flux study, 1992

(S. J. Prinsenberg, I. K. Peterson and G. A. Fowler, Phys. & Chem. Sci./BIO)
During the winter of 1992, the Newfoundland Sea-Ice Flux Study deployed 19 satellite-tracked ice beacons, on mobile pack ice off the Newfoundland/Labrador coast and on land-fast ice at Cartwright, to determine drift rates. Seven beacons collected ice and surface water temperature profile data for calculating ice thickness and growth and oceanic heat fluxes. At all deployment sites, ice thicknesses, ice salinity samples and temperature/salinity profiles of the water column were collected. The extent of the pack ice was above normal, with offshore winds keeping it further offshore than in 1991; also a year of above normal pack ice extent but with persistent onshore winds.

Variability of ice properties and geometry

(R. F. McKenna, IMD/NRC)
Experiments were conducted in March 1992 in the Newfoundland marginal ice zone to address the forces and processes involved when floes collide. A discrete numerical model has been developed to address elasticity, primary creep and microcracking when small ice samples are deformed. Progress has also been made on the development of a discrete model for determining the static properties of partially and fully consolidated broken ice masses.

Pack ice forces and displacement

(A. F. Aboulazm and others, Marine Institute/St John's)
Studies are underway of numerical simulation of forces and displacement in pack ice.

Full-scale trials, CCGS *Sir John Franklin*

(F. M. Williams and D. Spencer, IMD/NRC)
Full-scale trials were carried out in Notre Dame Bay, Newfoundland. Ship performance was determined as a function of ice and snow conditions. The effect of snowcover thickness and snow type have been identified and measured for the first time. A simple model was developed for thrust in ice as a function of ship speed and environmental parameters.

Ice resistance and fuel consumption

(A. F. Aboulazm and others, Marine Institute/St John's)
Fuel consumption for vessels is being related to pack ice resistance.

Ice scour

(C. M. T. Woodworth-Lynas, C-CORE/MUN)
Studies are underway into: processes of ice/seabed interaction; sub-scour deformation; processes in glacio-lacustrine/glacio-marine lithified sediments; and effects on benthic communities.

Surface wave radar development

(A. M. Ponsford, Raytheon Canada Ltd/Waterloo)
Surface wave radar detected icebergs and sea ice to ranges far beyond the microwave radar horizon from a shore installation. Data from icebergs have been ground-truthed out to 300 km.

MARINE ICE – ICE FORCES

Ice failure processes

(R. M. W. Frederking, LTL/NRC)
Medium-scale field indentor tests, which have implications for the design requirements of ships and structures subjected to ice loads, were analyzed. LTL, MUN and IMD are investigating the thermal behaviour and response of ice during continuous crushing.

(I. J. Jordaan and J. Y. Guigné, MUN, R. M. W. Frederking and N. K. Sinha, IME/NRCC)
Forces and local pressure distribution were studied in the field and ice near the indentor, where cracking and microstructural changes were taking place, was characterized. Compliance of the ice and changes in its structure were observed in more detail in the lab. An analysis based on nonlinear viscoelastic theory incorporating fracture and damage mechanics was formulated; providing insight into the interplay between these factors. The results form the basis of a practical analysis procedure and the concept of "critical zones" of high pressure which can explain the high local pressures observed and the scale effect.

Ice crushing processes

(R. E. Gagnon, IMD/NRC)
Pressure melting and heat generation by the viscous flow of melt appear to play an important role in ice crushing.

Ice loads model for simultaneous crushing

(R. W. Marcellus, CMEL)
Advances in the science of calculating ice forces on marine structures were summarized for the National Energy Board.

Load transmission through grounded rubble

(G. W. Timco and M. Sayed, LTL/NRC)
A test program with various agencies was conducted in the ice tank on load transmission through grounded ice rubble surrounding an offshore structure. A field program, with Esso Resources Canada and the National Energy Board, measured the grounding resistance of ice rubble on a soft sea-bed floor. In the lab, the mechanical properties of model and freshwater ice rubble were measured, using the new bi-axial compression tester.

Mechanical behaviour of broken ice

(Tai T. Wong, Hardy – AGRA Ltd, 219-18 Street S.E., Calgary, T2E 6J5, N. Morgenstern and D. Sego, ENG/ALTA)
A preliminary constitutive law for broken ice was established and used to simulate ice–structure interaction.

Ice impact on various contact surfaces

(H. R. Kivisild, HRK Consultants Ltd/1420 Premier Way S.W., Calgary, T2T 1L9)
Based on fracture mechanics, a formula was developed relating ice pressures to the dimensions of the contact face; models for dynamic pressures were produced. The history of ice testing in bore holes showed the applicability of the bore-hole jack.

Ice forces on structures

(F. M. Williams and M. Lau, IMD/NRC)
Model tests on downward breaking cones led to mathematical relations between ice forces and fundamental ice and ridge properties. Characteristics of peak dynamic response to ice forces have been identified for both stiff and flexible structures.

Snow and ice research by Sandwell Inc.

(D. M. Masterson, Sandwell Inc., Suite 805, 940 6th Avenue SW, Calgary, T2P 3T1)
Studies have been undertaken with various agencies on different aspects of ice forces and impacts and the development of spray technologies for ice islands.

Pressured ice with ships and structures

(G. W. Timco, LTL/NRC, with G. S. Newbury and S. J. Jones, IMD/NRC)
Model tests investigating the behaviour of pressured ice on fixed structures were completed and analyzed. A test on the behaviour of a ship in pressured ice conditions was performed. Information from the study is being compiled by German & Milne for the Canadian Coast Guard.

Deformation and failure behaviour of ice

(N. K. Sinha, LTL/NRC)
In situ borehole jack tests were conducted in first-year sea ice in Resolute Passage during the SIMS project. Constant stress creep tests were conducted on first-year sea ice in the laboratory. Testing of heavy ice, for Mobil, was completed and a report prepared. The first stage of a microstructure-based constitutive equation has been completed.

MARINE ICE – ICE PROPERTIES

Ice-basin model studies

(G. W. Timco and M. Irani, LTL/NRC)
Tests were completed (for Sandwell Inc.) measuring dynamic loads on the Chinese JZ-20-2-1 jacket platform. Drop impact tests for the CCG were completed. A test program in the ice tank measured the ice crushing forces of drifting ice floes on an isolated structure. In collaboration with the Norwegian Hydrotechnical Laboratory (Trondheim), the feasibility of using a boom to contain ice in northern areas where an oil spill has occurred was tested. Another ice tank test, for MUN and Esso Resources Canada Ltd., studied ice loads on a faceted conical-shaped structure.

The ice tank now has the capability of moving the ice sheet past a stationary structure during a test. This configuration is important in several different types of studies.

Physical and microstructural properties

(M. E. Shokr, Met. Services Res. Br./AES)
Basic information about ice-crystal structure and inclusions in ice (brine pockets and air bubbles) was obtained. Various air bubble shapes and orientations were found in multi-year ice. Except for ice surface temperature, other ice physical properties do not change significantly during the early melt season.

Ice fracturing, tomography, and mechanical properties

(Y. Xie, Ocean Acoustics/IOS)
Initial break-up of landfast ice consists of horizontal failure which induces rubbing between adjacent ice floes. A multi-year icefield (with rubble ice) responds to thermal stress (due to cooling) more readily than first-year ice. Inhomogeneities in ice structures can be studied through their modification of acoustic seismic signals generated by artificial sources.

Dielectric properties of sea ice

(M. E. Shokr, Met. Services Res. Br./AES)
Dielectric properties of sea ice are not sensitive to air temperature variation. The appropriate dielectric model should be selected based on its inherent assumption about the inclusion volume, shape, coherency and orientation.

Aircraft bearing capacity of sea ice

(R. W. Marcellus and M. Sander, CMEL)
The program BEARING was upgraded. It allows for simultaneous calculation of variations in ultimate load vs. ice thickness, load vs. loading radius, and stress vs. distance from the loaded area, etc.

(N. K. Sinha, LTL/NRC)
The DND/MOY operations manual for the aircraft bearing capacity of sea-ice covers is being examined and revised.

MARINE ICE – BIOLOGY

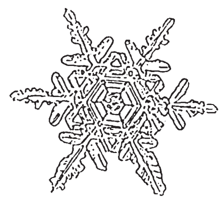
Productivity in ice-covered oceans

(Ralph E.H. Smith, Biology/WATER)
New methodologies suggest a more limited role for carbon-exchange (biologically mediated) between ice and water than previously thought. Biota modify sea-ice chemistry extensively and are highly cold-adapted.

Ice algae

(Harold Welch, Freshwater Institute/FOC)
The growth and role of ice algae is being investigated at Resolute Bay and Saqvaqjuaq, near Chesterfield Inlet.

Submitted by C. Simon L. Ommanney



USA - EASTERN

For abbreviations, see end of this report

MISCELLANEOUS

Icephobic coatings

(N. D. Mulherin , K. F. Jones, J. H. Lever, CRREL)
Test methods are being developed to evaluate protective surface materials and coatings for icing environments. Ice adhesion strength and coating durability tests will be used to rank commercially available products as a way of predicting their anti-icing or de-icing capability.

PERMAFROST

Stable isotope analyses as proxy paleoclimatic data in Arctic permafrost regions

(D. E. Lawson, CRREL)
Investigations are examining the processes and factors determining the oxygen and hydrogen isotope content of ground ice in permafrost, in order to define more precisely the relationship of stable isotope variations in permafrost to trends in paleotemperatures in the Alaskan Arctic.

SNOW

Snow signature dynamics

(R. E. Davis, A. Nolin, J. Shi, R. Jordan, J. Dozier, CRREL, CRSEO)
Electromagnetic signatures of snow in the visible/near-infrared and microwave spectral regions are controlled by the microstructure and presence of liquid water. Recent model simulations show that microstructural parameters controlling the bidirectional reflectance of solar radiation can be predicted from initial snow conditions and micrometeorology. Stereological measurements on snow section cuts can be used to measure the microstructural parameters for BRDF modeling, and can also provide estimates of the grain size distribution used in discrete-scatter models of radar signals from snow in the microwave spectrum. An energy and mass transfer model was also used to aid interpretation of millimeter-wave radar backscatter from wet snow.

Snow friction

(S.C. Colbeck, CRREL)
A review of ski friction was written and is now a CRREL monograph. Work on the electrical charging of ski bases was started last winter and will continue in the coming winter. In these measurements the ski is used as a capacitor to find the level of charge accumulation on the ski base.

Snow metamorphism

(S.C. Colbeck, CRREL)
Experiments were completed in layered snow to determine the effect of an impermeable layer on the vapor migration that causes crystal growth. Thin sections from this experiment have been prepared and will be analyzed to describe the geometry of both the grains and the vapor flow paths. These results will then be included in a model of snow metamorphism.

Tem-meter temperature

(S. C. Colbeck, CRREL)
The temperature profile in an ice sheet can be shifted away from the seasonal average by subsurface heating. Various sources of heat are being examined to judge their effectiveness. At this time it is uncertain how much heat is added or removed by air flow through the snow. All other mechanisms add heat.

ALPINE GLACIERS

Hydroglaciological processes controlling runoff and sediment yield

(D. E. Lawson, CRREL)
Analyses of subglacial processes and conditions affecting discharge, as well as sediment production, at Matanuska Glacier, Alaska. Links between climate, glacier mass balance, glaciohydrological processes and runoff are under investigation. Predictive physical model of runoff and sediment yield to be developed.

GPR surveys on the Matanuska Glacier, Alaska

(D. Lawson, S. Arcone, A. Delaney, CRREL)
Ground penetrating radar operating at 500 and 100 MHz is being used to study basal ice reflections and conduits therein in the ablation zone of the Matanuska Glacier in southern Alaska.

Mass balance of North Cascade glaciers

(M. Pelto, NCGCP)
Annual balance has been measured on ten North Cascade glaciers since 1984 by the North Cascade Glacier Climate Project (NCGCP):

1984	+0.45	1988	+0.09
1985	− 0.48	1989	− 0.27
1986	− 0.16	1990	− 0.59
1987	− 0.67	1991	+0.37

Recent fluctuations of Mt. Baker, Washington Glaciers

(M. Pelto, J. Harper, NCGCP)
All Mt. Baker glaciers advanced during the early and mid 1970s, the advance concluding in about 1978. In 1990 the terminus retreat from the 1970s maximum advance end moraines was measured on seven Mt. Baker glaciers: Coleman 74 m; Talum 70 m; Rainbow 63 m; Boulder 55 m; Deming 54 m; Squak 34 m; and Easton 9 m.

Changing glacier runoff due to glacier retreat

(M. Pelto, NCGCP)
In August 1985, Lewis Glacier had an area of 0.09 km^2 and total monthly runoff of 0.15 x 10^6 m^3. By August 1990 the glacier had disappeared, monthly runoff from the

basin was 0.04 x 10^6 m^3, only 27% of the glaciated flow despite an equal monthly precipitation in 1985 and 1990. As glaciers retreat the surface area exposed to late summer melting declines, reducing late summer water supply from glaciated alpine regions.

SEA ICE

Beaufort sea ice – Examination of the variability of SAR backscatter from first-year sea ice

(D. Farmer, NRL Polar Branch at CRREL; T. Lukowski, C. Livingstone, Canada Centre for Remote Sensing, Ottawa, Canada)
Two frequency, dual polarized SAR imagery was collected over a first-year sea-ice test area near Prudhoe Bay, Alaska in the spring of 1990. These data have been calibrated and the variability of SAR backscatter from first-year ice is being determined. Hopes are that the relationship between backscatter variability and physical changes in the snow and ice due to the onset of melt can be established.

Landing Craft Air-Cushion vehicle (LCAC) Arctic DEM/VAL 1992

(D. Farmer, NRL Polar Branch at CRREL)
Naval Sea Systems Command conducted tests of the LCAC in ice infested waters near Port Moellor, Alaska in March 1992. Concurrently, snow and ice measurements were made at selected locations (Goodnews Bay, Kvichak Bay, Egegik Bay, and Port Heiden). These surface measurements and an excellent collection of low altitude photography will be used to assist in the analysis of available ERS-1 SAR images collected during the LCAC test.

Waves in the marginal ice zone

(A. K. Liu, NASA/GSFC)
A coupled ocean–ice interaction numerical code has been developed to include the wave effects and wind stress for the predictions in the marginal ice zone (MIZ). The wave parameters are extracted from Synthetic Aperture Radar (SAR) and buoy data as the input for the ocean–ice interaction code. The ice edge is sharper and meanders with wave action after a couple of days. Upwelling at the ice edge is enhanced due to wave action and wind forcing.

Distribution of new and young sea ice types

(D. J. Cavalieri, NASA/GSFC)
A technique for mapping the distribution of new and young sea ice utilizing microwave spectral and polarization information from the DMSP Special Sensor Microwave/Imager (SSM/I) has been developed. The motivation for this work derives from the importance of these ice types to polar air–sea-ice processes studies, and from the need to improve the accuracy of sea ice concentration measurements from spaceborne radiometers. The distribution of these ice types in the Bering Sea compare well with corresponding distributions derived from NOAA imagery.

Sea ice validation for the DMSP SSM/I

(D. J. Cavalieri, NASA/GSFC)
The final report of the NASA Sea Ice Validation Program for the Imager is now available. The report provides a brief description of the instrument, the flow of SSM/I data from the satellite to NSIDC, which is responsible for distributing the mapped data on polar grids, the NASA Team algorithm used in deriving the sea ice parameters, and the comparative studies utilizing Landsat and NOAA satellite imagery and aircraft data from coordinated NASA and Navy SSM/I underflights. A summary of the sea-ice parameter accuracies and recommendations for needed algorithm improvements are also provided.

Length of the sea-ice season

(C. L. Parkinson, NASA/GSFC)
Nimbus 7 Scanning Multichannel Microwave Radiometer (SMMR) data for 1979–1986 have been used to calculate and map the length of the sea-ice season in the northern hemisphere and its changes over the course of the 1979–1986 period. Over that period, the season length tended to shorten in the eastern hemisphere of the north polar region, particularly in the Sea of Okhotsk, the Barents Sea, and the Kara Sea, and to lengthen in the western hemisphere of the Arctic, particularly in Davis Strait, the Labrador Sea, and the Beaufort Sea. Similar calculations are now being performed for the southern hemisphere.

Ice extent time series

(C. L. Parkinson, D. J. Cavalieri, NASA/GSFC)
A project has begun to lengthen the 1978–1987 time series of Arctic sea ice extents available from the Nimbus 7 Scanning Multichannel Microwave Radiometer (SMMR) data through use of the data from the Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave Imager (SSMI) launched in 1987. The lengthened time series will be analyzed regionally and hemispherically and examined to see whether the slight decreases noted for the Arctic as a whole during the SMMR period continued in subsequent years. A similar study is then planned for the southern hemisphere.

AVHRR cloud masks

(D. T. Eppler, Polar Oceanography Branch, NRL)
Computer-based methods are being developed to discriminate cloud-free, lead-rich regions from cloud-covered regions in AVHRR images of sea ice in the Arctic Basin.

Passive microwave signatures of sea ice

(D. T. Eppler, Polar Oceanography Branch, NRL)
Aircraft passive microwave imagery of the Bering Sea seasonal sea-ice cover is being analyzed to characterize brightness temperature signatures in support of efforts by other groups to develop SSM/I thin ice algorithms. Variation in brightness temperature signatures of multiyear ice is being investigated to assess its impact on error in ice concentrations retrieved from SSM/I sea-ice algorithms.

Sea ice model for climate studies

(G. M. Flato, W. D. Hibler III, Dartmouth College, Hanover, NH)
A simplified sea-ice rheology and an efficient numerical scheme have been developed to allow inclusion of sea-ice dynamics in large-scale climate studies. The model, termed the cavitating fluid model, has been formulated in

both rectangular and spherical coordinates and is particularly well suited to long-term simulations of the polar ice cover in global climate models. The principal advantages of this model are its relative simplicity, ease of implementation, and low computational cost.

Modeling sea-ice thickness statistics

(G. M. Flato, W. D. Hibler III, Dartmouth College, Hanover, NH)
The thickness distribution theory developed by Thorndike and others has been extended to include ridged and level ice distributions explicitly along with a variable thickness snow cover. A number of simulations of the Arctic ice cover over the period 1979–85 have been performed to investigate the effect of the so-called ridge redistributor on the shape of the thickness distribution function (a probabilistic description of the ice thickness). Comparisons have been made to submarine upward-looking sonar measurements of the thickness distribution function, to satellite observations of the ice edge and open water fraction, and to buoy-derived ice motion. On-going work is making use of ocean currents and heat flux from a highly detailed coupled ice-ocean model.

Simulations of pressure ridging

(M. Hopkins, CRREL)
Numerical experiments are being performed with a two-dimensional ridging model based on a particle simulation. Experiments begin with an intact ice sheet moving at a constant speed against a multi-year floe. Rubble broken dynamically from the intact sheet forms the ridge structure. Forces are calculated within the sheet and between the rubble blocks and the equations of motion for each block are calculated at every time step. Frictional and inelastic energy dissipation as well as losses from fracture are explicitly calculated.

A model of the Arctic ice pack

(M. Hopkins, CRREL)
A mesoscale model of the Arctic ice pack is being constructed based on a dynamic particle simulation in which individual multi-year ice floes and surrounding areas of first-year ice are explicitly modeled as discrete-convex polygons in a 2-D control area. Deformation of the control area will produce regions of local failure and areas of open water. The failure mechanisms which will be modeled are ridging, crushing, and splitting.

Arctic multi-year ice thickness

(W. B. Tucker III, CRREL)
Recent research on sea ice has been focused on the analysis of ice thickness and properties information obtained on field experiments. The analysis of over 3000 thickness measurements of multi-year ice indicates that at least 50% of the ice had been derived from deformation processes during its first season of growth. Even floes which appeared level on the surface often had significant bottomside relief. Investigations of ice properties have concentrated on near-surface properties thought to be important to microwave remote sensing. Observations show that variations in properties on the same floe can be as large as property differences between floes of the same type.

Sea-ice thickness

(A. Kovacs, CRREL)
Hand-held and airborne electromagnetic induction techniques are being investigated for the remote measurement of sea-ice thickness.

POLAR ICE CAPS

Ice sheet mass balance and surface climate

(H. J. Zwally, IOB/NASA GSFC)
The mass balance and surface climate of the Greenland and Antarctic ice sheets being investigated using satellite data. Radar altimetry data are used to determine changes in surface elevation related to changes in ice volume. Multi-frequency passive-microwave data are used to monitor surface melting and to develop a method for deriving accumulation rates.

Processing of satellite radar altimetry data

(H. J. Zwally, IOB/NASA GSFC)
Data over polar ice from Geosat and ERS-1 radar altimeters are corrected and placed in orbital-format data records, geo-referenced, and gridded-elevation data bases for glaciological studies. All data are "retracked" to correct for errors caused by range variations over sloping and undulating surfaces. Seasat and Geosat elevation data in the geo-referenced and gridded data bases will be distributed on CD-ROM format in 1993.

Mapping of Greenland with ERS-1 synthetic aperture radar

(R. Bindschadler, M. Fahnestock, NASA; R. Kwok, JPL)
Synthetic aperture radar (SAR) data from the ERS-1 satellite are being used to map the different physical and hydrologic boundaries of the Greenland ice sheet. These data will provide a baseline for future monitoring of the ice sheet. Image data are terrain corrected using a digital elevation model provided by S. Ekholm. The position of the current ice-sheet margin is being compared with previous positions digitized from published maps to identify sites of major change. Temporal monitoring on a monthly basis along a track covering all hydrologic zones is intended to study the quantitative effects of seasonal changes on backscatter. Full ice-sheet wide coverage will be mosaiced to produce a complete image of the ice sheet at 100 m resolution.

West Antarctic glaciology

(R. Bindschadler, NASA; R. Jacobel, St. Olafs; D. Blankenship, University of Texas)
Glaciological studies of the flow of ice streams D and E in West Antarctica are being pursued with a combination of satellite and airborne remote sensing and field studies. Sequential satellite imagery and surface surveys are used to map the velocity field to $\pm 10\,\mathrm{m\,a^{-1}}$ accuracy and sounding radars provide transects of ice thickness. These data will be combined to analyze the pattern of net mass balance along these ice streams. Surface measurements at RIGGS positions K3 and M3 have detected a thickening of 14 ± 11 m over 16 years in the mouths of these two ice streams. Satellite imagery, georeferenced by the US Geological Survey, is also providing maps that prove invaluable in the guiding of field traverses, in the planning of airborne data-collection programs, and in the interpretation of all data gathered in this region.

Ice sheet flow mechanics

(I. M. Whillans, C. J. van der Veen, BPRC-OSU)
Three successive field programs are being conducted on the mechanics controlling the fast flow of Ice Stream B in Antarctica. Strain rate and surface slope variations due to basal drag and side drag are being measured using the technique of stop-and-go kinematic GPS (Global Positioning System). The first field season (1991–92) was very successful.

Inland ice survey

(I. M. Whillans, R. A. Bindschadler, BPRC-OSU)
Accumulation rates and ice velocity are being obtained in the catchment of ice streams B and C. The motive is to refine the calculation of mass balance of the ice stream. Ice Stream B is currently thinning and Ice Stream C is thickening.

Compacted snow runway for McMurdo, Antarctica

(M. Mellor, G. Blaisdell, D. Diemand, V. Klockov, CRREL)
At a site located on the Ross Ice Shelf about 7 miles from McMurdo, a runway capable of supporting heavy wheeled aircraft is being constructed. The runway relies on the more than 100 ft thick glacial ice for bearing strength and a thin, well compacted snow cap for support of the wheel's contact pressure. The snow cap is required in order to raise the albedo of the runway surface to protect it from subsurface meltpools (formed by the "greenhouse effect"). The runway is situated just inside the zone of accumulation to minimize the export or import of snow. The runway is expected to provide for the use of wheeled aircraft after the annual sea-ice runway is gone when the US Antarctic Program would normally only be able to use specialised ski-wheel airplanes for all its needs.

RIVER AND LAKE ICE

Thickness profiling of freshwater ice using a millimeter-wave FM-CW radar

(N. E. Yankielun, CRREL)
A field-hardened, high-resolution, broadband millimeter wave (26.5 to 40 GHz) Frequency Modulated - Continuous Wave (FM-CW) radar employing real-time data acquisition and digital signal processing (DSP) techniques has been implemented for continuously acquiring, processing and displaying data for ice thickness profiling and studying surface scattering from freshwater lake and river ice sheets. Minimum ice thickness resolved is less than 3 cm ±10%. This radar has been successfully deployed from ground-mobile platforms and helicopters at heights of up to 10 m above ice surfaces at speeds up to 40 kh^{-1}.

A frazil ice concentration meter

(J. H. Lever, S. F. Daly, J. H. Rand, D. Furey, CRREL)
We have built a portable calorimeter to measure frazil ice concentration in homogeneous, flowing ice/water mixtures. It has a cycle time of about 10 minutes and can measure ice concentrations from 10^{-1} to 10^{-6} $g\,cm^{-3}$. Calibration tests have shown its measurement uncertainty to be about ±5%. The present meter is suitable for use in our refrigerated hydraulic flumes, and we are packaging a field model for use in rivers next winter.

River ice

GPR surveys of river icings, Sagavanirktok River, Alaska
(E. Chacho, S. Arcone, A. Delaney, CRREL)
Ground penetrating radar operating at 500 MHz is being used to study the distribution of unfrozen water to 10 m depth beneath channels and aufeis formations across the Sagavanirktok flood plain near Prudhoe Bay in mid-winter and early spring. Sub-channel unfrozen water gives excellent correlation with SAR C-Band imagery.

Ice-structure interaction

(D. S. Sodhi, CRREL)
Small-scale experiments were conducted with freshwater ice in 1988/89, to understand ice-structure interaction. The results showed that the interaction forces depend on the indentation velocity. The effective pressure was high (8–13 MPa) during low indentation velocity tests, and low (1.2–4.3 MPa) during high indentation velocity tests. Similar tests were conducted recently with a stiffer structure and segmented indentors, using urea and freshwater ice. Each segment of an indentor was supported on three load cells to measure the forces on that segment. Results of these tests have shown that the forces generated on different segments of an indentor occur simultaneously at low indentation velocity and randomly at high indentation velocity.

Vertical frazil distribution model

(C. P. Liou, M. G. Ferrick, CRREL)
A model has been developed for the evolution of frazil over depth and with time in a turbulent flow. The upward migration due to buoyancy of the frazil is opposed by intermittent mixing induced by large eddies. A simple surface removal model is used to simulate the effects of large eddy mixing. The model provides a physical basis for understanding the transition between well-mixed and layered states, and is consistent with existing empirical models and field data.

River ice motion near a breaking front

(M. G. Ferrick, P. B. Weyrick, S. T. Hunnewell, CRREL)
We developed an analysis of the motion of river ice near a breaking front that is consistent with observed data. The speed of the breaking front is varied and the ice motion parameters obtained represent different dynamic breakup behaviors that have been described previously. The results include the convergence of the moving ice with distance from the breaking front that quantifies the loss of surface area from the initial sheet required for ice continuity.

Submitted by W. B. Tucker III

Abbreviations used in the text:

BPRC-OSU:	Ohio State University, Columbus, OH
CRREL:	Cold Regions Research and Engineering Laboratory, Hanover, NH
GSFC:	Goddard Space Flight Center, Greenbelt, MD
IOB:	Ice and Oceans Branch
JPL:	Jet Propulsion Laboratory
NASA:	National Aeronautics and Space Administration, Washington, DC
NCGCP:	Nichols College, Dudley, MA
NRL:	Naval Research Laboratory, Hanover, NH

SELIGMAN CRYSTAL AWARD

Boulder, Colorado, 19 May 1992

The Society's Council agreed unanimously in 1988 that a Seligman Crystal was to be awarded to Hans Röthlisberger in recognition of his outstanding contributions in glacial hydrology, the study of water movements through and beneath glaciers.

The Crystal was presented by the President of the Society, Garry Clarke, in the presence of 85 members and visitors.

In his introduction the President said:

The Seligman Crystal is the highest honour of the International Glaciological Society. Named after Gerald Seligman, the Society's founder and first recipient of the crystal, the award is given from time-to-time to recognize exceptional scientific contributions. The scientist that we honour this evening is Hans Röthlisberger. Hans is one of the pioneers of a scientific style that has become dominant in the study of glaciers and ice sheets. We might call it the "geophysical style" and it is characterized by a strong emphasis on field measurements combined with a solid foundation in physics.

Hans' career in glaciology began in the 1950s when he was with the Institute of Geophysics at ETH, the Swiss Federal Institute of Technology. Invited to participate in a scientific expedition to Baffin Island, he enrolled as the expedition seismologist and used the seismic reflection method to map subglacial topography. Subsequently he joined the Snow Ice and Permafrost Research Establishment (now CRREL) as a visiting scientist in what Willy Weeks describes as the "Foreign Legion". In that capacity he conducted seismic and electrical sounding surveys in Greenland. Returning to Switzerland several years later, he rejoined ETH and devoted himself to both the practical and fundamental aspects of glaciology.

The tragedy of the 1965 Alalin Gletscher ice avalanche, which took 88 lives, set one major direction for his subsequent work. Hans devoted himself to the analysis, understanding and mitigation of potential glacier catastrophes. This work has a significant human dimension and there is no question that Hans' contributions have saved lives. As an example, he recognized the possibility that an ice avalanche from Bisgletscher could inundate the village of Randa. Using science and every other means at his disposal he attempted to gauge the risk and predicted, half a year before the event, that an avalanche would occur. He succesfully predicted the time of occurrence to within 14 days.

Hans' monumental contribution has been to the science of glacial hydrology—the study of how water moves through and beneath glaciers. His 1972 paper in the *Journal of Glaciology* is the seminal publication from which all modern work derives. The essence of this paper is the analysis of turbulent water flow through an ice-walled circular pipe—we now call such conduits R-channels, the "R" stands for Röthlisberger. There is much more to this problem than meets the eye: ice creep attempts to seal off the pipe and viscous dissipation works in the opposite sense, enlarging the pipe by melting. The results of the full analysis are both surprising and illuminating.

Those outside the discipline may not appreciate the central importance of glacial hydrology to our understanding of the flow of glaciers and ice sheets and to our understanding of practical problems involving flood hazards and hydro-electric engineering. Subglacial hydrology dictates the flow mechanics of glaciers and ice sheets, and the challenge of comprehending the interaction between flow mechanics and subglacial hydrology lies at the heart of some of the great unsolved problems of glaciology, such as what causes unstable flow of glaciers and ice streams.

I could go on to speak of Hans' service as President of the International Glaciological Society, of his scientific leadership at ETH, of his personal and professional generosity and of his splendid wife Doris, but I shall close now with a tribute from one of Hans' scientific colleagues, Barclay Kamb:

"Hans is a true sage of glaciology, whose wisdom stems from a special combination of physical understanding and abundant practical observation with a real concern for using that theoretical and practical understanding for the good of humanity."

Hans, it gives me great pleasure to present you with the Seligman Crystal—an honour you so richly deserve.

Replying, Hans Röthlisberger said:

My sincere thanks go to the President for his very kind introduction. Also his phone call from China at 4 o'clock on the morning of 29 August last year, waking me up from a relaxing night's sleep after a strenuous climb in the Alps, is a highly appreciated experience I would not want to miss! I was overwhelmed by his message that I should receive the Seligman Crystal. Wondering what may have been the reason for the Committee's and Council's decision, I was looking back to find infrequent publications and less accomplishments than a wealth of exciting experience. I came to realize how lucky I had been to participate in glaciological research at a time that may still in a way be looked upon as pioneering days. I will now try to convey some of the excitements of 40 years of glaciological research, and show you some slides.

First I want to introduce persons who have helped me to get where I stand now.

– One of my University teachers at the Swiss Federal Institute of Technology (ETH), Paul Niggli, a world-famous crystallographer-petrologist and a universal scientist, conveyed to me the importance of symmetry. The look to symmetry — or lack of it — helped me when tackling new problems.

– I keep the best of memories of many years of common efforts with Peter Kasser, my understanding boss in Zürich. A conscientious civil engineer and scientist, he knew to defend a valid cause with legal strictness, but also how to relax in celebration with friends. He taught me the importance of careful surveying early on. From him I learned to handle a theodolite.

– Pat Baird was the unforgettable leader of two expeditions of the Arctic Institute of North America to Baffin Island.

– Bill Ward was another member of the Baird expeditions. He introduced me to — then — "The British Glaciological Society" at Cambridge (foreigners were accepted).

– There I also met Hilda Richardson shortly after she had taken up work as Secretary of the Society — radiating efficiency and competence from the start.

– Henri Bader was chief scientist at the U.S. Army Snow, Ice and Permafrost Research Establishment (SIPRE, later becoming CRREL) when I was working there on a contract. I enjoyed his stimulating critical questions.

– My wife, Doris, got wet feet on Aletschgletscher in the early days of our marriage. She has managed to adjust to the slow and sometimes erratic behaviour of glaciers and those who work on them.

– Dame Agatha Christie provided reading material that enabled me to pick up some English in a pleasant way. Don't blame her for faulty syntax and inadequate expressions!

A fascinating subject that has always attracted me is the drainage of meltwater on and in a glacier. Near Camp TUTO in Northwest Greenland quite spectacular meltstreams leave the ice sheet at its very edge, some falling over marginal ice cliffs in pretty waterfalls. Such surface drainage, however, is not the rule; more commonly the meltwater disappears in moulins or crevasses in order to reappear from valley glaciers at a portal, from calving glaciers invisibly at depth in a lake or fiord. The semi-circular upwelling of turbid water at the front of a fairly active tidewater glacier in southwest-Greenland points to the existence of a major river that has picked up the sediment load at the glacier bed. The upwelling was strong enough to push a thick layer of broken ice floating on the fiord radially out of the way. It is an intriguing question how and where the water flows in a glacier. Dye tracing can be highly photogenic when a large meltstream, dyed in shining fluoresceine, disappears in a moulin. Dye tracing tells from where to where the water flows, how fast, and how it is spreading over time and possibly space. However, the method does not tell much about how and certainly not where it is flowing.

My own approach to how water flows through a glacier was theoretical. I simply assumed symmetry, that is to say equilibrium between two processes. These processes are the melting of ice by the flow of water and the closure of an opening by ice deformation under pressure. When watching a meltstream plunge down into a moulin it is obvious from the impressive noise that *some* potential energy must become transformed to heat. Frictional heat also becomes available further down. As the water warms up, ice melts away. One of my simplifications was that there would be instant heat transfer.

Now to the ice deformation part. Around a conduit at depth, the ice is under the pressure of the overburden. The hydrostatic pressure in the water is usually less. Depending on the pressure difference between ice and water, the ice moves radially towards the axis of the conduit. In steady state the same amount of ice moves into the opening as that which melts away by the action of the water. Everything remains stationary; discharge of water, water pressure and conduit radius. A simple differential equation can be written for this state. With modifications it should also apply to a conduit at the glacier bed, for instance for a conduit incised into the ice in the form of a semi-circle.

I am still puzzled that this easy solution to englacial and subglacial drainage had not been worked out by others long before I came across it. I must have been extremely lucky that the problem had waited for me! My further luck was to present the solution at a meeting in Cambridge, England, in 1969, at the Symposium on Hydrology of Glaciers, where also John Nye presented a related subject. His model was based on grooves incised in the rock bed. Hans Weertman later tagged the two modes of subglacial conduits as Nye-, or N- against Röthlisberger, or R-channels, respectively. That is how my name went into the glaciological literature. Of course, the equilibrium — or lack of it — between hydraulic melting and ice deformation should be basically the same in both cases. Only the coefficients and complications must change. When accounting for heat transfer from the water to the ice, and considering non-steady state flow of water, rather monstrous equations evolve, as Kolumban Hutter and Uli Spring have shown and partly solved numerically.

R-channels are filled with running water by definition, which means that they are hardly accessible. A tunnel formed near the surface when a small marginal lake drains into the glacier through a marginal crevasse gives a deceptive idea of accessibility. Our aim was rather to learn more about englacial and subglacial drainage from measurements than from direct observation. Almut Iken had been able to measure water level fluctuations by means of pressure transducers in moulins on White Glacier, Axel Heiberg Island, N.W.T., Canada, and she was eager to carry out similar observations in the Alps when she joined the VAW team. We were convinced that the key to success would be in a deep drilling procedure. In Zürich we could profit from a long tradition with the use of hot water applied to drilling. The "Kasser borer" had been used for many years to insert ablation stakes up to 30 m deep, occasionally for much deeper depth soundings. With a closed water circuit this apparatus was economic in water use, but not fast enough to drill quickly numerous holes to the glacier bed, as we intended to do. Fortunately I had witnessed in 1955 the successful use of a different procedure by a Swiss drilling firm, in which very high drilling speeds are achieved by spurting a jet of hot water into the ice. A crew of muscular drillers, operating with double-walled pipes fed into the glacier from a genuine derrick, reached the bed at the depth of some 150 m in about 19 hours. The operation was noteworthy also in other ways. The Swiss pioneer of glacier landings, Hermann Geiger, famous for daring mountain rescues, carried out the transport with a fixed wing aircraft (Piper) in difficult terrain.

The drilling operation on Saleina is quite fresh in my memory for still another reason. When the sound of running water was heard in one of the boreholes, the hydro-company engineers wondered whether the hole had by chance hit the main subglacial drainage channel, the one they intended to capture subglacially. A surface meltstream was guided into the hole. After some days the hole seemed to have become sufficiently enlarged for a person to be lowered down to have a look. It was decided that the glaciological expert was best qualified to go down — me. I suggested to check first if there were any obstructions, thinking that some suitable object should be lowered down on a rope. The doubtful adventure came prematurely to an end when a big boulder was pushed down instead and jammed. Some nightmarish sleepless hours, contemplating closure rates and piezometric water level fluctuations, may well be at the origin of my later involvement in the puzzle of subglacial water.

When taking up our own programme for drilling for piezometric holes we realized that we could not afford the handling of steel pipes and derricks. Student helpers had to replace the professional drillers. It was a small step to the use of pressure hoses, especially since the switch from pipes to a flexible hose had been made long before with the Kasser borer. Deep hot-water drilling by VAW started in 1972. At the beginning the water was heated with open-flame burners, but things got better soon thanks to the valuable advice by Heiri Rufli of Hans Oeschger's team. Various groups from a number of countries have gradually improved the method since. The "Carlsberg beercan contraption", a ring-shaped nozzle, was involuntarily added to the Danish equipment during fieldwork in Greenland when the main drill got frozen-in during my visit.

Not unless a substantial strand of the subglacial drainage network is accidentically intercepted by a drillhole can piezometer data be obtained directly. Often it takes time or even explosives to link up with the natural network. Surface water has then to be diverted into the hole to keep it open, but for undisturbed pressure readings the water has to be cut off again. The work is affected by pressure fluctuations during the daily cycle, changes of weather conditions, and so on; the original plan to map the water pressure of an entire subglacial drainage system has remained a dream.

On the occasion here in Boulder of the Symposium on Remote Sensing of Snow and Ice I figured that the audience might wish to hear also something about my own experience with remote sensing, how limited it may be. Let us nevertheless stay one moment longer with the subject of englacial and subglacial drainage. Although some seem to believe that water-filled channels might be spotted by radio-echo sounding, what looks more promising to me is to send a transmitter into a moulin and track it from the surface on its way through the glacier. Glacial hydrologists are waiting for this tool!

During my first visit to Greenland in 1951 as a "sledge dog" and porter for a Zürich geologist working for Lauge Koch, I met at Cecilia Nunatak a French gravitmetrist of the "Expéditions Polaires Françaises". When he heard that my interest was in seismic sounding he told me that there was no future in that method, as glacier depth could be determined much more easily and accurately by radar. It was fully eight years later that in 1959 Bud Waite showed up at Camp TUTO. His depth measurements, carried out with a modified Air Force 440 Mc radio altimeter mounted on a weasel compared well with my seismic soundings. About the same time Stan Evans started the successful programme of the Scott Polar Research Institute.

During the same Greenland summer season of 1959 I had been more actively involved in another remote sensing project long before "remote sensing" had become a household word. From Dave Barnes, whom I had met by chance at the Thule officer's club, I learnt that Charlie Bentley had carried out a detailed seismic reflection survey in the vicinity of Site 2 in 1956. The ice there is almost 2000 m thick. The objective was to repeat the survey of the same 975 m by 732 m marked area in order to determine the surface displacement. That is what we tried with a 1959 survey. Although the accuracy was not sufficient to determine the shift, we could conclude that not only travel time, but also quality and shape of the reflections changed characteristically over the area of investigation, i.e. that in principle the interference pattern might also be useful to compare successive surveys.

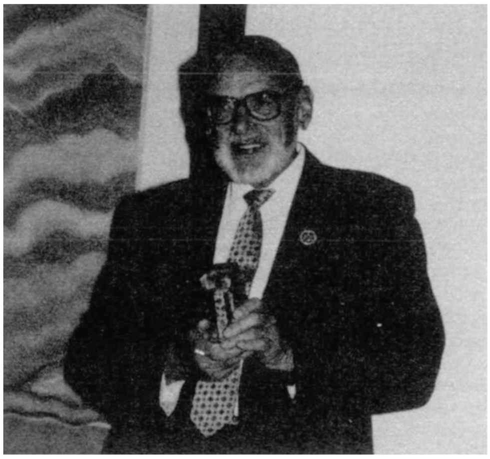
While involved in the pioneering phase of radio-echo sounding as a mere onlooker, remote sensing methods in an earthbound classical way played a fundamental role in part of my work. It varied from visual inspection from the air to photogrammetric surveying, the application of automatic cameras and monitoring by mechanical devices. On 30 August 1965 an ice avalanche from Allalingletscher covered part of the construction site of the Mattmark hydropower dam project, killing 88 workmen and engineers. Visual inspection showed that a much larger mass of ice than that which had fallen off was breaking up and obviously sliding down a steep slope. This was confirmed by detailed theodolite surveys on targets put down from a helicopter. Readings were taken at the interval of two hours during the rescue operation. Weekly aerial surveys served to find the distribution of velocity over the sliding area. Velocities amounted to several metres per day. Previous (1954) and later aerial photos showed that sliding of the Allalingletscher terminus occurred before and after the avalanche of 1965 without causing large ice avalanches.

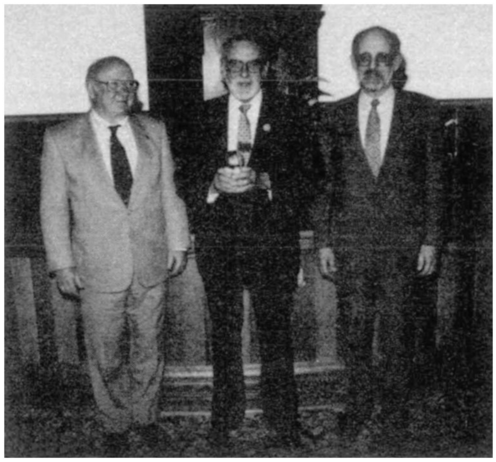
The experience from Mattmark helped to set up a monitoring programme at glacier de Giétro, which overhangs the Mauvoisin reservoir. Waves would splash over the dam when there was a major ice avalanche. Every summer movement of the glacier tongue is mechanically transmitted by a steel cable to a permanent installation in front of the glacier, from where an electrical cable connects with the power station in the valley below: remote sensing, earth-bound.

In September 1972 a threatening situation developed on the Weisshorn when a huge crevasse slowly opened up all the way across the hanging glacier crowning the 45° east face of the mountain. A major ice mass of some 500 000 m^3, comparable in volume to the Allalin avalanche, thereby became separated from the slightly flatter upper part of the glacier. With the previous experience of ice avalanches from the Bisgletscher, near Zermatt, which destroyed part of the town of Randa, an immediate effort to investigate and monitor the situation was indicated. The paths of five survey markers were regularly followed from the valley floor with laser-geodimeter and precision-theodolite to an accuracy of 2-3 cm. Getting across the separating crevasse to set the laser reflectors implied impressive mountaineering! It was the surveyor André Flotron who was instrumental in obtaining the best results. His name is also connected with the technique of obtaining glaciological information of high quality from an automatic Hasselblad camera in combination with the stereo plotter. In the case of the Weisshorn, such a camera was installed at a distance of 2 km on an adjacent summit (Bishorn, 4134 m a.s.l.). Flotron's evaluation of two photos taken 18 days apart revealed the overall pattern of the movement, illustrated by lines of equal displacements (a stereo effect is used, but instead of having two images of an identical object taken from two separate camera positions, there are two images of an object that has shifted, taken from a single camera point). The fact that a fairly uniform block of firn and ice moved at about 10 cm d^{-1} and that the shear deformation was strongly concentrated near the base looked threatening. However, Markus Aellen could show by comparing photos at various intervals that ice kept breaking off at the front and side of the moving ice mass, which diminished accordingly. When in early summer clouds kept interfering with the geodetic survey, a mechanical device similar to the one operating at the glacier de Giétro was installed. The "fixed" station, however, had to be mounted on the ice above the large crevasse. The movement was transmitted by radio to a recording station in the valley. A chart combining data from annual aerial surveys, the geodetic ground survey and the mechanical "clock" revealed that the acceleration started several years back, and that the velocity versus time curve could be matched quite accurately by a hyperbola. The problem remained that it was not clear at which point of the hyperbola the glacier would break off. Fortunately in Randa the threat of impending disaster decreased during the summer when the originally compact block split up into smaller blocks at fresh crevasses, and the empirical curve kept pointing to velocities approaching free fall around the end of August, i.e. well within the summer season; the catastrophic avalanche of 1819 had characteristically occurred in winter when the volume of snow and ice hitting the town amounted to more than ten times the original volume of glacier ice. An avalanche of roughly one third of the volume originally anticipated finally broke off on 19 August. It came to rest on a flat terrace of Bisgletscher still high up on Weisshorn. Interesting as such work may be, it turned out to be less rewarding as regards the reaction of the involved population, who had to live with fear and economic restrictions, although "nothing happened" after all.

The days on the glaciers were often exciting, usually strenuous, sometimes frustrating, but never dull. To be involved in that type of work would have been sufficiently rewarding in itself; to get rewarded in addition with the Seligman Crystal is almost too good to comprehend. The achievements now credited to me were to a large extent the product of common efforts with colleagues and staff at VAW. I want to sincerely thank them and many others. My thanks also go to the directors of VAW, Daniel Vischer and his predecessor Gerold Schnitter. Furthermore I am indepted to numerous officials of federal and cantonal agencies, as well as the representatives of power companies who have generously supported my glaciological activities.

Photos. by K. Steffen





Hans Röthlisberger — with — two previous recipients
Mark Meier Charlie Bentley

IGS SYMPOSIUM ON REMOTE SENSING OF SNOW AND ICE

Boulder, Colorado, USA, 17–22 May 1922
and

POST-SYMPOSIUM TOUR TO THE SOUTHWEST

160 participants had a busy, productive and enjoyable week on the campus of the University of Colorado. Concurrent sessions and several poster sessions were needed to enable authors of 120 papers to present their results. The well-organized meeting also included lively social events, such as the mid-week tour and barbecue in the Rocky Mountain National Park.

After the Symposium, 14 people joined Mark and Barbara Meier on a week-long tour of the Southwest — their "Personally Plagiarized Mini-guide", full of science, art, humour, with illustrations varying from maps and geological sections to cartoons and anecdotes, was greatly appreciated: as they quoted on the title page,

Von einem gelehrten Buche abgeschrieben ist ein Plagiat
Von zwei gelehrten Büchern abgeschrieben ist ein Essay
Von drei gelehrten Büchern abgeschrieben ist eine Dissertation
Von vier gelehrten Büchern abgeschrieben ist ein fünftes gelehrtes Buch *Anon*

We drove and walked through Arches National Park . . .

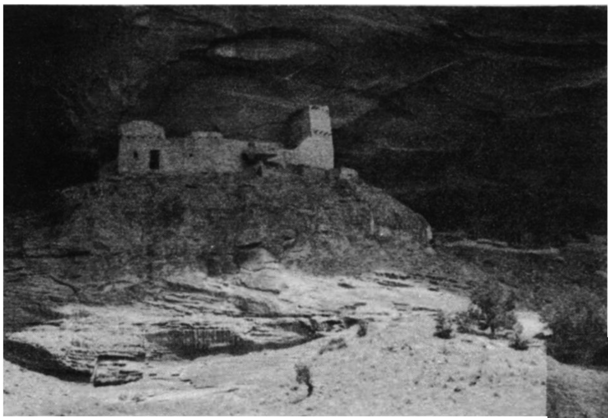
H. Richardson

H. Röthlisberger

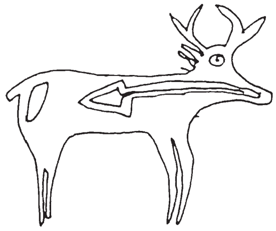
tried to guess the messages etched up to 4000 years ago on Newspaper Rock . . .

gazed in awe at the canyons of the Colorado Plateau . . .

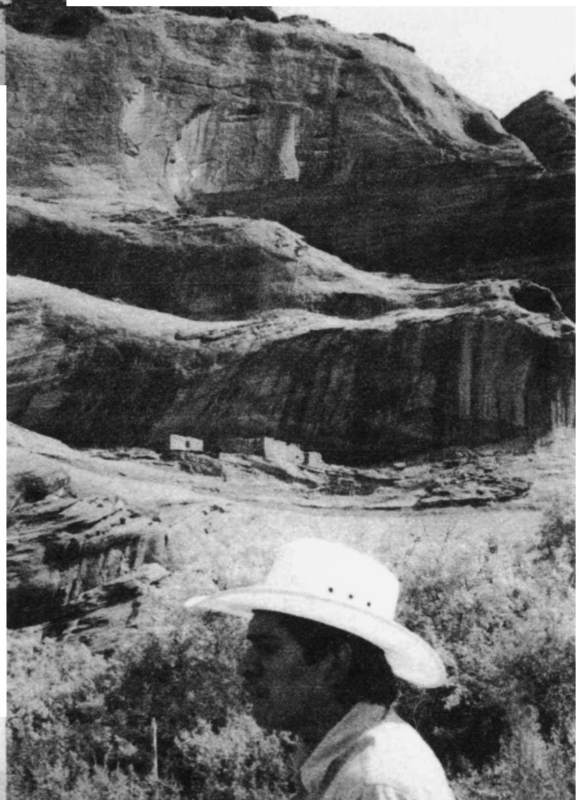
H. Richardson



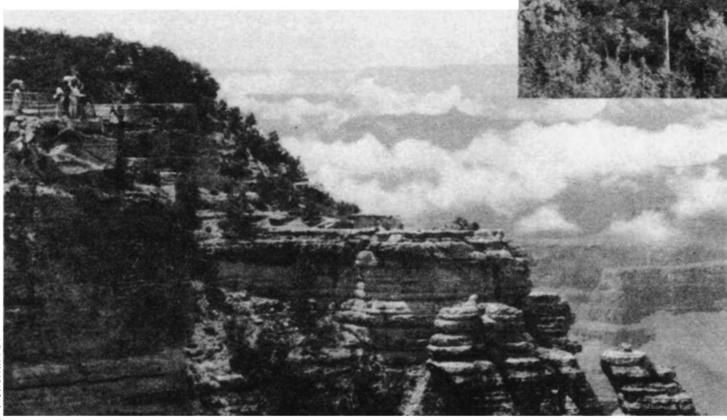
H. Richardson



In the Canyon de Chelly, our Navajo guide showed us the cliff dwellings of the ancient Anasazi people perched high above the valley floor in caves beneath overhanging rocks . . .



H. Richardson



H. Richardson

After more collapsed salt anticlines, microbiotic crust, desert varnish, and arts-and-crafts galore, we had misty views of the majestic Grand Canyon before completing the tour in Flagstaff, Arizona, with a visit to the Branch of Astrogeology of the U.S. Geological Survey.

THE SEARCH FOR A NEW SECRETARY GENERAL OF IGS

The Council has approved publication of the following notice about the job vacancy. This first appeared in the August 1992 Newsletter, mailed to members by air (where appropriate) in the middle of that month.

Hilda Richardson, Secretary General of the IGS, has announced she will retire after 40 years of service to the Society, on 31 December 1993. A Search Committee has been formed to look for a person to serve as her successor.

The IGS is the premier professional organization for those who study snow and ice in all its forms including engineering applications. Its Secretariat is based in Cambridge, England, and comprises a mainly part-time staff of seven. The Secretary General is responsible to the elected Council for day-to-day management of the Society's affairs including the Society's scientific publications (*Journal of Glaciology*, *Annals of Glaciology*, the newsbulletin *ICE* and occasional monographs).

The successful applicant will have experience of organizing scientific conferences in world-wide locations, knowledge and experience of computer-aided publishing techniques, familiarity with accounting procedures, cash-flow control, legal matters relevant to a learned society and registered charity established in Britain, and a relevant scientific background.

As a great deal of the success of the Society depends upon the personal characteristics of the Secretary General to deal with an international membership, particular emphasis will be placed on such qualities as well as empathy with the goals and objectives of the Society.

A salary starting at about £20,000 (depending upon experience) is offered, including a performance-related element. Terms and conditions of employment will be in accordance with British and European Community laws.

Those interested in this position can obtain further details from the IGS or should send by 31 December 1992 a full CV and other details to:

International Glaciological Society
For the attention of the Search Committee,
Secretary General Post,
Lensfield Road,
Cambridge CB2 1ER,
U.K.

INTERNATIONAL GLACIOLOGICAL SOCIETY

International Workshop on Glacier Hydrology
including Soirée Richardson
8–10 September 1993
Jesus College, Cambridge, UK

International Workshop on Glacier Hydrology

The Society will hold an international workshop on Glacier Hydrology in Cambridge, UK in September 1993. Registration will take place on Wednesday 8 September, and discussions will be held on Thursday 9 and Friday 10 September.

Aim of the workshop

The aim of the workshop is to provide a forum for discussion of developments in glacier hydrology. Structure and behaviour of subglacial hydrological systems are not only of intrinsic interest but are also crucial with respect to basal processes. Spatial and temporal variations in the basal hydrological system influence glacier sliding velocity and are instrumental in determining periods of slow and fast flow, including surges. Subglacial hydrological pathways interact with basal sediments, deformation of which also influences ice flow characteristics. Innovation and improvement in the design of sensors are providing more direct information about subglacial hydrological and glaciological conditions through borehole access. Detailed programmes of dye-tracing yield information concerning diurnal flow-through velocities and allow evaluation of the structure of drainage networks at seasonal timescales. Considerable experience has been gained in interpreting the quality of meltwaters emerging from glacier portals with a view to interpretation of the behaviour of and changes in basal drainage systems. The workshop aims to draw together experiences combining direct subglacial measurements and indirect indicators of basal drainage characteristics with observations of glacier flow.

Organisation

D. N. Collins (chairman), H. Björnsson, A. Fountain, E. M. Morris.
The registration fee will include organisation costs, distribution of abstracts, an Icebreaker on Wednesday 8 September in the form of a Garden Party and Buffet, and coffee and tea during the Workshop.

Programme

Registration will take place during the afternoon of Wednesday 8 September, followed by an Icebreaker. Sessions will be on Thursday 9 and Friday 10 September. There will be a poster display as an integral part of the Workshop.

Accommodation

The meeting will be held at Jesus College, where accommodation is available in single rooms. Local hotels offer double rooms.

VISAG

The meeting will be held in parallel with the Fifth International Symposium on Antarctic Glaciology, which is also based at Jesus College (5–10 September).

Presentations

Short contributions on topics relevant to the Workshop aims will be welcomed.

Soirée Richardson

Late afternoon and the evening of Thursday 9 September have been set aside for events to mark the retirement of Hilda Richardson as Secretary-General of the International Glaciological Society, after forty years nurturing the affairs of the Society. From 1600 h, several short appreciations will be presented, after which a Banquet (jointly with VISAG) will be held in honour of Hilda Richardson in College Hall. Please note that all members of the Society are welcome to the Soirée Richardson irrespective of whether they are registering for the Workshop or VISAG.

Further information may be obtained from Dr David N. Collins, Department of Geography, University of Manchester, Manchester M13 9PL, UK. Telephone: 061-275 3646; Fax: +44 61-273 4407.

JOURNAL OF GLACIOLOGY

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

C P WAKE AND M P SEARLE
Rapid advance of Pumarkish Glacier, Hispar Glacier basin, Karakoram Himalaya.

G DELISLE
Global change, Antarctic meteorite traps and the East Antarctic ice sheet.

S FUJITA AND S MAE
Strain in the ice sheet deduced from the crystal orientation fabrics from bare icefields adjacent to the Sør Rondane Mountains, Dronning Maud Land, East Antarctica.

P FEMENIAS, F REMY, P RAIZONVILLE AND J F MINSTER
Analysis of satellite altimeter height measurements above continental ice sheets.

D M McCLUNG AND J TWEEDY
Characteristics of avalanching: Kootenay Pass, British Columbia.

D M McCLUNG AND R L ARMSTRONG
Temperate glacier time response from field data.

A M GURNELL
How many reservoirs? an analysis of flow recessions from a glacier basin.

M TRANTER, G BROWN, R RAISWELL, M SHARP AND A GURNELL
A conceptual model of solute acquisition by Alpine glacial meltwaters.

J LELIWA-KOPYSTYNSKI AND N MAENO
Icy/rocky prous mixtures: compaction experiments and interpretation.

B HANSON AND R LeB. HOOKE
Short-term velocity variations and basal coupling near a bergschrund, Storglaciären, Sweden.

J F. BOLZAN AND M STROBEL
Accumulation rate variations around Summit, Greenland.

M E SHOKR AND D G BARBER
Temporal evolution of physical and dielectric properties of sea ice and snow during the early melt season: observations from SIMS '90 experiment.

M P SCHWITTER AND C F RAYMOND
Changes in the longitudinal profiles of glaciers during advance and retreat.

S CARVER, D SEAR AND E VALENTINE
An observation of roll waves in a supra-glacial meltwater channel, Harlech Gletscher, East Greenland.

I D GOODWIN
Basal ice accretion and debris entrainment within the coastal ice margin, Law Dome, Antarctica.

A J ARISTARAIN AND R J DELMAS
Firn core study from the southern Patagonia ice cap, South America.

E BLAKE, G K C CLARKE AND M C GERIN
Tools for examining subglacial bed deformation.

M G FERRICK AND K J CLAFFEY
Vector analysis of ice fabric data.

J FASTOOK AND P HOLMLUND
A glaciological model of the Younger Dryas event in Scandinavia.

E W WOLFF AND A P REID
Capture and electron microscopy of individual snow crystals.

M O JEFFRIES, W F WEEKS, R SHAW AND K MORRIS
Structural characteristics of congelation and platelet ice and their role in the development of Antarctic landfast sea ice.

T UCHIDA, T HONDOH, S MAE, V Ya LIPENKOV AND P DUVAL
Air-hydrate crystals in deep ice core samples from Vostok Station, Antarctica.

J L TISON, J R PETIT, J M BARNOLA AND W C MAHANEY
Debris entrainment at the ice–bedrock interface in subfreezing temperature conditions Adélie Land, Antarctica).

Recent meetings (of other organizations)

MIDWEST GLACIOLOGISTS

The first annual Midwest Glaciology Meeting took place on 24–25 April 1992 at the University of Minnesota. The meeting was proposed and organized by Jack Kohler and Peter Jansson, both of the University of Minnesota. The meeting is intended to become an annual but somewhat informal gathering of glaciologists and glacial geologists from the Midwest United States. Judging from the 50 or so participants, the Midwest is a rather loosely defined area encompassing Minnesota, Wisconsin, Ohio, Illinois, Pennsylvania, Texas, California, New York, Maryland and Delaware.

The meeting consisted of 31 presentations on a wide variety of topics including ice and till dynamics, hydrology and 3-D modeling studies of Storglaciären, Sweden; the sedimentology of Glacier Bay, Alaska; supercooled water discharge from Matanuska Glacier, Alaska; ice dynamics, mass balance, micropaleontology, till strength, magnetics and gravity of the West Antarctic ice sheet, its ice streams, and the underlying sediments and bedrock; sea level measurements and their relation to the possible collapse of the West Antarctic ice sheet, and the dynamics of the southern margin of the Laurentide ice sheet. All presentations were oral with no abstracts or manuscripts submitted, and hence no publications will result from this meeting.

The participants spent an enjoyable Friday evening discussing glaciology over pizza and refreshments at the home of Roger Hooke. Overall the two-day meeting was judged both informative and productive. The second annual Midwest Glaciology Meeting is planned for spring 1993 and will be held at the Geophysical and Polar Research Center, University of Wisconsin, Madison.

Glaciological Diary

** IGS Symposia
* Co-sponsored by IGS

1992

30 November-3 December
Circumpolar Universities Cooperation Conference, Rovaniemi, Finland (Outi Snellman, International Relations, University of Lapland, P.O. Box 122, SF-96101 Rovaniemi, Finland)

1993

31 January-5 February
Joint International Symposium ISY/PIE and Okhotsk Sea and Sea Ice '93, Mombetsu, Hokkaido, Japan (The Okhotsk Sea and Cold Ocean Research Association, c/o Department of Planning and Coordination. Mombetsu Municipal Office, Saiwai-2, Mombetsu, Hokkaido 094, Japan)

4–8 April
25th International Symposium on Remote Sensing and Global Environmental Change: tools for sustainable development, Graz, Austria (ERIM/International Symposium, P.O. Box 134001, Ann Arbor, MI 48113-4001, U.S.A.)

18-23 April
** Symposium on Applied Ice and Snow Research, Rovaniemi, Finland. Co-sponsored by Ministry of Education, Finland, Arctic Centre, University of Lapland, City of Rovaniemi (Secretary General, IGS, Lensfield Road, Cambridge CB2 1ER, U.K.)

30 May–3 June
International Conference on Freshwater, Marine and Wetland Interfaces: dynamics and management, Edmonton, Alberta, Canada (ASLO/SWS 1993 Conference, Environmental Research and Studies Centre, University of Alberta, CW-401L Bio Sciences Building, Edmonton, Alberta, Canada T6G 2E9)

6-11 June
ISOPE-93, Third International Offshore and Polar Engineering Conference, Singapore (ISOPE-93, P.O. Box 1107, Golden, CO 80402-1107, U.S.A.)

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

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

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

20-26 September
International Symposium on Seasonal and Long-term Fluctuations of Nival and Glacial Processes in Mountains at Different Scales of Analysis, Tashkent, Uzbekistan (Dr V.G. Konovalov, Central Asian Regional Research Hydrometeorological Institute, 72, Observatorskaya str., Tashkent, Uzbekistan 700052)

News

INTERNATIONAL ARCTIC SCIENCE COMMITTEE

The non-governmental International Arctic Science Committee (IASC) was established in August 1990 to encourage and facilitate cooperation in all aspects of arctic research, in all countries engaged in arctic research, and in all areas of the arctic region. The arctic scientific communities in member countries are connected with the IASC Council and AISC Regional Board through a single national scientific organization, thereby providing the first organizational framework for arctic research to gain acceptance in the political as well as scientific arenas. This structure makes IASC unique. It also should enable IASC to assemble a robust scientific agenda.

The first Council meeting was held in January 1991 with a total of 14 countries admitted as members. In 1992, a workshop was held in Iceland on the topic of global change in the Arctic, covering the following core areas: atmosphere–ice–ocean interactions, terrestrial and marine ecosystems, ice-sheets, glaciers and paleodata, atmospheric chemistry and biogeochemical cycles, human dimensions of global change.

New members

David B. Bahr, Institute of Arctic and Alpine Research, Campus Box 450, University of Colorado, Boulder, CO 80309, U.S.A.
Arne Friedmann, Hallerstrasse 6, D-7800 Freiburg, Germany
E. A. Joyce, Flat 5, 21 Lansdown Crescent, Cheltenham, Gloucester GL50 2LF, U.K.
Claude Kergomard, Laboratoire d'Optique Atmospherique, BAT P5, USTL, F-59655 Villeneuve d'Ascq Cedex, France
C. J. Keylock, Roseneath, Redwood Road, Sidmouth, Devon EX10 9AB, U.K.
Arjen J. M. Koomen, Hondiusstraat 5^{II}, 1056 DK Amsterdam, The Netherlands
D. Lemaire-Ronveaux, 554 Fairview Road, Medford 08055, U.S.A.
L. McKittrick, Civil and Agr. Engr., Montana State University, 205 Cobleigh Hall, Bozeman, MT 59717, U.S.A.
C. Mätzler, Institute of Applied Physics, University of Bern, Sidlerstrasse 5, CH-3012 Bern, Switzerland
Sandra Passchier, Nieuwe Looiersstraat 34C, 1017 VC Amsterdam, The Netherlands
J. Rose, Department of Geography, Royal Holloway and Bedford New College, Egham, Surrey TW20 0EX, U.K.
Joe Stock, P.O. Box 146, Albion, WA 99102, U.S.A.

Glaciers-Ocean-Atmosphere Interactions

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(published December 1991)
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The International Association of Hydrological Sciences (IAHS) is the international nongovernmental organization which deals with hydrology and water resources, including snow and ice. Individual membership is free and open to everyone who endeavours to participate in IAHS activities. For more information about membership, please contact:
Mr H. J. Colenbrander, Secretary General IAHS, Rozendaalselaan 36, 6881 LD Velp, The Netherlands.

edited by V. M. Kotlyakov, A. Ushakov & A. Glazovsky

The papers in this book consider: ice coring for revealing paleoglobal changes of climate parameters, of atmospheric chemistry and of volcanic events; the role of glaciation in global sea fluctuations; complex analysis of sea ice, snow cover variations and glacier mass balance fluctuations in sensitive regions such as the Polar and Central Asian areas; snow/ice-atmosphere interactions in the climate system.

The papers were selected for the symposium of the same title held in St Petersburg (formerly Leningrad) in September 1990. They are arranged under the following topics:

- ***ice cores as indicators of global changes*** (6 papers)
- ***sea ice in the global interaction system*** (7 papers)
- ***modelling of ice sheets and their components*** (7 papers)
- ***glaciation and the global sea level*** (4 papers)
- ***ice cores and ice chemistry*** (4 papers)
- ***mass balance and heat balance*** (10 papers)
- ***paleovariations*** (4 papers)
- ***ice in water*** (5 papers)
- ***glaciation-atmosphere interactions*** (8 papers)

The papers contribute to a better understanding of past and future geosphere changes.

INTERNATIONAL GLACIOLOGICAL SOCIETY

Lensfield Road, Cambridge CB2 1ER, England

SECRETARY GENERAL H. Richardson

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ICE

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

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

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

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