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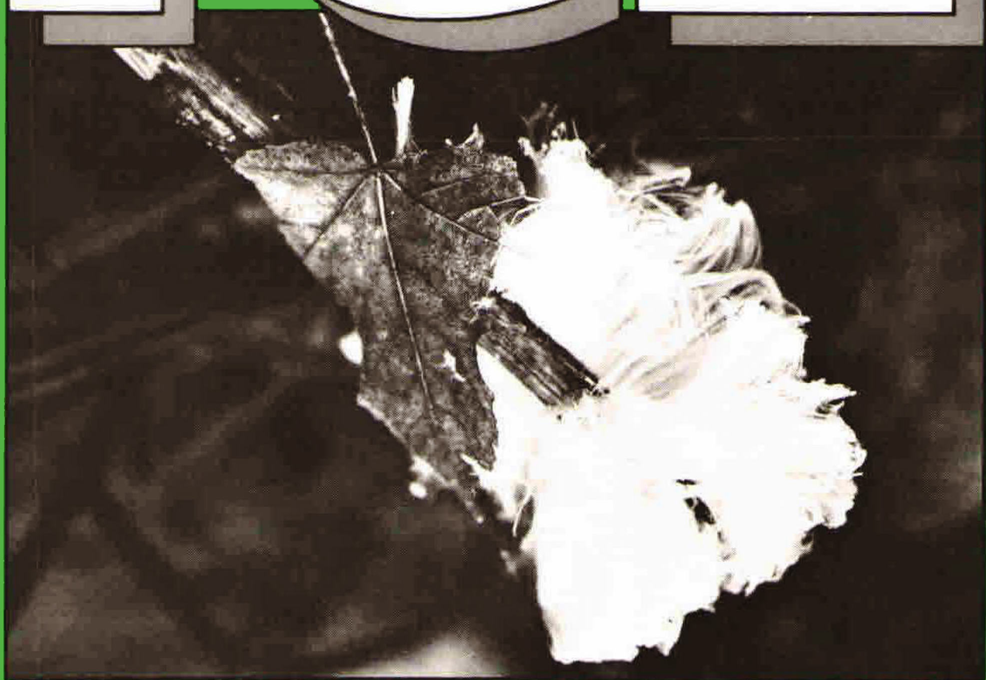

NEWS BULLETIN OF THE INTERNATIONAL GLACIOLOGICAL SOCIETY

INTERNATIONAL GLACIOLOGICAL SOCIETY
Lensfield Road, Cambridge CB2 1ER, England

BOOKS

The IGS will soon add to its list of published books, with a translation of a Russian book on sea ice and a reprint of a field guide to snow crystals.

Available in January 1992 will be:

The heat budget of Arctic ice in winter, by Aleksandr P. Makshtas, Arctic and Antarctic Research Institute.

English translation by Edgar L. Andreas, U.S. Army Cold Regions Research and Engineering Laboratory. The price per copy will be £15/$25. Order forms will be sent to members later.

Available in June 1992 will be a reprint edition of:

Field guide to snow crystals, by Edward R. LaChapelle

This was first published in 1969 and is now out of print. The price per copy will be announced later, and an order form sent to members.

Enquiries should be addressed to the Secretary General.

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CONTENTS

COVER PICTURE: Needle ice. Photograph by E. Wengi, Swiss Federal Institute for Snow and Avalanche Research, 7260 Weissfluhjoch, Davos, Switzerland.

Recent work

CANADA

GENERAL

CRYSYS-A CRYospheric SYStem to monitor global change in Canada

(R. Simard, J. Cihlar, T. Fisher, R. Leconte, M. Manore, M.-C. Mouchot (CCRS) and others.)
An information system for understanding and monitoring global change in Canada using cryosphere variables such as sea ice, snow, permafrost, glaciers, ice caps, and lake and river ice is being developed. The project is not yet fully implemented, but has been endorsed by NASA.

(M.M. Brugman, T. Prowse, A. Wankiewicz and S. Ommanney (NHRI))
Brugman is a principal investigator and team leader for the Glaciers and Ice Caps unit of CRYSYS. Other NHRI team members include Prowse for Lake and River Ice, Ommanney for Information, and Wankiewicz for Snow. The first field experiment took place in the spring of 1991 in conjunction with a NASA overflight. The first deliverable will be the glacier inventory of Yukon Territory to be completed by Ommanney in 1992.

Northern hydrological research

(T.D. Prowse and C.S.L. Ommanney (NHRI))
Following a standard format, reviews were written by various Canadian northern specialists on: general northern hydrology (T.D. Prowse); snow hydrology (P. Marsh); permafrost hydrology (M.-K. Woo); ground-water hydrology (R.O. van Everdingen); hydrology of floating ice (R. Gerard); glacier hydrology (G.J. Young); water quality (D.J. Gregor); regional energy balances (W.R. Rouse); regional hydrology (J.H. Wedel); and water management (B. Gibson); and published by NHRI as Science Report No.1. The Proceedings of a Symposium on the same topic, held in Saskatoon, 10–12 July 1990, were published in 1991.

Advancement of northern scholarship

(ACUNS, 1915-130 Albert Str., Ottawa, Ont, 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.

Workshop on the Mackenzie Delta

(P. Marsh and C.S.L. Ommanney (NHRI))
A Workshop on the Mackenzie Delta, environmental interactions and implications of development, was held from October 17–18, 1989, at the National Hydrology Research Centre, Saskatoon, Saskatchewan. The proceedings were published mid-1991.

Project WILD snow and ice

(C.S.L. Ommanney (NHRI))
The Canadian Wildlife Federation is developing environmental teaching components for Grades 1–13 based on snow and ice as part of a supplementary curriculum program known as Project WILD. NHRI is collaborating with them by providing background information on possible themes and units.

GLACIERS

Glacier Mass Balance Workshop, Seattle

(M.M. Brugman and C.S.L. Ommanney (NHRI) with D.S. Munro (GEOG/UTE) and USGS)
A new era in U.S./Canadian collaboration on glacier research was ushered in with the creation of a North American Committee on Climate and Glaciers and the subsequent successful organization of a workshop on glacier mass-balance methodology in Seattle, sponsored by the NRC Subcommittee on Glaciers.

M. Brugman and G. Østrem (Norway) are collaborating on a new edition of the glacier mass-balance manual that has served as an international standard for the last 25 years.

Fracture mechanisms of rock and mineral fragments transported by glaciers

(H.H. Schloessin (GPHYS/WEST) with W.C. Mahaney (YORKA))
Rock and minerals on and within glaciers are relatively well preserved and can suffer fracture from frost splitting and mutual contact. However, those within an ice body form misfitting inhomogeneous inclusions and elastic inhomogeneities in an applied stress field which can generate high stress concentrations leading to fracture. The feasibility and efficiency of this type of fracture in ice are supported by theory and the results of some simple laboratory tests.

Large glaciofluvial systems

(T.A. Brennand (GEOG/ALTA))
Some glaciofluvial systems of eskers in southern Ontario and Quebec appear to be composed of a number of large-scale building blocks or bedforms, which together suggest powerful, pulsating flows, at the time of formation.

Ice-margin positions during the Wisconsinan

(J.-M.M. Dubois et M. Parent (CARTEL))
A Late-Glacial remnant ice cap has been identified in the Eastern Townships. There was another on Anticosti Island that marked the margin of the Laurentide Ice Sheet throughout the Wisconsinan. Only the southern portion of the Magdalen Islands was covered in ice.

GLACIERS – ARCTIC

Ice core analysis and climate change

(R.M. Koerner, B.T. Alt, J.C. Bourgeois, R. Dubey, D.A. Fisher and M. Parnandi (TSDGSC))
Based on results obtained to date, the present climate shows no trend over the past 30 years. The 100 year trend is for warming which is not unique in terms of the past 10 000 years.

The mass balance of four ice caps was again measured in the Queen Elizabeth Islands. Two of the ice caps have been measured regularly for 30 years; separate records exist for ice melt and snow accumulation.

Shallow ice cores from northern Ellesmere Island have been studied for anion and cation concentrations from 1880 to 1988. Results, particularly since about 1955, confirm earlier studies of increasing pollution concentrations in recent snows.

Ice-flow properties, deduced from continuing borehole closure measurements, are being modelled in conjunction with detailed ice-vector measurements made by E. Waddington (Univ. Washington). For the second complete year, six-hourly averages of air temperature, relative humidity, snow depth and firn temperature (2.5, 5.0, 7.5 and 10 m depth) were recorded on the Agassiz Ice Cap. The data-logger was restarted and another one set up at the top of the ice cap. A new electro-mechanical ice drill, based on the Danish shallow drill, will be field tested in the spring of 1991.

Snow samples from Agassiz Ice Cap show the relationship between seasonal and annual pollen concentrations and synoptic climate. 50-L pre-Holocene ice samples from one of the boreholes were analyzed, and three separate one-tonne snow samples, collected 1 km from the Ice Island camp of the Polar Continental Shelf Project, and from the Agassiz and Devon ice caps, were melted and filtered. The filters will be analyzed for micrometeorites at Le Centre des Faibles Radioactivités, Gif-sur-Yvette, France.

Vapour transport was modelled to simulate $\delta^{18}O$ and δD concentrations. The Reeh 3 D ice-sheet model was modified and used for time-slice representations of the Laurentide Ice Sheet between 10 000 and 6 000 years ago. Mean synoptic situations have been related to accumulation and ablation conditions on Canadian ice caps using a Soviet model as part of a cooperative study between AES, the GSC and the Arctic and Antarctic Institute in Leningrad, USSR.

Trace organic compounds in snow and ice

(D.J. Gregor (NWRI))
Twenty stations throughout the NWT were sampled in 1990 for total annual deposition of organochlorines including pesticides, PCBs and PAHs. A snow pit was sampled on the Agassiz Ice Cap, Ellesmere Island for annual contaminant deposition and residues. The 10 m pit will provide a record from 1960 to the present.

Axel Heiberg Island, NWT

(W.P. Adams and M.A. Ecclestone (GEOG/TRENT))
Two years in the 30 year mass-balance record of White Glacier show net losses an order-of-magnitude larger than mean net loss. Similarly, for the Baby Glacier, occasional high net-loss seasons offset years of net accumulation. Such years, through their impact on glacier drainage systems, have great impact on the regional hydrology.

(G.J. Young and P.J. Glenday (CRRC/WLU))
White Glacier will be resurveyed and mapped to assess the glacio-hydrological response to climatic fluctuations since 1960.

(Y. Moisan (CARTEL))
Recent changes in the snout and proglacial zone of the White and Thompson Glacier complex, based on surveys of the distal perimeter in 1989, were analyzed.

Ice-cap monitoring

(J.R. Weber (GDGSC) and R.M. Koerner (TSDGSC))
As part of global-change studies to measure absolute elevation changes of Arctic ice caps, the first measurements on the Devon and Agassiz ice cap summits were made using a micro-gravimetric method controlled with GPS positioning. The Barnes Ice Cap survey is scheduled for the end of July 1991.

Barnes Ice Cap, Baffin Island

(J.D. Jacobs (GEOG/MUN) and R. Heron (GEOG/WIND))
Preliminary findings from the northwest margin of the Barnes Ice Cap show a 620 m retreat of Lewis Glacier from the snout position in 1961. Northwards the retreat of the ice-cap margin was less than 200 m in the same period, while to the south, at Triangle Glacier, more than 1 km of retreat has occurred.

GLACIERS – YUKON

Mt Logan (5951 m) ice core analysis

(G. Holdsworth, S. Fogarasi and B. McCarthy (NHRI))
Snow accumulation rates from 1700–1860 A.D. are significantly-lower than from 1860 to 1987. There is a teleconnection between the Mt Logan net snow-accumulation time-series and some instrumental precipitation time-series elsewhere in the Northern Hemisphere. The main atmospheric pollution of high-altitude snow is by volcanic-eruption gas plumes and possibly forest fires; apart from atmospheric nuclear-weapons testing, there is no evidence of other anthropogenic acid pollution.

The stable isotopes of water show a distinctive altitudinal distribution. Several profiles indicate an iso-δ step separating a lower region of altitude-dependent isotopic fractionation (1750–3350 m), from another sequence above about 5300 m. The gross features can be explained by the structure of the lower- and mid-troposphere and are compatible with the concept of secondary-source moisture arriving via the upper troposphere.

Eclipse ice core site, YT

(G. Holdsworth and A. Dalton (NHRI))
An automatic weather station was established at Eclipse to help interpret some aspects of the ice-core record. Temperature and wind data were collected for the winter 1989/90. The station will be removed in 1991.

Canadian–Rufli–Rand ice core drill

(G. Holdsworth, M.N. Demuth and A. Dalton (NHRI))
The remaining electrical, hydraulic and mechanical assembly work for the new Canadian–Rufli–Rand ice core drill was completed. The drill was field tested in the Saint Elias Mountains and at Eclipse station. An engineering and operational/logistics manual for the new drill system is now being prepared.

Cause and mechanics of glacier surging

(G.K.C. Clarke, E.W. Blake, D.B. Stone, T. Murray, U.H. Fischer, B.S. Waddington and J.P. Schmok (GPHYS/UBC))
Trapridge Glacier, Yukon Territory, 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.

Sedimentation in glacier ice-dammed lakes

(P.G. Johnson and J.N. Kasper (GEOG/OTT))
The variability in input of water and sediment to a lake in the Kaskawulsh Glacier system produces annual, daily and short-time frame-changes in the sedimentary record. Deltas formed during the filling of the lake have a retrogressive stepped form and are entirely reworked either during the drainage of the lake or during the subsequent filling. The fossil record of the lake demonstrates a semi-permanent period which has evolved into annual draining with downwasting of the damming glacier since the Little Ice Age. Hence there are problems using the sedimentary record from alpine glaciers to reconstruct a glacier hydrological record.

Hydrological system of Alpine glaciers

(P.G. Johnson and G. Kruszynski (GEOG/OTT))
From discharge, suspended sediment load, climatic conditions, and the geology and topography of the basin, a linked-cavity and conduit-drainage system model has been proposed. It evolves spatially and temporally in response to precipitation and melt. Seasons dominated by snow and ice melt produce a temporal trend in the up-glacier progression of cavity-to-conduit connection, release of water from cavities producing pulses in the discharge; early rainstorms force the opening of conduits and have less-progressive release of cavity-stored water. Where the suspended-sediment source is primarily subglacial, variations in concentrations are produced by migration of conduits.

Variability in glacier discharge and suspended sediment regimes

(P.G. Johnson and G. Kruszynski (GEOG/OTT))
Pulses in discharge and suspended-sediment concentration occur frequently over short time-scales. They are not necessarily correlated, so that there are both dependent and independent events, and can be one order-of-magnitude greater than the background flow. Various discharge-pulse patterns can be recognised on the hydrograph. The suspended-sediment source depends on the characteristics of each glacier and glacier basin, varying from mobilisation at the terminus to subglacial sources.

GLACIERS – BRITISH COLUMBIA

"Mawer" Glacier, BC

(J.P. Schmok and M. Maxwell (SNOW))
An isopach map from radar depth measurements of the lower five kilometres of "Mawer" Glacier was produced to guide subsequent rotary drilling for minerals.

Tats Glacier, Alsek Ranges, BC

(J.P. Schmok and M. Maxwell (SNOW))
Glacier mass balance, radar depth, subglacial water-pressure, subglacial water transit times, surface-flow and strain characteristics were measured in the summer of 1990 to provide baseline data required for the Windy Craggy environmental impact assessment (EIA).

(Geddes Resources Consultants including K. Ricker (RICK/ACC))
Study of the moraines down-valley show that, during the Kluane Glaciation, the glacier forelands were levelled by a southeastward moving ice sheet. The smallest and closest moraine to the snout of Tats Glacier was laid down *c.* 1950, indicating an annual retreat of about 7.0 m a^{-1} to 1987. The glacier has a snout covered by a thick debris mantle which tends to retard ablation, but it does not appear to be a surger despite its looped medial moraines. The glacier is the main access route to the Windy Craggy Mine.

(M.M. Brugman (NHRI))
Phase I of the Geddes EIA statement on the proposed Windy Craggy Mine was reviewed. The glaciological problems identified were incorporated into the next phase requirements identified by EC in Vancouver.

High runoff fiords, North Coast, BC

(K. Ricker (RICK/ACC) and J.W. McDonald (Seakem Oceanography Ltd.))
Fiord with high glacier-melt discharge are unsuitable for net-pen salmonid aquaculture because of diluted, turbid surface waters. Undesirable fiords from 53° to 56° N have been identified. They include the Portland and Observatory Inlet areas with large mountain ice sheets (100s of km^2 in extent) as well as the Douglas and Gardner waterways with "hundreds" of small glaciers (only a few km^2 in extent).

Iskut River Basin, BC

(O. Mokievsky-Zubok and A. Chichagov (GCS))
The three glaciers studied, Andrei, Yuri and Alexander, showed a negative 1990 mass balance of –0.42, –1.07 and –1.07 m H_2O respectively.

Homathko River Basin, BC

(O. Mokievsky-Zubok and A. Chichagov (GCS))
The two glaciers studied, Tiedemann and Bench, showed a negative 1990 mass balance of –1.56 and –1.06 m H_2O respectively.

Overlord Glacier, Coast Mountains, BC

(K. Ricker (RICK/ACC) and W. Tupper (BCIT))
Up to about 1987 Overlord Glacier had been markedly advancing. Two surveys of the snout since then have shown a slight recession of about 1.5 m a^{-1}. Three moraine crests have been assigned the following ages: 1748–1821 A.D., 1875–1884 AD., and 1911–1923 AD. Historical photos show a younger moraine developed prior to 1931 AD. The healthy state of Overlord Glacier is attributed to several factors: large névé-to-outlet-tongue area ratio; névé elevation above the regional snowline of about 2000 m (for ice-covered surfaces); and an overall favourable aspect.

Mountain hydrology and glacial melt-water

(M.M. Brugman (NHRI))
A strategy for future NHRI mountain hydrology studies was developed during the fall of 1989 and forms the basis of the program carried out in the summer of 1990 in the Rocky and Coast mountains. This is the re-activation of a long-term program begun in the early 1960s for the IHD. During 1990, the studies at Peyto, Sentinel, Helm and Place glaciers were re-established and measurements of the

winter, summer and net balances obtained. Two new meteorological stations were installed and tested.

Wedgemount Glacier, Coast Mountains, BC

(W. Tupper (BCIT) and K. Ricker (RICK/ACC))
Photo-theodolite and field-camera surveys of the lower glacier and snout were carried out from 1988 to 1990, and upper stations were occupied in 1990. Ablation stake measurements were discontinued in 1987. Ice recession continues and the snout is no longer a cliff-fronted feature calving into the lake. In 1990 the equilibrium line was much higher than usual; the surface was extremely rough and dirty at the usual equilibrium line (*c.* 2150 m). Surveys of the glacier will be conducted biennially except for the quadrennial year of the WGMS reports.

Coast mountain glaciers, BC

(M.M. Brugman and T. Carter (NHRI))
Following the retirement of O. Mokievsky-Zubok, UBC undertook the mass-balance, geodetic and photogrammetric surveys of Place, Sentinel, and Helm glaciers for NHRI. For the 1989 balance year all glaciers exhibited a specific mass loss (in m H_2O) as follows: Sentinel –0.90; Place –1.04; Helm –1.67. Subnormal snowpacks contributed more to these negative net balances than above-normal summer temperatures. Cumulative balance data indicate a mass loss from Place Glacier of 16.88 m H_2O since 1965, and from Helm Glacier of 13.49 m H_2O since 1977. The apparent mass gain of 4.42 m H_2O since 1966 for Sentinel Glacier, which has retreated 570 m, pointed to the urgent need to establish geodetic control on the mass balance. This was done in 1990 and confirmed initial estimates of an imbalance of about 1.2 m.

In 1990, one hut at Sentinel Glacier was completely refurbished. A special investigation of albedo was carried out and tests made on radiation penetration into the snow cover using a spectrophotometer.

Woolsey Glacier

(G.J. Young and P.J. Glenday (CRRC/WLU))
Woolsey Glacier is being remapped to assess the glacio-hydrological response to climatic fluctuations since the 1966 IHD survey.

GLACIERS – ROCKY MOUNTAINS

State of Canada's glaciers

(C.S.L. Ommanney (NHRI)
Recent glacier activity and studies in the Rockies during the last century have been documented for the USGS Satellite Image Atlas of Glaciers of the world.

"Small River Glacier" hydrology

(C.C. Smart (GEOG/WEST))
Some 70% of the "Small River Glacier" (BC) drains underground through two karst aquifers. Drainage is through low-pressure conduits which enter the aquifers at distinctive sink points at the bed. Catchment boundaries are fuzzy and shift with time and discharge. Much of the basal drainage appears to be adjusted to the conduit system, although some patches are poorly connected. Runoff from the "discrete" accumulation area is steady and unresponsive. In contrast, the "discrete" ablation area is very flashy with runoff closely tracking solar radiation.

Cline Glacier ice mine

(M.M. Brugman (NHRI))
Based on available information, it was concluded that the effect on mass balance and runoff of ice mining by the Ice Age Company at Cline Glacier would be minimal, but claims about the age of the ice could not be supported.

Clear-sky net radiation field of a mountain glacier environment from remote sensing

(D.J. Gratton and P.J. Howarth (GEOG/WATER))
LANDSAT-5 thematic mapper yields accurate surface-cover albedo and long-wave emittance values for a mountain glacier basin (Athabasca Glacier). Terrain-reflected and terrain-emitted radiation should not be neglected in many areas of the basin; it represents an important part of the incoming radiation process.

Peyto Glacier, Alberta

(M.M. Brugman, G. Holdsworth and T. Carter (NHRI))
The glacier continues to lose mass. A total survey station was used to determine the magnitude of this loss since the IHD map was made. Discharge measurements reveal continuous flow throughout the winter. Wood samples, found near the snout, were prepared for ^{14}C dating and sectioning.

(D.S. Munro (GEOG/UTE))
On Peyto Glacier, radiative- and sensible-heat exchange account for most of the energy used to melt snow and ice, the latter accounting for nearly 50% of the energy used to melt snow. Modelling shows that glacier ablation is highly sensitive to radiative exchange terms, particularly the surface albedo.

(P.M. Cutler (now at GEOL&GPHYS, Univ. Minnesota) and D.S. Munro (GEOG/UTE))
On the Peyto Glacier tongue visible reflectivities were higher than near-infrared values; over moraine the pattern was reversed. The near-infrared range displayed less spatial variation than the visible. The minimum difference between visible reflectivity at clean and dirty ice was 0.17; near-infrared values differed by only 0.05. Impurity content was more important than surface roughness for spatial variation. The snow showed greater temporal variation. Results suggest a separate treatment of visible and near-infrared reflectivities in glacier mass-balance models. The unresponsive nature of glacier ice and moraine reflectivity permits confidence in the accurate representation of satellite imagery obtained within a 6 hour period centred on solar noon. For metamorphosed snow the period would be reduced to 4 hours.

(P.J. Glenday (CRRC/WLU))
Digital terrain modelling and analysis has been applied to produce a 1989 glacier, slope and aspect map (scale 1 : 10 000) and to the computation of volumetric change.

Ram River Glacier

(G.J. Young and P.J. Glenday (CRRC/WLU))
Ram River Glacier is being remapped to assess the glacio-hydrological response to climatic fluctuations since the 1966 IHD survey.

Little Ice Age activity, Peter Lougheed and Elk Lakes Provincial Parks, Alberta and BC

(D.P. McCarthy and D.J. Smith (GEOG/SASK))
Archival and geobotanical data show ice fronts were within 300 m of the Neoglacial maximum positions in 1916 AD and are now up to *c.* 2.5 km up-valley. Field investigations of 20 forefields found morphological and datable evidence for 14th to 19th century Little Ice Age advances. There is no evidence for recent advances at these sites.

The Rae Glacier project

(D.J. Smith and C. Lawby (GEOG/SASK))
Rae Glacier has retreated 565 m (mean 7.5 m a^{-1}) from a terminal position reached in approximately 1916. Over that interval the total volumetric ice loss has exceeded 1.370 × $10^7 m^3$ (1916–1958, 8.768 × $10^6 m^3$; 1958–1990, 4.932 × $10^6 m^3$).

SNOW – GENERAL

Canadian Snow and Wind Institute

(F.H. Theakston (CSWI))
The Winter Cities Association has sponsored a Canadian Snow and Wind Institute. This will be a Canadian centre of expertise in snow and wind control as it pertains to the transportation infrastructure and the safe passage of people and goods. It will coordinate activities in this field with respect to research, education, and promotion. Although it is a national organization it will maintain close ties with international councils in other northern regions and countries. It will establish a data base and offer assistance in training personnel, and organizing meetings, workshops and conferences related to snow and wind problems.

Trafficability of snow

(R.N. Yong, A.M.O. Mohamed and D.M. Xu (GRC))
The energy partition method provides a way of establishing relationships between useful and lost energies due to: a) snow deformation; b) tyre deformation; 3) slip; and 4) total input energy. Field data from a deep snowpack at Fernie, BC and predicted data from the proposed model were in good agreement. The model not only determines whether a vehicle can or cannot cross a deep snowpack, but also provides detailed information on the best inflation benefit for a particular payload requirement.

Optical properties of falling snow

(D.L. Hutt (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 multiple-scattering effects.

SNOW – ARCTIC CANADA

Isotopic composition of Arctic precipitation

(F.A. Michel (ES/CARL))
Work is still in progress on determining the isotopic composition (^{18}O, ^{2}H, ^{3}H) of precipitation from AES stations across the Arctic.

Hydroclimatology and sedimentology of a high Arctic mountainous watershed

(D.R. Hardy and R.S. Bradley (GEOG/Massachusetts))
Studies are being carried out in northern Ellesmere Island to: quantify winter snow accumulation within a drainage basin and characterize spatial variability of the snow cover; characterize meteorological parameters controlling meltwater production and streamflow; and to characterize the isotopic composition of streamwater inputs (snowmelt, glacier melt, permafrost active-layer melt), and delineate the relative contribution of each.

Hydrology of a perennial snowbank, Melville Island, NWT

(A.G. Lewkowicz and K.L. Young (GEOG/UTE))
The major water source was snowbank melt and the major sink-surface runoff; both exceeded 500 mm making the water flux through the basin more than double that of typical basins in the central Archipelago. The discharge record was characteristically proglacial rather than nival. Energy fluxes at the snow surface were measured from three towers. During the melt season, net radiation accounted for 85% of the energy absorbed, sensible heat 15% and latent heat was a net loss of 2%.

In spring, the snowbank is up to 10 m thick. Tritium concentrations show the basal 2 m of ice pre-dates 1957. The hypothesized climate warming is unlikely to eliminate the perennial snow unless accompanied by substantially less snow drifting at the site.

Residual snowcover in the Canadian Arctic and Alpine environments in summer

(B. Lauriol, C. Duguay and D. Lagarec (GEOG/OTT))
Research is underway to: evaluate the regional maximum snow depth in winter in the Kluane Range, Yukon and the Northwest Territories; determine the snow disappearance patterns and fractionation process in northern Canada; assess potential impacts on climatic change; and to derive the reflectance and albedo of snow in alpine environments using remotely sensed data for improving estimates of the radiation budget.

Runoff in high-latitude permafrost basins

(P. Marsh and J. Pomeroy (NHRI))
Results demonstrate the importance of meltwater infiltration into the frozen active layer, and outline the processes controlling active-layer soil moisture — a dominant factor controlling infiltration and therefore snowmelt runoff.

Mesoscale climatology of Baffin Island

(J.D. Jacobs (GEOG/MUN))
Field data and optimal interpolation techniques have improved mapping of summer climatic anomalies in the large lakes region of interior Baffin Island. Automatic station data on winter precipitation improved mapping into the interior of snowfall from winter storm events.

SNOW – WESTERN CANADA

Simulation of a prairie snowpack

(C. Fisher and R.F. Hopkinson (AESR))
The assumption of one-in-ten for snowfall conversion to water equivalent, in general, overestimates the situation in the southern Prairies. Melt coefficients were varied in an interactive program, the Regina–Saskatchewan Model, where it was demonstrated that no single coefficient was valid throughout the snow season.

Prairie snow-cover determination

(B.E. Goodison and A.E. Walker (CCC/AES))
Algorithms have been developed and tested for determining snow water-equivalent (SWE) from passive-microwave satellite data for the open-prairie region. A vertically polarized brightness–temperature gradient has been used for three winter seasons (1988/89–1990/91) to produce near real-time SWE maps from SSM/I data for dry snow conditions. Government water-resource agencies have provided important feedback with respect to validation of the SWE information derived. Over forested areas the "open prairie" SWE algorithm has generally produced values significantly lower than ground measurements.

Storage capacities of over-wintering crop residues

(H. Steppuhn (SCRS/AC))
Empirical models can determine total storage capacities of over-wintering crop residues, but relating them to snowfall and environmental conditions is difficult.

Snow Transport

(J.W. Pomeroy, W.N. Nicholaichuk (NHRI) with D.M. Gray, T. Brown (ENG/SASK) and T.D. Davies (School of Environmental Sciences, Univ. East Anglia))
Wind transport of snow profoundly affects the hydrology of wind-swept cold regions. Over a representative 1 km field in the southern Prairies, typically 42% of snowfall is sublimated annually during wind transport, and 35% is relocated, providing a net snowcover loss of 77% before spring melt. Of the annual snow transport, about 30% is by saltation; the rest travels in turbulent suspension to several metres above the surface. However, near Resolute Bay, NWT, winds maintain a much higher proportion of snow in saltation.

Acidic ion concentrations in blowing snow show a three-fold increase from surface snow in contaminant levels, due largely to sublimation of ice from blowing snow crystals. Hence a two-fold increase in contaminant concentrations in drifted snow vs. non-drifted snow.

Snow interception in conifer canopies is often controlled by the flexure of the branch. Measurements suggest an explanation for unloading of intercepted snow when warming occurs after a snowstorm. Further measurements are quantifying the flux of snow particles, heat, water vapour, radiation and momentum to conifer branches during and after snowfalls in order to model the snow-interception losses of forests.

SNOW – CENTRAL CANADA

Hydrochemical fluxes during snowmelt

(J.M. Buttle, K. Sami and D. 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 extension down the stream channel, rather than to a ground-water ridging mechanism operating under adjacent hillslopes. Ground-water recharge through the unsaturated zone is via translatory flow, although bypassing flow was evident in near-surface soils during the initial snowmelt period. Up to 19% of premelt soil water may be immobile. Unsaturated soil hydraulic conductivities estimated using ^{2}H as a tracer during snowmelt ranged from 1.1×10^{-7} to $6.8 \times 10^{-8}\,m\,s^{-1}$.

Snowmelt runoff in suburban catchments

(J.M. Buttle and A. Vonk (GEOG/TRENT))
Suburban catchments experience higher snowmelt rates than open fields and forests, and respond more rapidly to snowmelt and rain-on-snow events than rural basins do. Progressive suburban development has led to a 6-fold increase in the spring quickflow response ratio and an increase in the number of snowmelt events that generate quickflow. Chloride export patterns during snowmelt and rain-on-snow differ as a result of changes in contributing areas.

SNOW – EASTERN CANADA

Snow-atmosphere interaction

(H.G. Jones (INRS))
Experiments on the dynamics of chemical species in cold (< –5°) snowpacks at Lac Laflamme and Schefferville (Quebec) have shown that NO_3 concentrations diminish in snow during certain periods. These experiments were repeated on the Agassiz Ice Cap in 1990 and 1991.

Spring snowmelt at Lac Laflamme

(J. Stein, C. Maul , M. Prévost, R. Barry and A.P. Plamondon (FOR/LAVAL))
Snowmelt surface runoff is more important than previously thought. There is also a clear indication that the freezing processes at the soil surface is an important processes affecting snowmelt pathways.

Chemistry and microbiology of snowmelt

(H.G. Jones (INRS))
It has been shown that the interaction of snow melt water with organic particulates (litter fall) in forest snowpacks leads to depletion of NH_4^+ and NO_3 in melt-water discharge. Studies on microbiological populations revealed the importance of snow algae to the dynamics of many ionic species, notably NH_4, NO_3 and SO_4.

Late-winter snowcover and climate

(C.E. Banfield (GEOG/MUN))
The late-winter snowcover in Grand Lake Basin, Newfoundland, shows considerable inter-annual variability, but with overall maxima in depth and water content during the 1930s and early 1970s, and a minimum in the 1950s. The seasonal climate variables exerting most influence appear to be mean winter temperature and rainfall.

REMOTE SENSING AND METHODS

Workshop on Remote Sensing in Hydrology

(A. Wankiewicz, R. Perla and G. Kite (NHRI))
A Workshop on the Application of Remote Sensing in Hydrology was held at NHRC on February 13–14, 1990. It included sessions on Hydrologic Models and Microwave Hydrology. The Proceedings were published as NHRI Symposium No.5.

Sensing of snow and ice properties

(M.N. Demuth, M.M. Brugman and T. Carter (NHRI))
A portable, frequency-modulated continuous-wave (FM-CW) radar system (2-4 GHz) is under development. Bandwidth, sweep frequency, FFT windowing and Hibert transformation parameters can be selected by operator. The unit can also be used as a fixed-frequency scatterometer and preliminary field trials have been encouraging. Passive radar reflectors were deployed in the accumulation zone of Sentinel Glacier, BC to determine the viability of replacing mass-balance poles with expendable reflectors. Standard tri-planar corner reflectors were also buried. A sledge mounted FM-CW radar can be guided into position using a remotely positioned total survey instrument.

Microwave remote sensing of snow

(R. Perla (NHRI))
The real permittivity of 200 snow samples, measured with a wide range of density and wetness in a capacitive cell at 1 MHz and at 0°C, fits three empirical functions. In agreement with microwave measurements, the empirical constant (q) was found to be 0.4 for wet snow, but higher at both the dry (0.7) and very wet extremes (0.6). These values are consistent with snow microstructure modelled as a sintered ice skeleton with water inclusions disconnected for low volume proportion of water (v_W) and connected as $v_W \rightarrow 1$.

Satellite monitoring of snow and soil moisture

(A. Wankiewicz (NHRI))
Nimbus-5 ESMR observations from 17 different watersheds were used to estimate spring runoff in the Rocky Mountains and Plains regions. Average snowmelt runoff and microwave brightness are correlated. For Rocky Mountain watersheds (5000–20 000 km^2) the results are almost as good as conventional snow courses for 1973–76. Inter-annual variations in snowpack and brightness are localized. For the plains, a good multiple correlation exists between microwave brightness, spring runoff, and previous October streamflow.

In the Iron Creek (3500 km^2) and Antler River (3200 km^2) basins, a microwave-emissivity index was computed as the ratio of monthly mean brightness to surface temperature. This index could be used to monitor monthly basin moisture status.

Models and remote sensing

(G. Kite (NHRI))
Watershed model performance was improved with the use of daily snowcover data from the NOAA visible and IR bands and with land classification data from LANDSAT but not with NOAA cloud-cover data.

Use of SAR for snow hydrology

(R. Leconte (CCRS) and D. Mullins (Intera Kenting))
The qualitative and quantitative interpretation of airborne SAR imagery, acquired in spring 1990, and the development of microwave models of snowpacks, that will be tested using airborne data, has started. Initial findings suggest that dry snow is not completely transparent at X- and C-band frequencies, and that the interaction microwave-energy/snowpack/soil is complex and depends on such factors as soil state (frozen, unfrozen), layering and the presence of ice layers in the snowpack.

WMO solid precipitation intercomparison

(B.E. Goodison and J.R. Metcalfe (CCC/AES))
An octagonal, vertical, double-fence shield surrounding a Tretyakov precipitation gauge is the reference standard. Canada has established six evaluation stations representing different climatic and physiographic regimes. Wetting losses for the Canadian Nipher Shield Snow Gauge System (National Standard), a non-recording gauge, are significant and initial results suggest they could be slightly higher for old gauges. The addition of the large Nipher-type shield on recording gauges at automatic stations, particularly in windy environments, offers a viable method of minimizing catch errors while providing measurements compatible with Canadian National Standard.

(B.E. Goodison, J. Metcalfe and K. Jones (AESR))
Results from the intercomparison show that the Canadian Nipher and large-scale Nipher are very similar as well as Russian double-fenced snow gauge. The US Wyoming catches about 75% and Alter shields only 50–60% of the Canadian gauges.

Spatial prediction of snowcover development

(H.B. Granberg (CARTEL) with G.J. Irwin (DRES))
Useful information on snow conditions can be derived from digital-terrain information and standard weather data.

AVALANCHES

Snow slope stability evaluation and avalanche hazard forecasting

(C.D. Johnston and J.B. Jamieson (ENG/CAL))
Work continues on refining and evaluating various field tests of snow-slab stability (e.g. rutschblock shear frame) as well as assessment of the spatial variability of the shear strength of active weak layers.

ATMOSPHERIC ICE

Atmospheric icing of structures

(J.A. Druez (UQAC))
Work continues of ice accretion and shedding rates on electrical conductors as a function of conductor type, ice loads on power lines and icing events duration. The adhesive, tensile and comparative strength of glaze, rime and spray-ice is being investigated as a function of

temperature, wind velocity, liquid-water content, droplet diameters and strain rate.

Ice accretion on insulators and conductors

(M. Farzaneh and 10 researchers (UQAC))
For low or medium intensity ice accretion, the amount of ice accreted on a high voltage conductor is much higher under positive and alternative voltages than under a negative voltage. There is no major change in the weight, density or grain texture of hard rime grown on the surface of insulators submitted to DC or AC high voltage. Minimum flashover voltage of an insulator covered with hard rime is about 40% lower than that of a wet insulator.

PERMAFROST AND GROUND ICE

Clarification of perennial ground ice by thermally-induced regelation

(E. Perfect, P.H. Groenevelt and R.D. Miller (LRS))
The model predicts net upward migration of mineral particles embedded in ice-rich permafrost under the influence of surficial temperature oscillations. This movement occurs over a relatively narrow time band within each annual cycle. A maximum flux of 10^{-11} m s^{-1} was calculated at the permafrost table. Fluxes decrease rapidly with the depth. Over geological time, embedded mineral particles will be expelled into the overlying active layer leaving ice as a pure phase in the thermo-active zone. This fits with field observations of the vertical distribution of perennial ground ice.

Movement of steel rods through warm ice

(D.H. Shields and L. Domaschuk (ENG/MAN))
The rods quickly moved to steady-state (secondary creep) displacement conditions. There was no sign of failure (tertiary creep). There were both instantaneous (elastic) displacement and primary creep on initial application of the load.

Ground ice studies in the USSR

(F.A. Michel (ES/CARL)
The ground ice at the several sites on the Yamal Peninsula, northwest Siberia, USSR, investigated to date can be classified as wedge ice or segregated ice.

PERMAFROST

Onshore/offshore transect, Beaufort Shelf

(S.R. Dallimore, S. Blasco, D. Gillespie, J.A. Hunter, P.J. Kurfurst, A.S. Judge, F.M. Nixon, B.R. Pelletier, S.E. Pullen, A.E. Taylor and J.-S. Vincent (TSD/GSC))
This program will document permafrost conditions in the upper 100 m of the coastal margin of the Beaufort Shelf and correlate them with onshore areas. It involves route selection, drilling, geophysical surveys, ground thermal-data collection, sample testing and data analyses. Ground-ice studies include salinity, isotopes and chemistry as well as geothermal modelling.

Nature and origin of ground ice

(W.H. Pollard (GEOG/McG))
Regionally (e.g. Herschel Island, Yukon Coast, Fosheim Peninsula) ground-ice characteristics have provided information on paleoclimate conditions associated with ground-ice aggradation as well as recent climate changes post-dating ground ice. These studies are improving knowledge of the distribution and range of contents of ground ice which will be important in the event of global warming.

Development of ice wedges

(A.G. Lewkowicz (GEOG/UTE))
Data collection and analysis is in progress on relation past and present ice-wedge growth to climatic factors on Fosheim Peninsula, Ellesmere Island.

Hydrological processes

(M.-K. Woo (GEOG/McM))
Satellite images taken during the snowmelt season revealed patches of early melt zones, tens of kilometres across, on the lowlands of Fosheim Peninsula. Temperatures, snow ablation, and frost-table depths within and around one such patch showed it had higher temperatures, earlier snowmelt, and a deeper frost table. Superimposed on the meso-scale climatic and hydrological characteristics are local influences of slope orientation and elevation. Sites established in 1989 continue to define spatial and temporal changes in the thermal and hydrological regimes.

Precipitation is the major moisture source during years with near-normal temperatures while ground-ice melt provides an alternative source during warmer years. This fail-safe moisture supply ensures lusher vegetation than expected of polar deserts.

Characterization of ground ice

(S.R. Dallimore (TSDGSC))
The development and testing of models of ground-ice characterization within permafrost regions of northern Canada and the Cordillera continues. A report summarizing ground-ice occurrence in the Beaufort Sea coastlands is in preparation.

Geological and geotechnical conditions, Beaufort Sea coastal zone

(S.R. Dallimore, J.R. Bélanger, A.S. Dyke, A.S. Judge, P.J. Kurfurst, P.A. Egginton, J.-S. Vincent and J.A.M. Hunter (TSDGSC))
Work includes laboratory analysis and modelling to characterize material and ground-ice properties in the Yukon coastal plain, the Mackenzie Delta, the Liverpool Bay area and on Richards Island and the Tuktoyaktuk Peninsula.

Permafrost/climate relationships

(D. Etkin and A. Headley (CCC/AES))
The existing climate data base was examined to determine the extent of any changes in climate parameters of importance to permafrost regimes in the Mackenzie Valley. January and mean annual temperatures have generally increased, both since 1940 and since 1970, and the warming trend extends beyond the lowest layers of the atmosphere. Snow depths showed high year-to-year variability, with trends tending to a slight decrease since 1970. Stuart's frost index model showed lower values over the past 17 years.

Properties and distribution of ground ice

(P.J. Kurfurst and S.R. Dallimore (TSDGSC))

Several types of massive ice, including buried glacial ice, have been found in the Tuktoyaktuk coastlands area. Their properties and behaviour differ due to different origin and type of host soil.

Mackenzie Delta hydrology and ecosystem

(P. Marsh (NHRI))

Ongoing research illustrated the importance of permafrost in controlling the hydrological regime of delta lakes. It plays a major role in forming lake basins and affects water supply to the lake by: delaying and limiting snowmelt runoff due to the large negative soil heat-flux; and limiting ground-water flow from the lake. Without permafrost these lakes would experience a very different hydrological regime and would not maintain stable water-levels.

Permafrost research — Norman Wells Pipeline

(M.M. Burgess and A.S. Judge (TSDGSC) with K.L. McInnes (DIAND), C. Tarnocai (AC) and Interprovincial Pipeline)

The project has developed an understanding of the behaviour of a small diameter, buried, "ambient temperature" oil pipeline in discontinuous permafrost. Instrumentation has shown that pipe temperatures are 70°C, and that mechanisms of pipe/ground heat exchange are complex, particularly beneath insulated thaw-sensitive slopes where thaw depths have begun to exceed predictions in several areas after only 6 years of operation. Monitoring of the right-of-way continues and contributes to global change research.

Thermal and hydrological investigations

(C.R. Burn (GEOG/UBC))

Permafrost of the southern Yukon has degraded and cannot be sustained after a forest fire. Temperature profiles in permafrost at Mayo, YT show warming in response to climatic trends of the last two decades.

Effects of Disturbances in the Sub-Arctic

(G.P. Kershaw, K.E. Evans, B.J. Gallinger and S. Nolte (GEOG/ALTA))

After six growing seasons, thaw depths continue to increase on cleared rights-of-way and in simulated pipeline trenches. The thaw depths beneath an experimental oil spill are increasing in response to higher surface temperatures and greater net radiation produced by lower albedo.

Palsa Evolution in Alpine Tundra

(G.P. Kershaw, L.J. Kershaw and K. Skaret (GEOG/ALTA))

A project to determine the present status of permafrost features such as palsas and peat plateaux was initiated in July 1990. It will also consider the nature of seasonal changes in the active layer and microclimatic processes affecting it; describe the development of features and relate this to environmental change including climate; and construct a numerical/conceptual model of palsa evolution in the alpine, discontinuous permafrost environment. As yet data from the first field season have not been analyzed.

PERMAFROST – QUEBEC

Permafrost in northern Quebec

(M. Allard, M.-K. Seguin (CEN/LAVAL), B. Ladanyi (ENG/MONT), W. Pollard (GEOG/McG) et al.)

New relationships have been established between the electrical and physical properties of permafrost, new information obtained on the thermal regime of permafrost in tidal marshes and along shorelines, thermal data acquired from > 15 locations across northern Quebec, and radar data obtained on palsas, ice wedges and frost blisters.

Failure of frozen sand under triaxial compression

(B. Ladanyi and J.-F. Morel (NEC/EP))

When a dense granular material with a viscoplastic matrix, such as ice, is submitted to uniaxial or triaxial compression, one portion of its strength is thought to be due to the internal confinement resulting from tensile stresses generated in the matrix when it tends to oppose the dilation. A new conceptual model describing this phenomenon was checked by performing triaxial compression tests on frozen and unfrozen sand. The test results confirm that the effect of "internal confinement" or "dilatancy hardening" is responsible for about half the compression strength observed in uniaxial compression tests with ice-saturated frozen sand.

Borehole dilatometer creep and relaxation yesting in frozen soils and ice

(B. Ladanyi, J.R. Murat, J. Sgaoula, M. Melouki and B. Touileb (NEC/EP))

The study comprised both in situ tests, at two permafrost sites (CRREL Permafrost Tunnel, Alaska and Longyearbyen, Svalbard), and full-scale tests under well-controlled cold-room conditions. The results were interpreted by three methods (ageing-creep theory, reference-stress, and isochronous curves). 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.

Modelling coupled processes in freezing soils

(B. Ladanyi and M. Shen (NEC/EP))

The newly developed conceptual model and a numerical solution, involving a combination of the finite-difference method and the finite-element method, 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, which is being carried out 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.

Axial and lateral loads on permafrost piles

(B. Ladanyi, A. Thériault and A. Foriero (NEC/EP))

Complete analytical and numerical solutions for stress redistribution with load and time in long, compressible, axially loaded piles, embedded in permafrost have been obtained and compared with laboratory and field test results. For the latter, several different analytical and numerical solutions were developed and evaluated.

Geophysics applied to permafrost

(M.-K. Seguin, M. Allard, R. Lévesque, J. Stein, J.A. Pilon and F. Padilla (GEOL/LAVAL))
Electrical, seismic and electromagnetic (EM) (conventional and ground-probing radar) methods can define the lateral extent of the permafrost (PF) surface. Electrical and EM methods can also determine its vertical extent, but because of a hidden layer underneath the PF, the refraction seismic method is not effective. The temperature of PF was monitored with thermistors and ice and ice content detected using combined geophysical methods. The integration includes gravity, electrical resistivity, induced polarization, self potential, multifrequency–multiseparation EM techniques and ground-probing radar. Both surface and downhole geophysical methods are complementary for mapping PF distribution and obtaining information on its properties (e.g., density, electrical resistivity, chargeability, dielectric constant, dynamic elastic moduli, thermal conductivity, water and ice content).

Frozen soil processes

(H.N. Hayhoe and D. Balchin (LRRC/AC))
Time-domain reflectometry and linear displacement transducers are useful for monitoring freezing and thawing processes under field conditions. Soil temperature gradients at the freezing front can be related to accumulative frost heave.

Electrical freezing potentials

(V.R. Parameswaran (IAR/NRC) with J.R. Mackay (GEOG/UBC))
Ice negative potentials (50 to 80 mV) were measured on electrodes located at the freezing front in the core of a pingo. The advancing freezing front in successive years could be located by this technique.

GPR and EM conductivity surveys

(R. Pelletier-Travis (Stennis Labs, NASA) and L. Davis (CANPOLAR))
Ground Penetrating Radar was able to measure peat thickness and delineate stratifications within the peat near Moosonee, Ontario. Airborne measurements work well up to about 5 m when it becomes difficult to detect the bottom of the peat. EM conductivity shows promise if the conductivity of the peat remains essentially constant.

Permafrost distribution, history and processes

(A.S. Judge (TSDGSC))
Radar technologies were further explored as remote-sensing tools for permafrost and ground-ice mapping. The possible integration of SAR and GPR was evaluated with Atlantic Scientific and further applications of GPR examined in studies of fluvial processes with CAL. The deep subsurface thermal field in the Beaufort Sea region was mapped using industry borehole data. Results were tied to the distribution of permafrost and the recent glaciological history.

In situ creep properties of frozen soils and ice by means of the sharp cone test

(B. Ladanyi, P. Talabard and J. Sgaoula (NEC/EP))
This method consists in pushing a smooth, low-angle cone into a predrilled conical portion of a borehole. The creep properties of the material are determined by applying a constant axial load to the cone, and by observing its time-dependent axial displacement tending to enlarge the hole. The test results, obtained 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.

(B. Ladanyi, P. Huneault, B. Touileb and A. Ducharme (NEC/EP) with Tom Lunne (Norway) and P. Vergobbi and B. Lhuiller (France))
Tests carried out in 1988 in frozen silt in the CRREL permafrost tunnel in Alaska, as well as those in sea ice on the east coast of Newfoundland (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 continuously profile frozen-soil strength down to a given depth, or to determine the frozen soil or ice strength vs. strain-rate behaviour within a selected soil layer.

Analysis of ground-temperature profiles

(A.E. Taylor (TSDGSC))
A winch and logger system was used to measure quasi-continuous temperature profiles in boreholes and in the 1977 ice-core borehole on the Agassiz Ice Cap.

Heat and mass transfer in frozen porous media

(W.K.P. Van Loon (AUN))
Time-domain reflectometry is a very useful in situ method for measuring liquid water content and bulk electrical conductivity in frozen soils.

PHYSICS OF ICE

Ice properties

(E. Whalley (SIMS/NRC))
The entropy of amorphous ice relative to that of ice Ic was determined by a new thermodynamic method. It is a small fraction of other estimates. The density of the translational and the rotational vibrations of high-density and low-density amorphous ice were determined by inelastic neutron scattering (with E.C. Svensson, V.F. Sears, J.H. Root and C. Szornel (AECL, Chalk R.) and E.D. Hallman (Laurentian Univ.)). The transverse and longitudinal translational vibrations and the rotational vibrations of ice are well separated. The harmonic component of the heat capacity was calculated from these spectra, and so the anharmonic component of the heat capacity was obtained for the first time for a polyatomic crystal. The Brillouin spectra of the crystalline phases of ice at 0–10 kbar and –35.5°C has been reported with H. Kiefte and M.J. Clouter (MUN).

LAKE AND RIVER ICE – ARCTIC

Borehole indentor measurements

(N.K. Sinha (LTL/NRC))
In situ tests were carried out on freshwater lake ice, first-year Labrador sea ice, freshwater ice-island shelf-ice and multi-year ice-island ice using the NRC borehole indentor system.

Colour Lake, Axel Heiberg Island

(W.P. Adams, P.T. Doran, M.A. Ecclestone and J. Buttle (GEOG/TRENT))
Background information on Colour Lake, its catchment and the role of single and multi-year ice covers, has been collected and the results are being analyzed and prepared for publication.

Ice regimes, Mackenzie Delta and Hay River

(D.A. Sherstone (Science Inst. of the NWT, Box 1617, Yellowknife, NWT, X1A 2P2))
Ten winters' monitoring rates of ice growth, the timing of maximum ice thickness and the rate of ice decay for the Mackenzie Delta confirm that maximum thickness is achieved later than earlier studies reported. Mackenzie Delta ice is consistently thinner in channels on the east side of the Delta, thicker on the west. Central channels show greater year-to-year variations. This may be due to freeze-up events and timing in Middle and Oniak Channels. Four winters' data from Hay River indicate maximum thickness is reached in the first two weeks of April for all sites. Ice can thin by as much as 50% prior to break-up.

Strength and rupture of decaying river-ice

(M.N. Demuth, T.D. Prowse and H.A.M. Chew (NHRI))
Based mainly on studies of Liard River ice, dominant failure modes contributing to ice-cover break-up have been identified and classified according to their scale, mechanism and rate of evolution. The role of large-scale flaws and ice-cover variability in the promotion of ice failure was examined. A physical model of ice-overthrust flexural failure was developed, describing an intact brash-ice fragmentation process.

The strength and variability of pre-break-up ice-covers was characterized with a borehole-jack indentor. A model, based on plasticity, describes the jack indentation characteristics and estimates ice-compressive strength. An ice-stiffness index, obtained using the jack, has allowed the determination of profile properties in structurally variable ice covers. This has important implications for the flexural properties used in ice-cover failure modelling.

Freshwater-ice break-up process

(T.D. Prowse, M.N. Demuth and H.A.M. Chew (NHRI))
A relationship between changes in ice strength and internal melt porosity has been established from concurrent field measurements of energy balance and flexural strength. A preliminary model of the nature of the melt geometry has been developed and some quantification made of the effect of internal porosity changes on the optical properties of the cover. The magnitude and relative importance of hydrothermal and atmospheric heat fluxes to the decay of an ice jam has been established. Results led to the first calculation of ice-jam porosity from field data.

Radiation-ice modelling

(H.A.M. Chew, T.D. Prowse and M.N. Demuth (NHRI))
A solar radiation simulation system using a high-power arc lamp, from which the light is columnated and directed to a temperature and environment control chamber where incoming and transmitted energies were measured, has been set up. Albedo and radiation measurements were made at Floral Pond and Waskesiu (Saskatchewan), and on the Liard River, near Fort Simpson, NWT. HORZ-CODE, an AES model for calculating solar energy at the horizontal surface has been evaluated. Despite the lack of radiation data from Fort Simpson, some of the sub-models' predictions for energy at the horizontal surface agree well with the measured Liard River values.

Yukon River headwaters lakes

(P.F. Hamblin, E.C. Carmack and J.C. Patterson (NWRI))
A thermodynamic model of an ice-covered lake was developed and tested on Lake Laberge (YT): the water/lake-ice heat flux was quantified in terms of a sensible heat transfer coefficient; inflow mixing is controlled by outflow conditions in large ice-covered lakes.

LAKE AND RIVER ICE – EASTERN CANADA

Ice in lake systems, Schefferville, PQ

(W.P. Adams, M.A. Ecclestone and O. Choulik (GEOG/TRENT))
From 1977–1983, oxygen concentrations were monitored in seven lakes near Schefferville. Half did not thermally stratify during the summer. Winter oxygen depletion proceeded linearly from freeze-up in late-October until early May, when the melting snowcover and increasing solar penetration through the ice cover resulted in an increase in photosynthesis and in the concentration of whole-lake oxygen. Winter depletion rates ranged from $0.047\,g\,O_2\,m^{-2}\,d^{-1}$ in oligotrophic Lake Dian to $0.225\,g\,O_2\,m^{-2}\,d^{-1}$ in Lake Lejeune. Rates appear to reflect the difference in trophic status rather than morphometric parameters.

Sub-ice layering Lac Laflamme, Quebec

(J. Roberge (350 Latourelle #1, Quebec, G1R 1C8))
The sub-ice circulation of waters from five different origins was studied during spring melt. Three distinct low pH episodes were recorded. The first (pH 5) occurred in the early melt period; snow and ice meltwaters layered beneath the ice forming a stratum $\approx$20 cm thick. The others, (pH 5.3 and 5.1) during the massive melt period, were due to peak flows of hillslope through-flow which entered the lake and formed a layer 20–40 cm thick in the water column. The ice cover thus not only modified the nearshore water quality by inducing thermal layering, but also strongly influenced the quality of the outflow waters due to the segregation and rapid evacuation of the through-flow and surface meltwaters.

Restigouche River ice study, NB

(S. Beltaos (NWRI) and B.C. Burrell (NBEPS))
The configuration of a jam near the toe on the Restigouche River has been predicted using a numerical algorithm that solves appropriate differential equations.

GPR ice jam surveys, Saint John River, NB

(S. Ismail (N.B. Power) and Les Davis (CANPOLAR))
A ground-penetrating radar, operating at 50 MHz, could detect and estimate the thickness of both broken ice and slush ice to depths of seven metres on the Saint John River near Perth-Andover, New Brunswick.

Nashwaak River, NB

(N. El-Jabi (ENG/MONCTON))
A non-dimensional index, based on hydro-meterological parameters, has been developed for forecasting ice jamming and break-up for the Nashwaak River.

Ice-jam occurrence and break-up

(S. Beltaos and J. Wong (NWRI))
A semi-empirical method has been developed to forecast the onset of river-ice break-up, based on analysis of fracture processes and historical data. A numerical model (RIVJAM) can compute the longitudinal variation of thickness and water-levels along a break-up jam, including the toe region.

(S. Sarraf (ENG/CONC))
The transient behaviour of river flow during ice-jam formation and release has been investigated. This has included testing and validating numerical models, particularly a 2D model based on depth-averaged hydro- and thermodynamic equations, and investigating the heat-flux and melting-rate of a fragmented ice-cover. Heat exchanges with the atmosphere have been computed for varying meteorological conditions.

Geological aspects of drift ice

(J.-C. Dionne (CEN and GEOG/LAVAL))
In studying ice as an agent of erosion, transportation and sedimentation, in various environments, drift ice has been found to be a major agent for transporting coarse and fine-grained sediment in the St. Lawrence estuary.

Model Ice Material

(S. Beltaos and J. Wong (NWRI))
SYG-ICE is a material based on plaster, PVC resin and glass microbubbles. It has the required mechanical properties to simulate ice breaking under laboratory conditions and attendant scale reductions.

SEA ICE

Long-term variability in the Arctic Ocean

(E.C. Carmack (IOS))
Recent studies show that exports of freshwater, from river inflow and sea-ice formation, may control the thermohaline circulation of the world ocean, and thus have a major effect on global climate.

(D.M. Holland (MET/McG))
Working is starting on comparing coupled ice/ocean general circulation model results with observations of ice characteristics to understand the causes of interannual variability.

Arctic buoy program

(W.D. Hume (4999-98th Ave, Edmonton, Alta, T6B 2X3))
AES deployed two buoys in the Arctic Ocean in 1990, when other international participants deployed in excess of 20 buoys. Data are transmitted over the Global Telecommunications System and archived in Ottawa.

Sea-ice diatoms

(M. Poulin and P.B. Hamilton (PS))
Work is underway on the taxonomic, morphological and phytogeographical characteristics of about 100 diatom species inhabiting the lower sections of sea ice in the Canadian Arctic.

Inuit use of sea ice

(R. Riewe (ZOO/MAN))
Most present-day Inuit communities lie along the Arctic coastline and rely on marine ecosystems. Hunting territories in the Nunavut region vary from 42 600 to 205 000 km^2 with an average of 107 337 km^2; about one-third of these encompass marine areas. The Inuit have an extensive language and technology for sea ice. Their ecological knowledge of this environment is extremely rich but has received little attention from southern biologists.

Climate change and Beaufort Sea ice

(T. Agnew (CCC/AES))
A 50% or more reduction in sea-ice thickness in winter is one of the estimated potential changes in the Beaufort Sea ice regime due to a doubling of CO_2 concentrations.

Beaufort Sea ice forecast model verification

(T.G. Brown, F.G. Bercha, B. Dixit and R.W. Marcellus (BERCHA))
Statistical procedures were developed for verification of ice movement, total and partial ice concentrations, ice pressure, and ice-edge location in which the output from any sea-ice forecast model is compared with Beaufort Sea data acquired from two periods in 1986. The data include the necessary information to execute the sea-ice forecast model, including initial ice conditions, ocean currents, and wind fields for a total duration of 120 hours in each period. The output verification data include all necessary information to cover the majority of the current regional ice-modelled area which is approximately 800 km^2.

Pack-ice driving forces

(R.M.W. Frederking and M. Sayed (LTL/NRC))
Pack-ice driving forces were measured during March to May 1991 in the Beaufort Sea. Also, stress measurements were made in the marginal ice zone of the Barents Sea with the Norwegian Hydrotechnical Laboratory and C-CORE.

Ice subsurface characterization

(H. Melling (IOS))
Sonar deployments in the Beaufort Sea in 1990 showed their suitability for ice-field measurements. The average thickness of ice was roughly twice that attributable to local thermodynamic growth. The most extreme feature observed had a draft of 27 m.

Ridge statistics

(M. Sayed and R.M.W. Frederking (LTL/NRC))
An aerial survey of the Beaufort Sea ice cover was made in

April 1991. It was co-ordinated with measurements of keel geometry by IOS and BIO. Analysis of the two-dimensional ridging characteristics in the Beaufort Sea is underway in collaboration with J. Lewis (GEOG/McG).

Energy-flux density estimation, North Water

(K. Steffen (CIRES))
Based on satellite passive-microwave measurements, more than 20% young ice (<0.3 m) was found in the North Water area (100 000 km^2) throughout most winters, with maximal values of 60% and more, and only a few per cent of open water. The mean loss for the entire North Water was found to be 77 W m^{-2} for November to March 1986–87. Future work will involve monitoring the North Water area with ERS-1 SAR data during the two winters 1992 and 1993.

Sea ice and atmospheric circulation

(T. Agnew (CCC/AES))
For the Baffin Bay/Davis Strait areas advection of ice and in situ freezing play important roles in ice formation. In the Greenland Sea, extremes of sea-ice cover are determined more by atmospheric advection.

Northumberland Strait – ice studies

(T.G. Brown, J.R. Bruce and A.W. Poon (BERCHA))
Simulation models show the impact of a bridge on the ice regime in Northumberland Strait in terms of blocking ice moving through the Strait and its effect on the length of the ice season. The models show that maximum delays of as little as 1–2 days will occur. Supporting studies characterized ice in the Strait in terms of floe sizes, ridging frequencies, strengths, and thicknesses. Techniques used included high-resolution synthetic-aperture radar data, field programs of ridge measurement and ice sampling, and analysis of photos.

Sea ice off Labrador

(M. Ikeda (BIO))
Labrador ice forms mainly north of 55° N and is advected southward. Ice cover shows clear inter-annual variabilities, which are mostly accounted for by air temperature. Convection and shoreward heat advection limit offshore ice extension. Remote-sensing data are useful for ice-motion detection and ocean-current estimates.

(C.L. Tang (BIO))
The seasonal advance and retreat of the sea ice over the Newfoundland Shelf is controlled by advection and heat balance at the air/ice and ice/water interfaces. The short-term ice movement is primarily wind-driven being linearly related to the surface wind velocity.

Floe collisions in the Labrador ice margin

(G.B. Crocker and R. McKenna (C-CORE))
Floe collisions account for only a small percentage of wave energy decay in marginal ice zones (approximately 10% or less). They do however play an important role in determining the floe size distributions and the deterioration of floes near the ice edge.

East Coast ice and climate change

(R.D. Brown (CCC/AES))
The advection of upstream ice from Baffin Bay/Davis Strait onto the Labrador Shelf in spring, and local spring wind conditions, were found to be key factors associated with inter-annual variability in iceberg severity on the Grand Banks. Upstream processes, such as iceberg calving, were not as important over the last ~100 year time-scale considered.

Iceberg movement in sea ice

(S. Venkatesh (CCC/AES))
Iceberg drift in sea ice that is not under stress is not significantly affected by the presence of the sea ice. The deterioration of an iceberg as it emerges from sea ice is very well simulated by the deterioration model.

Ice and iceberg forecast system (IIFS)

(M. El-Tahan (CORETEC))
An integrated sea-ice and iceberg forecast and data-management system has been developed. It includes operationally tested iceberg and sea-ice-edge drift-prediction models as well as a comprehensive data base on icebergs (size parameters, drift trajectories, drift speed, densities, flux) measured wind and current data and ice-edge movements.

SAR ice interpretation guide

(F.G. Bercha, V.L. Shaw, J.W. Steen and J.A. Dechka (BERCHA))
The sea-ice interpretation guide, developed for the AES sea-ice observers, presents the principles of radar, interpretation of radar imagery, and numerous examples of sea-ice interpretation.

Sensing of sea ice

(J. Sutton and S. Patterson (INTERA Kenting, 2 Gurdwara Rd, Suite 200, Nepean, Ont, K2E 1A2))
SAR and SLAR is used to monitor ice conditions through the data analysis and collection capabilities of STAR-1 and STAR-2, complemented by laser/IR/air-photo data. Results are mostly in confidential reports to clients (i.e. oil companies, shipping companies, etc.)

(E.M. Krakowski (INTERA Technologies Ltd., 2500 - 101 6th Ave S.W., Calgary, Alta, T2P 3P4))
SAR imagery of ice conditions in Canadian waters is being collected for the Canadian Coast Guard.

Marine currents determined from ice flow

(J.-M.M. Dubois et P. Larouche (CARTEL))
The direction and speed of marine currents is being evaluated by remote sensing of the displacement of ice blocks. Wind stress and the Coriolis effect must be considered. With MSS images, both analogue and digital techniques provide comparable results.

Acoustic remote sensing of sea ice

(Y. Xie and D.M. Farmer (IOS))
Snow a few centimetres thick almost eliminates the thermal response of sea ice to cooling effects at night. The sound signatures from cracking, e.g., the duration and the spectra of the signal, can be used to infer elastic parameters of an ice cover and its thickness. Ice break-ups, especially of land-fast ice, leads to ice rubbing between floes, which induces a pure tone sound in the ocean. Its frequency is related to the shear wave speed and thickness of the ice sheet.

Ice radar for measuring thickness of ice

(K. Iizuka (ENG/UT))
A surface-borne ice radar has been successful developed and tested. It is now being converted into an airborne radar for measuring ice thickness.

Ice thickness from ground penetrating radar

(J.P. Todoeschuk (now with ICI Explosives Technical Centre, 801 Richelieu Blvd, McMasterville, P.Q., J3G 1T9) and R.I. Verrall (DREP))
Ground-penetrating radar (GPR) gives good thickness results on multi-year sea ice and on permanent land-fast ice; that of Ellesmere Island often has parallel ridges and troughs on the surface called rolls. Elevation and GPR thickness measurements near Stuckberry Point show rolls on the bottom of the ice that have the same wavelength, larger amplitude, and a 90° phase shift.

GPR for long-range ocean remote sensing

(A.M. Ponsford, L.D. Cuff and S.K. Srivastava (NORDCO Ltd., Donovan's Industrial Park, 34 Glencoe Dr, Box 8833, St. John's, Nfld, A1B 3T2))
Long-range detection and tracking of icebergs, vessels and aircraft, up to 500 km, has been achieved using computer simulation software and an operational radar, as well as mapping of the sea-ice/open-sea boundaries. There is excellent agreement between computer simulation and measured data. Models were also developed for the radar cross section of icebergs and propagation loss over sea ice.

Surface-based radar for ice surveillance

(S. Haykin, B. Currie, C. Krasnor, V. Kezys and P. Weber (CRL/McM))
A field experiment was conducted in June 1989 at Cape Bonavista, Newfoundland, using CRL's experimental IPIX radar. This X-band system permits the study of numerous radar parameters including resolution, pulse compression, coherence, Doppler processing, dual-polarization, and within-band dual-frequency operation. The radar is computer-controlled and data are collected digitally. The Doppler and polarization characteristics of the ice targets differ substantially from the sea, permitting significantly improved detection. Collaboration is with Litton Systems Canada, who will commercialize the final radar design.

Sea-ice and snow thickness sensor

(J.R. Rossiter, L. Lalumiere (CANPOLAR) and S. Holladay (Aerodat Ltd.))
Initial measurements of sea-ice thickness in the Arctic and off Canada's East Coast, based on EM induction, have been successful. A pre-production prototype incorporating a radar-based snow-thickness sensor is being tested in the Beaufort Sea in April 1991.

Acoustic measurements of ice properties

(G.B. Crocker, J. Guigné and P. Hunt (C-CORE))
Preliminary assessments of using non-linear acoustic techniques to measure ice thickness, underside roughness, internal structure, etc. are very encouraging. The ice/water and ice/air interfaces could be resolved with millimetre-scale accuracy. Also, bubble layers in the ice clearly showed up as distinct acoustic returns.

Laser profiling of Antarctic ice

(H.B. Granberg (CARTEL) with M. Leppäranta (Finnish Institute for Marine Research))
Preliminary results of an evaluation of ice ridging characteristics show a greater amount of ice ridging in the Weddell Sea than in the Ross Sea.

Laser profiling for ERS-1 (BEPERS-88)

(H.B. Granberg (CARTEL) with J.E. Lewis (McG) and M. Leppäranta (Finnish Institute for Marine Res.))
Some 60 laser profiles, 6–24 km long, were obtained in the Bay of Bothnia to characterize ice surface roughness for calibrating and interpreting SAR images.

SAR/laser profile analysis

(H.B. Granberg (CARTEL) with T. Thompson, B. Hakansson and M. Moberg (Swedish Meteorological and Hydrological Institute))
A study is underway to examine the efficiency of SAR as an indicator of ice conditions (as determined by aerial photography and laser/video profiles).

ICE AND ENGINEERING

Habbakuk Project

(L.W. Gold (LTL/NRC))
A record of Canadian participation in the Habbakuk Project during World War II, and of the reports arising from that work, has been prepared and is ready for publication. The proposal called for construction of a giant "iceberg" aircraft carrier out of "pykrete" (an ice and frozen wood pulp mixture).

Deformation properties of spray ice

(L. Domaschuk and D.H. Shields (ENG/MAN))
There are still insufficient data to determine the consolidation properties of spray ice under varying conditions of initial density, pressure and porewater salinity.

Sea-ice islands from ice–water mixtures

(K. Szilder, E.P. Lozowski and T.W. Forest (MET/ALTA))
Ice-water mixtures for ice-island construction are highly efficient and not very sensitive to air temperature and wind. The advantage over spraying and flooding is particularly apparent for warm weather conditions.

Extension of spray ice technology

(J.S. Weaver, J.P. Poplin and K.R. Croasdale (ESSO))
Methods were evaluated to reduce spray-ice ablation and edge erosion, including surface coatings of gravel and wood products and fabric sheets. The drilling season on spray-ice islands can probably be extended into June. Ice forces were measured in the landfast ice around the Molikpaq at the Isserk I-15 drilling location. Ways of reducing the loads that an ice sheet can exert on a structure were assessed. The newest program is investigating the sliding resistance of grounded ice-rubble with a spray-ice surcharge. The use of snow as an ice-load mitigation agent, and a small helicopter-transportable spray system are also being evaluated.

Sensor for detection of atmospheric ice

(S. Inkpen, C. Nolan (INSTRUMAR Ltd, Box 13246, Stn A, St. John's, Nfld, A1B 4A5) with M. Oleskiew (NRC))
A sensor which detects ice accretion on ground-based structures (IM101 Ice Monitor) uses surface electrical impedance and surface temperature. It can reliably measure atmospheric icing events. Detection levels can be adjusted to reflect the sensitivity required for differing applications. The unit will be available commercially in July 1991. Work continues on a more advanced version for aircraft ice sensing.

Modelling of ice growth

(E.P. Lozowski, K. Szilder and W.P. Zakrzewski (MET/ALTA))
Icing is a complex phenomenon that depends on: the mechanism and rate of water delivery to the target; heat transfer; and synoptic conditions. For ship icing, icing rates and ice loads are ship-dependent and vary over the ship. Icing is most sensitive to air temperature, wind speed, sea surface temperature, and ship speed and heading. It can significantly reduce ship stability and cause a ship to capsize.

Sloping structure research

(K.R. Croasdale and M. Metge (ESSO))
Tests were performed on a 1/10th-scale model of a six-sided conical-shaped cone with facets in 1988/89, and a 1/20th-scale model similar to that used earlier in 1989/90. The changes in scale made it possible to model larger prototype ridges with dimensions closer to design values. Two seasons of large-scale tests in the ESSO Ice Basin in Calgary have been successfully completed. The ice properties in year 2 exceeded expectations partly due to the installation of a new spray-ice system for making weaker ice. Four series of tests were carried out in the first year and 5 in the second year. Each series consisted of at least two runs of ridges and sheet ice.

Ice interaction with structures

(I.J. Jordaan and others (Ocean Eng. Res. Cen./ENG/MUN))
It has been found that viscoelasticity, fracture and damage mechanics are the appropriate tools for modelling the fracture and crushing of ice during interaction with structures.

Ice crushing by low velocity impact and cratering mechanisms

(H.H. Schloessin (GPHYS/WEST) with G.W. Timco and R.M.W. Frederking (LTL/NRC))
The characteristic time sequences of elastic and plastic impact phases were determined from accelerometer pressure-gauge and load-cell records of three sets of 200–600 cm s^{-1} impact tests, carried out at the Hydraulics Laboratory (IME/NRC) on mostly S-2 ice. The impacts, of ~7 ms total duration, consist of a rapid deceleration (braking) phase followed by a main, plastic, slow deceleration phase with build-up to maximum contact pressure and subsequent recovery, for ice 20.3–25.4 cm thick, and of a rapid deceleration followed by a slow deceleration phase, already continuing onsets of recovery, for ice 30.5–36.8 cm thick. The observations emphasize that plastic deformation and fracture of ice sheets consisting of large grains with preferred orientation reflect the prevalent single-crystal anisotropy.

Bearing capacity of ice

(N.K. Sinha (LTL/NRC))
A finite-element numerical analysis has been made to predict the response of a floating drilling platform using a realistic rheological model for ice developed at NRC. A revised manual will be produced for aircraft operations on sea-ice covers for National Defence. During Winterlude in Ottawa, measurements were made of the crowd-induced deflection of ice on Dows Lake.

Computer simulation of ice dynamics

(O.G. Vinogradov, A.M. Vinogradov, A. Springer and P. Wierzba (ENG/CAL))
The methodology and computer code for simulating the motion of broken ice against obstructions are developed. The dynamic ice-structure interaction in the buckling mode of failure was investigated using a Monte Carlo simulation.

Behaviour of broken ice rubble

(M. Sayed and G.W. Timco (LTL/NRC))
Measurements of the behaviour and flow of crushed ice were made in small-scale laboratory tests, particularly the pressures associated with the extrusion of crushed ice particles. Laboratory tests were also performed to measure the bulk behaviour of ice rubble using a newly developed, large (1 m × 1 m × 0.5 m) bi-axial compression test cell. A field project on the sliding resistance of spray-ice surcharged rubble on soft clay was conducted as Joint Industry Project with ESSO.

Behaviour of ice rubble

(T.T. Wong (Hardy BBT Ltd., 219-18 Str. SE, Calgary, Alta, T2E 6J5) and N.R. Morgenstern (ENG/ALTA))
Ice rubble belongs to the class of particulate materials made up of deformable (or weak) grains. An elasto-plastic constitutive model was developed for young broken ice. Berm geometry and rubble accumulation will affect ice-load transmission.

Field measurements of ice forces

(R.M.W. Frederking and M. Sayed (LTL/NRC))
Medium-scale indentation tests were performed at the Ice Island research station. Ice-force measurements were continued on three light piers in the St. Lawrence Seaway. Local impact forces on bridge piers were measured on an instrumented pier in the Rideau River.

Ship interactions with actual ice conditions

(C. Daley (FLEET))
A simple ice-edge brittle-failure model has been developed which is capable of reproducing many of the features of tests of ice-block, and ice-face crushing tests, including: force time-histories, ice-flake size distribution, width of high-pressure solid ice contact, ice-force statistical properties. There has been some progress in ice-cover description, and methods to handle general ship interactions with non-infinite ice using fractal geometries.

Ice forces on ships and structures

(F.M. Williams (IMD))
Full-scale trials of the CCGS *Sir John Franklin* were conducted in 1991 off the coast of Newfoundland. Considerable data on the properties of the ice being

traversed were obtained. Model scale experiments were conducted on a conical structure in the IMD ice tank.

Ice/propeller interaction

(S. Newbury and S.J. Jones (IMD))
A new project will determine the relevant ice/propeller interaction forces for revised Arctic Machinery Regulations being developed by the Canadian Coast Guard. It is a joint collaboration with the Finnish Board of Navigation that will run for three years.

Structural response due to ice loading

(G.W. Timco (LTL/NRC))
Tests were performed on ice loads due to dynamic ice loading. Models of the Great Belt Link (Denmark) and the JZ20 platform (Bohai Bay, China) were tested to measure the dynamic amplifications of loads due to structural vibrations.

Impact tests on freshwater ice

(G.W. Timco and R.M.W. Frederking (LTL/NRC))
Laboratory tests were conducted on the forces and pressures associated with low-speed (2–6 $m\,s^{-1}$) impact of projectiles on sheets of freshwater ice. Various conditions of impact energy, projectile geometry and ice geometry were used. The results provide insight into ice behaviour and pressures during impact loading.

SEA ICE PROPERTIES

Fractal characteristics of sea ice

(G.B. Crocker and G. Cammaert (C-CORE))
Uniaxial crushing of sea-ice and lake-ice samples produced classic fractal particle-size distribution and distinctive fractal dimensions.

Brittle–ductile transition during indentation

(L.W. Gold (LTL/NRC))
The maximum in the dependence of the failure stress on indentation rate for a rectangular rigid indenter acting on the edge of a large ice plate can be explained using elastic theory and a strain-rate dependent fracture toughness. For the criteria of failure applied, the indentation pressure at failure varied inversely as the square root of the width of the indenter. Work is continuing on other shapes of indenters.

Creep of mono- and bi-ice crystals

(B. Michel and B. Doyon (LMG/LAVAL))
For monocrystals, the creep law depends essentially on the reduced shear stress on the basal plane, except for large crystals where kinking occurs. The creep for two crystals introduces strain hardening and a much reduced rate of permanent creep in the worst-oriented crystal.

Crack formation in columnar-grained ice

(L.W. Gold and S.J. Jones (IMD))
The ratio of transgranular to grain boundary cracks decreases with increasing strain rate and decreasing grain size and temperature. Both families have a log–normal distribution in crack width. The mean value of the crack width depends on strain, strain rate, temperature, and grain size. The strain rate and temperature dependence found for the elastic modulus agree with published results.

Deformation and current effects on fabric development in columnar ice

(B. Michel, E. Stander and P. Barrette (LMG/LAVAL))
Large deformations lead to important recrystallization and a 3-point preferred orientation caused by slip plane rotation and dynamic recrystallization.

Fracture of ice

(B. Parsons (IMD))
Field work in Resolute Bay in 1991 was to determine the effects, if any, of ageing and blunting of cracks on the fracture toughness and strength of ice.

Constitutive modelling of ice

(N.K. Sinha (LTL/NRC))
The Sinha constitutive model was extended to incorporate the effects of porosity and grain structure.

Model ice development

(D. Spencer and S.J. Jones (IMD))
An underwater carriage has been designed and built, from which small air bubbles (~1 mm diameter) are released. These bubbles get incorporated into the growing ice sheet, thus reducing its density to a realistic full-scale value for sea ice of approximately 0.9 $Mg\,m^3$.

Behaviour of oil spills in ice-infested waters

(S. Venkatesh (CCC/AES))
The following results have been obtained: for ice concentrations >30%, the oil drifts with the ice; equilibrium oil thickness in slush-ice is nearly four times that on cold water; at an ice concentration of ~80%, the oil on the water surface gets trapped between ice floes and does not spread laterally.

Abbreviations used
AC = Agriculture Canada, Ottawa, Ontario, K1A 0C6
ACC = Alpine Club of Canada, Canmore, Alta, T0L 0C0
AES = Atmospheric Environment Service, 4905 Dufferin Street, Downsview, Ont, M3H 5T4
AESR = Scientific Services, AES, Box 480, Regina, Sask, S4P 3Y4
ALTA = Univ. of Alta, Edmonton, Alta, T6G 2H4
AUN = Agricultural Univ., Duivendal 1, 6701 P Wageningen, The Netherlands
BCIT = Survey Dept, BC Inst. of Technology, 3700 Willingdon, Burnaby, BC, V5G 3H2
BERCHA = F.G. Bercha and Assoc. (Alta) Ltd., 250 - 1220 Kensington Rd NW, Calgary, Alta, T2N 3P5
BIO = Bedford Inst. of Oceanography, Box 1006, Dartmouth, N.S., B2Y 4A2
CAL = Univ. Calgary, Calgary, Alta, T2N 1N4
CANPOLAR = CANPOLAR Consultants Ltd., Unit 4, 265 Rimrock Rd, Toronto, Ont, M3J 3C6
CARL = Carleton Univ., Ottawa, Ont, K1S 5B6
CARTEL = Centre d'applications et de recherches en télédétection, Univ. de Sherbrooke, 2500 blvd Univ., Sherbrooke (PQ), J1K 2R1
CCC = Canadian Climate Centre, AES
C-CORE = Centre for Cold Ocean Resources Engineering, MUN
CCRS = Canada Centre for Remote Sensing, 1547 Merivale Rd, Ottawa, Ont, K1A 0Y7
CEN = Centre d'Études nordiques, LAVAL

CIRES = Coop. Inst. for Res. in Environmental Sci., Univ. of Colorado, Boulder, CO 80309-0216, U.S.A.
CONC = Univ. Concordia, Montreal (PQ), H3G 1M8
CORETEC = CORETEC Inc., Cold Regions Research & Technology, Box 2638, St. John's, Nfld, A1C 6K1
CRL = Communications Research Lab., ENG/McM
CRRC = Cold Regions Research Centre, WLU
CSWI = Canadian Snow and Wind Inst., Unit 1, 335 Laird Road, Guelph, Ont, N1H 6J3
DIAND = Dept. of Indian and Northern Affairs
DREP = Defence Res. Est. Pacific, FMO, Victoria, B.C., V0S 1B0
DRES = Defence Res. Est. Suffield, Alta
DREV = Defence Res. Est. Valcartier, Box 8800, Courcelette (PQ), G0A 1R0
EC = Environment Canada
EMR = Energy, Mines & Res. Canada, Ottawa, Ont.
EP = École Polytechnique, CP 6079, Succ. A, Montréal (PQ), H3C 3A7
ESSO = Esso Resources Canada Ltd., 3535 Research Rd N.W., Calgary, Alta, T2S 2K8
FOC = Fisheries and Oceans Canada
FLEET = Fleet Technology Ltd, 311 Legget Dr., Kanata, Ont, K2K 1Z8
GCS = Glacier Consulting Services, 2225 Prince of Wales Drive, Ottawa, Ont, K2E 6Z8
GDGSC = GPHYS/GSC, 1 Observ. Cres, K1A 0Y3
GRC = Geotechnical Res. Centre, McG, 817 Sherbrooke Str. W., H3A 2K6
GSC = Geological Survey of Canada, Ottawa, Ont.
GUELPH = Univ. of Guelph, Guelph, Ont, N1G 2W1
IAR = Institute for Aerospace Research, NRC
IMD = Inst. of Marine Dynamics, NRC, Box 12093, Station A, St. John's, Nfld, A1B 3T5
INRS = Inst. national de la recherche scientifique, 2700 Einstein, CP 7500, Ste-Foy (Québec), G1V 4C7
IOS = Inst. of Ocean Sciences, Box 6000, 9860 West Saanich Rd, Sidney, B.C., V8L 4B2
LAVAL = Univ. Laval, Cité universitaire, Ste-Foy (PQ), G1K 7P4
LMG = Lab. de mécanique de glace, ENG/LAVAL
LRRC = Land Resource Res. Centre, Res. Branch, AC
LRS = Dept Land Resource Sci., Ont Agricultural Coll., GUELPH
LTL = Low Temperature Lab, Div. Mechanical Engineering, NRC
MAN = Univ. of Manitoba, Winnipeg, Man, R3T 2N2
McG = McGill Univ., Montréal, (PQ) H3A 2K6
McM = McMaster Univ., Hamilton, Ont, L8S 4K1
MONCTON = Univ. de Moncton, Moncton (N-B), E1A 3E9
MUN = Memorial Univ. of Nfld, St. John's, Nfld, A1B 3X9
NBEPS = Environmental Planning and Science Br., Dept of the Environment, Fredericton, N.B.
NEC = Northern Engineering Centre, EP
NHRI = Nat. Hydrology Res. Inst., EC, 11 Innovation Blvd, Saskatoon, Sask, S7N 3H5
NRC = National Res. Council, Ottawa, Ont, K1A 0R6
NWRI = Nat. Water Res. Inst., EC, 867 Lakeshore Rd, Box 5050, Burlington, Ont, L7R 4A6
OTT = Univ. of Ottawa, Ottawa, Ont, K1N 6N5
PS = Phycology Sect., Botany Div., Cdn Museum of Nature, Box 3443, Station 'D', Ottawa, Ont, K1P 6P4
RICK = Karl E. Ricker, 868 11th Str., West Vancouver, BC, V7T 2M2
SASK = Univ. of Sask, Saskatoon, Sask, S7N 0W0
SCRS = Swift Current Research Stn, AC, Box 1030, Swift Current, Sask, S9H 3X2
SIMS = Steacie Inst. for Molecular Science, NRC
SNOW = Snowline Research and Consulting Ltd., #2304, 8805 Hudson Str., Vancouver, BC, V6P 4M9
TOR = Univ. of Toronto, Toronto, Ont, M5S 1A4
TRENT = Trent Univ., Box 4800, Peterborough, Ont, K9J 7B8
TSDGSC = Terrain Sciences Div. (GSC), 601 Booth Str., K1A 0E8
UBC = Univ. of B.C., Vancouver, BC, V6T 1Z4
UQAC = Dept des Sciences Appliquées, Univ. du Québec Chicoutimi, Chicoutimi (PQ), G7H 2B1
UTE = Erindale Coll., UT, 100 St. George Street, Mississauga, Ont, M5S 1A1
WATER = Univ. of Waterloo, Waterloo, Ont, N2L 3G1
WEST = Univ. of Western Ontario, London, Ont, N6A 5B7
WIND = Univ. of Windsor, Windsor, Ont, N9B 3P4
WLU = Wilfrid Laurier Univ., Waterloo, Ont, N2L 3C5
YORKA = Atkinson Coll., York Univ., Ont, M3J 1P3

ENG = Engineering
ES = Earth Sciences
FOR = Forestry
GA = Geophysics & Astronomy
GEOG = Geography
GPHYS = Geophysics
MET = Meteorology
PHYS = Physics
ZOO = Zoology

Submitted by C. Simon L. Ommanney

USSR

SOVIET GLACIOLOGICAL RESEARCH IN 1990

In 1990 glaciological research was carried out in the Caucasus, Central Asia, the Khibini Mountains, Siberia, the Far East, Kamchatka, the Arctic and Antarctica.

The investigations were carried out by the following organizations, which are identified in the text by their abbreviations:

Institute of Geography, USSR Academy of Sciences	IG AS
Institute of Water-Ecological Problems of the FED of the USSR Academy of Sciences	IWEP
Institute of Volcanology of the FED of the USSR Academy of Sciences	IV FED
Institute of Geology of the Academy of Sciences of Estonian SSR	IG AS ESSR
Institute of Geography of the Academy of Sciences of the Kazakh SSR	IG AS KazSSR
Department of Nature Protection of the Academy of Sciences of the Tadjik SSR	DNP AS TadSSR
Tien Shan Physics-Geographical station of the Academy of Sciences of Kirghizstan	TSPGS
Institutes of the USSR State Committee for Hydrometeorology:	
Middle Asia	MARI
Transcaucasus	TRI
Ukraine	URI
Arctic and Antarctic	AARI
Boards of the USSR State Committee for Hydrometeorology:	
Azerbaijan	Azerhydromet
West-Siberian	WShydromet
North-Caucasus	NChydromet
Novosibirsk Institute of Railway Transport	NIRI
Industrial Research Institute of Engineering Constructions "Stroyizyskaniya" of Gosstroy of the USSR	IRIEC
Kirghiz Aerogeodetic Enterprise of the General Department of Geodesy and Cartography at the Council of Ministers of the USSR	KirgAGE
Moscow University	MSU
Leningrad University	LSU
Tomsk University	TSU
Kazan University	KZU
Kazakh Pedagogical Institute named after Abay	KazPI
Leningrad Mining Institute	LMI

The information is based on reports of the above organizations received by the Section of Glaciology of the Soviet Geophysical Committee.

GLACIERS

Modelling of ice sheets and mountain glaciers

(A.N. Salamatin, V.A. Chugunov, KSU)
A mathematical model as to how temperature fields are formed in the central areas of ice sheets was elaborated. Using the quasi-inversion method within the framework of Milankovich's theory the reverse task was solved, so that on the basis of the thermometry in a deep borehole at the Vostok Station temperature fluctuations over the past 200 000–300 000 years could be reconstructed. The temporal alterations of temperature in the past were estimated without calculating directly the age of ice; the values estimated correspond to the known results of field observations.

A mathematical model was developed which describes the reaction of a mountain glacier if, after a volcanic eruption, a layer of ash is accumulated on the ice and ablation stops. A study was made as to what is typical for the surges of a glacier and how a "new" glacier body is formed on the ash layer in the conditions of glaciation of Kamchatka.

A model of the flow of a mountain glacier along the fixed band of flow was applied to estimate mass balance distribution along the flowline. Estimations of balance curves, based on the shape and surface and dimensions of a glacier, were evaluated. Satisfactory results can be obtained for the upper difficult-of-access areas of glacier nourishment only if precise data on the ablation rate of the glacier tongue are available.

The topography of glaciers

(V.A. Kuzmichenok, KirgAGE)
A three-year cycle of the annual surface topographic survey of the surface of Golubin Glacier was completed. On the basis of the results of the survey using a radar portable locator, TGU maps were compiled on a scale of 1 : 10 000 of the relief of the bed and thickness of the glacier.

A preliminary stereophotogrammetric processing of the four aerial photographic flights (22 February 1990, 8 May 1990, 6 August 1990 and 12 September 1990) of the tongue of the Medvezhiy surging glacier was carried out. The potential sun illumination of the surface of the Medvezhiy and Pakhiakor glaciers was calculated.

Methods and a programme of calculating distribution of the surface area of mountain glaciers with regard to altitudinal intervals using the Furie incomplete polygon were elaborated. For substantiation of dependencies, digital models of the relief of glaciers of the Ak-Shiyrak Ridge referring to different time (178 glaciers in two periods) were used.

Glaciers of Kamchatcka

(Ya.D. Muraviev, IV FED)

At the control glacier Kozelsky in the Avachinskaya group of volcanoes the 1989/90 winter balance was 361 $g\,cm^{-2}$ (taking into account the internal infiltration nourishment equal to 17 $g\,cm^{-2}$). This value is close to the value of accumulation of the previous year. The summer balance is equal to –489 $g\,cm^{-2}$ which caused strongly negative mass balance in the third consecutive year. In 1989/90 balance year is was –128 $g\,cm^{-2}$. Aerovisual study of the Kamchatka glaciers at the end of the ablation season shows that most glaciers are in a negative balance state. The firn-line altitude exceeded the average value by 200–250 m at the south of eastern Kamchatcka and by 50–120 m at the Kronotsky peninsula, and is close to the average at the north of Sredinny ridge.

Radio-echo sounding of the glaciers of Altai

(S.A. Nikitin, TSU)

Maps of bed rock and thickness of Maly Aktru and Vodopadny glaciers at a scale of 1 : 10 000 were compiled. The survey was made by portable radar TGU. Maly Aktru glacier (area of 2.95 km^2) has an average thickness of 85 m and a volume of 0.2518 km^3. The area of Vodopadny Glacier is 0.8 km^3, thickness 52 m and volume 0.0417 km^3.

Fluctuations of the Alatai glaciers

(Yu.K. Narozhny, TSU)

Second- and third-class observations of glacier fluctuations were continued. In 1989/90 in the Aktru basin the amount of precipitation was greater than usual, by 7% of the norm in winter and by 29% in summer. Air temperature was close to the average. The total accumulation on glaciers exceeded the average values by 10–17 $g\,cm^{-2}$. Values of melting also exceeded the norm by 5–10%. As a result the mass balance of glaciers was positive; on Maly Aktru it was +11 $g\,cm^{-2}$. Thus, since 1982/83 balance year, the mass of the Altai glaciers has been increasing. The surface velocity in the middle parts of glacier tongues increased considerably, and retreat of the front slowed down. The total value of runoff in the mountain glacier basin of Aktru from 1 May–1 September 1990 was 26.6 mln m^3, or 763 mm (close to the average).

Kazakhstan glaciers

(IG AS KazSSR)

The Tuyuksu and Shokal'sky glaciers in the Zailijsky Alatau and Shumsky and Muraviev glaciers in the Dzhungarsky Alatau were observed. The annual mass balance and its components were calculated. The variation of the surface altitude and volume of a number of glaciers of Zailijsky Alatau was estimated. Climatic conditions of the glacial zone over the last 5 years were analyzed. Tables of mass balance of glaciers over 1987/88 and 1988/89 were compiled for the *Mass Balance Bulletin*. The present-day glaciation of mountains of southeastern Kazakhstan and ice resources in glaciers were estimated, and statistical forecast of the glaciation evolution was made. A set of models of computer calculations of a number of quasi-stationary characteristics of the glaciers' dynamics was elaborated.

On Tuyuksu glacier a laboratory for the study of ice physics and frozen rocks was equipped. Sources of acoustic emission in frozen soil were identified. It was determined how the strength of glacial ice changes under the impact of pollution.

Soviet–Chinese experiment

(M.B. Dyurgerov, IG AS)

In 1990 the joint Soviet–Chinese experiment on the study of mass balance was completed. It was carried out on three glaciers of the Tien Shan simultaneously: Tuyuksu, Sary-Tor (USSR) and No. 1 (Urumchi, China) according to a single research programme. As a result, the theory of monitoring the mass balance of glaciers and water runoff from them was experimentally confirmed. It was shown that within the limits of the Tien Shan the additional runoff from glaciers into rivers is greatest in the western part where glaciation decreases by 0.2–0.3% annually; changes of glacier mass during a year are considerably greater than the inter-annual ones.

Glaciers of the central and interior Tien Shan

(A.N. Dikikh, TSPGS)

Area distribution of glaciers on the ridges was estimated. The most glaciated ridges are Terskej-Ala-Too (879.7 km^2) and Kokshaal (824.5 km^2).

The area occupied by glaciers on Postyshev and Ak-Zoo ridges is the smallest and is equal to 8.7 km^2 and 6.7 km^2 respectively. Snow precipitation on glacier accumulation areas varies from 600–900 mm, while melting the same areas varies from 3.2–10.8 $mm\,°C^{-1}$. In the Issyk-Kul' basin 190 cm of ice melts off glacier tongues, in the interior of Tien Shan 210–220 cm and in central Tien Shan 250 cm. Melting of glaciers with a southern aspect is 118%, and western one 123% of the melting value of glaciers with a northern aspect. The glacier balance is constantly negative and varies from 20–30 $g\,cm^{-2}$. The most negative balance was observed on glaciers which are situated on ridges with a maximum altitude lower than 4500 m.

The present-day ice resources are 25.97 km^3 in Issyl-Kul' basin , in the Sary-Dzhaz basin 208.4 km^3, and 46.13 km^3 in the Bolshoj Naryn basin. Share of the glacial waters in the annual runoff volume varies from 17–49% and in the summer period from 34–81%.

Study of Yuzhny Inylchek Glacier

(A.V. Orlov, IG AS)

An expedition in central Tien Shan on Yuzhny Inylchek glacier and Akshijrak Massif carried out meteorological, glaciological, hydrological, aerovisual, geodetic and palæogeographical observations from the glacier front up to the altitude of 5100 m in this poorly studied region of the Tien Shan.

Drilling of Grigoriev Glacier

(S.M. Arkhipov, V.N. Mikhalenko, M.Yu. Moskalevsky, IG AS)

Ice core drilling, radio-echo sounding and mass-balance studies on the flat top of Grigoriev Glacier were completed during a joint Soviet–American expedition.

Glaciation of the eastern Pamirs

(DNP AS TadSSR)

Using the studies of glaciers of the eastern Pamirs made in 1986–90, detailed maps of annual total precipitation, annual value of evaporation and annual modulus of runoff over the territory of the eastern Pamirs were compiled, and the role of non-glacial glaciological formations (aufeises, snow patches) in the runoff of the region's rivers was identified.

Influence of the evolution of the Pamirs-Alay glaciation on the river runoff

(V.G. Konovalov, MARI)

To estimate the change in the glaciation area, the aerial survey of 1957–59 and space images of 1978–80 were used. Over the past 25–30 years the glaciation area of the Gissaro-Alay decreased by 15.8%, and of the Pamirs by 10.8%. The ratio of advancing, stable and reheating glaciers on Gissaro-Alay is 1 : 4.7 : 17.4, and in the Pamirs –1 : 0.7 : 4.1. Firn areas also decreased. Ice volume of the Gissaro-Alay glaciers decreased by 16.6% and in the Pamirs by 12.4%. Annual total melting of glaciers and glacier-derived runoff decreased in the Pamirs and Gissaro-Alay and smaller water discharge from glaciers did not result in a decrease of the average volumes of runoff of the Zeravshan, Vakhsh and Pyandzh rivers in July–September because of increased snow-accumulation on the area which became free of ice. From 1984 to 1990 data on snow-line altitude on glaciers in the main part of glacial area in Central Asia were collected.

Forecast of glacial and snow components of the Sokh and Isfara rivers in July–September

(F.I. Pertsiger, MARI)

Using separate forecasts of glacial and snow components in runoff, the long-term forecasts of runoff in July, August and September were elaborated. The forecast is from 1–4 months ahead, accuracy 80–92%. Methods are being tested at present.

Abramov Glacier

(G.M. Kamnyansky, MARI)

In the basin of Arbramov glacier monthly observations of glacier mass balance and its components were continued. The changes of the surface level, snow line and location of the glacier terminus of Abramov glacier were observed. Velocity of glacier was measured on eight transverse profiles. The glacier continues to retreat, with a total negative annual mass balance. During the whole year the altitude, water content, density and temperature of snow cover were measured at six points monthly and at three points every decade. The background pollution of the environment was observed. Meteorological, actinometrical and ozonometrical observations were made in accordance with the programme for a second category meteorological station. Snow distribution on different types of glacial–nival zone was studied on five polygons of the basin. A drifted snow patch was drilled to estimate the anthropogenic pollution. Over the last 100–150 years the content of heavy metals and chlorine salts did not increase on the background level.

Mass balance of five glaciers in Sokh and Isfara basins was estimated by remote observations on an ablation area of average altitude.

Hydrological regime and state of the contemporary glaciation of the Caucasus

(V.Sh. Tsomaya, TRI)

Parameters of glacier regime and surrounding natural factors over the last 150–200 years were analyzed. Different methods were recommended for the calculation and forecast of parameters of glacier regime and river runoff, taking into account glacier alimentation and cyclic fluctuations of river runoff.

Aerial photography of the Elbrus Glacier

(Yu.F. Knizhnikov, E.A. Zolotarev, MSU)

Repeated aerial photosurvey of the Elbrus Glacier from helicopter and surface velocity measurements were continued. Two approaches were applied: (a) "total model" where stereo pairs form from images at different times from two points in space; (b) "pseudoparallaxes" with perspective phototransformation of images at different times reduced to a single scale. Different methods used to measure short-term (end of summer) and average annual velocities of the Kyukyurtlyu Glacier surface gave comparable results differing from each other by 11% on average. A map of average annual velocities of Kyukyurtlyu Glacier was compiled. The maximum velocities are 130–140 m a^{-1} at a point 2.5 km up the glacier.

Fluctuations of Bolshoi Azau Glacier, Caucasus

(E.A. Zolotarev, MSU)

Four maps of different time and different scales since 1887 and data from the phototheodolite surveys of 1973, 1980 and 1987 were used to construct digital models of the glacier. Total decrease of the glacier's volume over 100 years is 0.88 km^3 or 0.009 $km^3 a^{-1}$. During the last 30 years rates of the glacier's decrease are lower by four times as compared to the previous interval.

Study of Dzhankuat Glacier, Caucasus

(V.V. Popovnin, MSU)

The mass balance of the Dzhankuat Glacier has been measured for 23 years. It is evident that the glacier budget has improved. For the first time the mass balance was positive for four years in succession. A glaciological geoinformational system, at local level, of the Dzhankuat system began to be elaborated.

Fluctuations of glaciers of the northern Caucasus

(V.D. Panov, NChydromet.)

22 glaciers of mainly valley type were observed. Over the period 1989–1990 16 glaciers retreated, 3 advanced and 3 were stable. The maximum retreat (12.5 m) was registered on Nizhnij Kulak Glacier. Mizhirgi Glacier continued to advance and during 1989–90 moved down the valley by 12.9 m. Maly Aktru Glacier advanced by 4.1 m over the same period. Bezengi Glacier is retreating, but by a negligible amount, –0.7 m. Termini of tongues of many

corrie and corrie-valley glaciers in the Laba and Belaya river basins were covered by large snow patches by the end of the ablation season.

Summer air temperature in the mountains

(N.V. Dvidovich, IG AS)
Temporal variability of air temperature is one of the main factors and, at the same time, an indicator of glacier stability. Variability of summer air temperature increases with altitude. In the Caucasus the maximum variability occurs at the altitude of 2–3 km; anomalies of summer temperature of the same type are more often found in continental climates.

Investigations of the Elbrus glaciation

(A.B. Bazhev, IG AS)
Field investigations during several years on the southern slope of Elbrus, in the Caucasus, made it possible to obtain data on the variability of all the components of mass balance. Together with the Meteorological Institute of Stockholm University studies of macroparticles in glacial cores were started.

Glaciers of Daghestan

(I.A. Aliev, Azerhydromet.)
On Murkar, Tikhitsar (Bazar-Dyuzi ridge), Yuzhny and Yugo-Vostochny (Bogossky ridge) glaciers the front position surface elevation, velocity and ice ablation on transverse profiles were measured. Water discharge of Kila River (Yuzhny and Yugo-Vostochny glaciers) and Selda River (Tikhitsar and Murkar glaciers) was measured. Glaciers continued to retreat by 5–7 $m\,a^{-1}$, except for the Yuzhny glacier which still tends to grow.

Medvezhi Glacier surge

(D.G. Tsetkov, IG AS)
On the basis of a series of aerial photographs, the kinematics of the Medvezhi glacier surge in 1988–89 was analyzed. The surge started in the head of the pulsating part, probably in the zone of the maximum movement velocity. The glacier's surge in 1988–89 was less than in 1963 and 1973. Probably, the next passive stage will be shorter than the previous one.

Automation of ice core study

(V.S. Zagorodnov, IG AS)
The possibility of making automatic investigations of the main structural characteristics of glacial ice (size and orientation of *c*-axis of crystals, concentration and size of air inclusions) was proved experimentally. A new method of water sampling from a core was worked out.

SNOW COVER AND AVALANCHES

Snow cover of western Siberia in 1990

(A.I. Zagrebnev, WShydromet.)
According to the results of a gamma survey, the water content of snow cover in the lowland basins of the Vasyugan, Parabel, Chaya and Ket' rivers varies from 62–307 mm; in the Inya, Berd' and Chumysh river basins from 50–260 mm; in the Mountain Altai in the basins of the Katun' river head and its tributaries (the Koksa and Chemal rivers) from 40–1000 m. According to data from a ground snow survey, the water content of the snow cover in the Altai Mountains varies from 70–860 mm, snow density from 0.17–0.42 $g\,cm^{-3}$, thickness of snow cover from 40–205 cm (from 20 to more than 300 cm by snowstakes). In the Kuznetsky Alatau the water content of the snow cover varies from 570–1110 mm with densities from 0.27–0.49 $g\,cm^{-3}$ and thicknesses from 115–280 cm. Data from a snow survey were used to forecast the maximum water levels of the rivers of the Ob Basin and the water inflow into Novosibirsk reservoir.

Snow survey observations in the Greater Caucasus.

(V.D. Panov, NChydromet.)
The maximum snow accumulation was observed in the western Caucasus in the basins of the Belaya, Laba, Maly Zelenchuk, Shakh and Mzymta rivers, where at the end of March in the Belaya river basin the depth was 380 cm (1530 m altitude), and for the Marukha river 530 cm (2500 m altitude), with over 500 cm depth for the Mzymta river basin at an altitude of over 2000 m. In the central Caucasus at altitudes of 1600–2600 m the snow cover was 170–230 cm thick in its western part and 500–100 cm in the eastern one (the region of Kazenjam Lake). On the whole, the amount of snow in the western Caucasus and the western part of the central Caucasus was higher by 10–20% than in the winter of 1988/89, while in the eastern part of the central Caucasus the amount of snow in 1989/90 was less by 50% than in 1988/89.

Reference book on snow cover in mountains of the USSR: section on the Caucasus

(V.Sh. Tsomaya, TRI)
For the first time statistical processing of data on snow cover obtained during snow surveys, from meteorological stations and aerial observations was made. Statistical characteristics of the norm and variability of thickness, density and water content of the snow cover were calculated for altitudindal zones and points. This reference book on snow cover in the Caucasus contains comprehensive information on snow cover and has no equivalent in the hydrometeorological service.

Reference book on snow cover in the Crimea mountains and the Ukraine Carpathians

(V.F. Grischenko, A.V. Scherbak, URI)
On the basis of all data a reference book on snow cover in the Crimea mountains and the Ukraine Carpathians was prepared, containing data on snow-cover regime in the different altitudinal zones of river basins.

Snow avalanches in the Kuznetsky Alatau and the Altai in 1990

(A.I. Zagrebnev, WShydromet.)
In the Kuznetsky Alatau during the field period from January–April 73 avalanches were registered from 50–3000 m^3 in volume, consisting mainly of new and wet snow. Field observations embraced valleys of the Tom river from the Bel'sy River mouth to the Kazyr River mouth, the valleys of the Amzas and Alguj rivers. In the maintainous Altai in February, March and April aerial visual observations registered 280 avalanches, mainly of

drifted, new and wet snow from 50–15 000 m^3 volume. The greatest number of avalanches (220) was observed in April in the Katun river basin up from the Kaitanak River mouth.

Snow cover and avalanches in Kazakhstan

(V.M. Blagoveschensky, IG AS KazSSR)

The following studies were undertaken: methods of quantitative estimation of avalanche hazards with determination of avalanche parameters (volumes, run-out distance and height of avalanche body) and estimation of costs of anti-avalanche measures; regularities of spatial distribution of avalanche-hazard areas in the mountains of the Ili-Balkhash region and the characteristics of avalanche regime; maps of avalanche hazards of a number of mountainous regions in southeastern Kazakhstan and Central Asia; the influence of local factors on the distribution of snow cover on mountain slopes ; and regularities of distribution of snow resources in mountain basins; spatial–temporal variability of maximum snow resources in the mountains of southeastern Kazakhstan; maps of snowiness; characteristics of snowiness and avalanche activity in control basins of the Zailijsky and Dzhungarsky Alatau; large-scale estimation of snowiness and avalanche hazard along the route of the electric power line for the international tourist complex in the Zailijsky Alatau.

Methods of background forecast of avalanches for Transcaucasus

(K.L. Abdushelishvili, I.V. Chogovadze, TRI)

Forecast of snowfalls and air temperature was used as input data to predict mass snow avalanches on the southern slopes of the eastern part of the central Caucasus (at 12, 24 and 36 h intervals).

Snow avalanches on the Dzhvari–Mestia road

(K.L. Abdushelishvili, L.A. Kaldani, TRI)

Distribution and regime of snow avalanches in the region of the road and morphometrical characteristics of avalanche sites were investigated. A map was made of the distribution of avalanches and avalanche parameters calculated.

Avalanche hazard at Pasanauri, Gvidake, Roshka and Makarta villages of the Dushetsky region

(K.L. Abdushelishvili, L.A. Kaldani, M.E. Sulakvelidze, TRI)

Field cartographical and archival data were used to compile the large-scale maps of avalanche distribution limits. Morphometrical characteristics of avalanche catchment and estimated values of volume, run-out limit and other parameters of avalanches were found.

Physical–mechanical properties of snow cover on Krestovy mountain pass, the Caucasus

(L.D. Sesiashvili, TRI)

On the basis of a field study of the physical–mechanical properties of snow cover, methods to determine the most stressed zones and to test properties of snow cover on slopes were recommended, thereby making it possible to develop methods of forecasting local avalanche hazards.

Forecast of snow avalanches of various origins in the Ukraine Carparthians and Crimea

(V.F. Grischenko, URI)

Alternative methods of forecasting dry and wet snow avalanches for low and middle mountain regions (lower than 1200 m) of the Ukraine Carparthians were developed. Accuracy of the forecast methods were for dry snow avalanches: 88.6%, forecast of phenomena presence: 75% (with the author's check-up on independent material 80 and 66.7%); wet snow avalanches: 83.9 and 81.8% (on independent material 85.7 and 85.7%). The main factor of avalanche formation in Crimean mountains is a rapid increase of snow cover thickness (10 cm d^{-1}).

Zoning and protection of the Russian Republic territory from hazardous geological processes

(A.L. Ragozin, O.V. Slipko, IRIEC)

From the group of geological hazards (earthquakes, landslides, erosion, abrasion, flooding, karst, underwashing) the role of the cryogenic ones was estimated: aufeis formation, thermokarst, heaving, thermoerosion, solifluction; and the glacial ones: avalanches, mudflows.

Separate maps of distribution and intensity of manifestation of each process on scales of 1 : 5 000 000 and 1 : 500 000 were compiled. On the basis of separate maps and general maps of zoning of natural and technogenic conditions, a synthetic map on a scale 1 : 5 000 000 was compiled. It presents information on all hazardous processes estimated according to four categories of manifestation: disastrous, very dangerous, dangerous, moderately dangerous.

The map-scheme of territory protection from natural hazards gives an estimation of development risk: legends present the main directions of engineering protection for the territory. Catalogues of natural hazards in each area are enclosed, while catalogues of real data are available on the manifestation of these processes, with estimations of damage and cost of protection in some cases. Analysis of these data and experts' estimation of damage caused by each process are given in the reports.

Chemistry and pollution of snow cover

(A.V. Ivanov, IWEP)

Review of data on snow cover chemistry, 1976–90, in the Amur River region and the Sea of Okhotsk region showed that climate and economic activity are the main factors of the formation of chemical composition of snow. Fires in some years of drought and careless fire-handling in forests result in increases of concentration of practically all components. Mineralization of snow on fast ice sharply increases due to salt flow from the underlying surface. It was determined that the snow cover on the coast of the southwestern part of the Sea of Okhotsk is polluted with sulphates and nitrates which did not occur 10 years ago.

PALÆOGLACIOLOGY

Fluctuations of precipitation and temperature

(V.E. Dmitriev, TSU)
An empirical model for estimation of annual sums of precipitation and percentage of solid precipitaiton with global changes of air temperature was elaborated. The model was tested with information on the Holocene of the European part of the USSR and west Siberian plain.

Rock glaciers of the Altai

(O.N. Solomina, IG AS)
Lichen and radio-carbon data indicate that rock glaciers of the Altai were active in the Middle Holocene, Late Holocene (2500–200 years ago) and 200–300 years ago.

Ancient glaciation of Altai-Sayany mountain area

(V.S. Sheinkman, TSU)
Fifty new dates of absolute age were received; they proved the maximum was in the Late Pleistocene. According to palæocryological data, glaciation developed in the high temperature cryolithic zone in an environment that was a little more severe.

Fluctuations of glaciers of the Tien Shan in the Holocene

(O.N. Solomina, IG AS)
According to the data from lichenometry, dendrochronology and ^{14}C dating, it was determined that in the internal Tien Shan during the Holocene repeated advances of glaciers were approximately of the same amplitude; at the end of the eighteenth to the beginning of the nineteenth centuries the amount of precipitation in this region was twice as high as in the present day.

Isotopic analysis of oxygen of massive ice and polygonal wedge ice on Yamal and Gyda peninsulas

(R. Vajkmyae, IG AS ESSR)
On the basis of isotopic analysis it was determined that massive ice on the Yamal peninsula has an intraground or buried glacier origin and not a buried marine one as was considered earlier. On the basis of ^{14}C analysis it was determined that thick polygonal wedge ice, the isotope oxygen composition of which fluctuates from –21.1% to –24.8%, formed approximately 10 500 years ago.

Investigations on De-Long Archipelago

(S.M. Makeev, AARI)
Field palæoglaciological investigations showed that Zhokhov Island was glaciated twice in the Late Pleistocene and Holocene. Glaciation of the " Zyrianka Ice Age" was greater than that in Sartan Ice Age. The latter was of limited character — only corrie and niche glaciers developed which existed only 3 000–5 000 years and had disappeared by the beginning of the Holocene. Previous investigations showed that in the Sartan Ice Age on Bennett, Zhannetta and Genriatta islands the glaciers were sheet type, while on Anzhu islands there were no glaciers at all.

Shore lines on Zemlya Aleksandry

(A.F. Glazovsky, IG AS)
Field work in August 1990 by the Soviet–Swedish expedition on Zemlya Aleksandry, the western-most island of the Franz Josef Land archipelago, made it possible to collect a great number of samples of driftwood, whale bones and shells from shore lines up to 23 m a.s.l. According to preliminary data, driftwood age from the 23 m level is 6090 years B.P.

ENGINEERING GLACIOLOGY

Construction and preservation of ice wharves

(AARI)
A new method of construction of ice wharves with large ice blocks, grouted by fresh water with an ice composite, was worked out. A complex of new ice-cutting equipment was elaborated making it possible to stock ice blocks in industrial volumes. A theory was worked out and an estimation made of the possiblity of protecting an ice wharf with the help of a system of clod sources. Estimation of the strength of an ice wharf and a thermo-physical forecast of its state were obtained. The effects of waves, level processes and loads upon an ice wharf were analysed. In December 1990 a successful unloading of the vessel *Academician Fedorov* was made.

Construction and use of runways on deep snow

(AARI)
The heat regime and influence of snow metamorphism on the strength of the runway were studied at Molodezhnaya, Antarctica, a snow airfield for heavy wheeled aircraft. Remote radiometry methods were applied to determine the density of the snow pavement on airfields and roads. Reliable dependence between compressive strength of artificially compressed snow, density and temperature was noted; correlation relationships between the characteristics of thermal radio radiation of snow pavements, their density and heat content, were identified.

Snow avalanche and drift protection

(NIRI)
Snow drifting was studied in Kazakhstan, the North and in mountainous regions of Kirghizstan, Baikal–Amur railroad, Shoria and Kamchatka. Work on the interaction of a falling snow mass with fences made it possible to improve their design (A.K. Dyunin).

For the first time in the USSR a system of avalanche-braking constructions was successfully tested on a gigantic avalanche-hazardous Kochkobulak slope, dangerous for the Sysamyr–Toktogul road. In April 1990 it stopped an avalanche of about 1 000 000 m^3 in volume. This type of protection seems to be much more advantageous and reliable than the usual galleries designed for this region, and to make it unnecessary to move the road to some other position (A.M. Zhilin).

In order to substantiate parameters of building over avalanche-hazardous slopes, investigations were made in laboratory conditions at a scale of 1 : 1 to discover how snow masses slide down from slopes and how pulse loads and morphological elements of slope impact this process (S.S. Shevchuk).

In the place where Baikalsky and Severo–Mujsky ridges are crossed by the Baikalo-Amurskaya railway, braking and avalanche defence systems were investigated and constructed. New avalanche-directing constructions were theoretically substantiated and designed (V.S. Matvienko).

In Kazakhstan, snow drifts on small railway embankments and in hollows was studied. On a number of railway sections independent transverse profiles of the roadbed were tested and control areas were set up. The results will be studied not only in the Kazakhstan steppes, but in the tundra zones of Yamal (A.A. Komarov).

Guide on protection of railways from snow drifts and avalanches was prepared and is in press.

Method of sprinkling

(A.V. Sosnovsky, V.G. Khodakov, IG AS)
The method of sprinkling for the formation of artificial firn-ice massifs was continued, for the purpose of desalination and purification of water, accumulation of water and cold for a hot and dry period of the year, for engineering construction and other purposes; a forecast was given of the efficiency of the method in different natural conditions.

ICE COVER

Study of sea-ice cover

(A.A. Romanov, I.A. Appel, AARI)
A numerical model of how ice cover in the Arctic basin was used to study redistribution of ice related to heat and dynamic factors has been developed. The model simulates seasonal and inter-annual variability of ice cover. The model was used to investigate the external causes of sea ice changes.

The role of the main meteorological and hydrological processes in large ice anomalies in the Soviet Arctic was identified. Limits of forecasting large anomalies of ice phenomena and new methods of forecasting large ice anomalies for the Soviet Arctic with an accuracy of 75–95% were determined.

New methods of specialized forecasts for navigation along the northern shipping route were elaborated: conditions of winter navigation in the Kara Sea; ice thickness on the fairway and speed of piloting ships in the mouth areas of the Ob and Yenisei rivers; and the average-season conditions for sailing along the are areas of the western and eastern regions in summer.

Seasonal, interannual and interdecadal variability of all characteristics of ice cover of the Arctic Basin and shelf Arctic seas was analysed. A monograph *Ices of the Arctic Basin and shelf seas* was prepared.

Recommendations based on applied research into the impact of strong compression of ice, coating of ships' hulls, "ice river" phenomena and icing of ships were made.

Forecasting of ice cover in the Southern Ocean has been formulated, based on the following: a working concept, a scheme showing predominating quasi-two-year fluctuations of ice coverage of the Southern Ocean, a classification of 110 Antarctic stationary polynyas according to the seasonal rhythm of their development. An applied research recommendation "Conditions of ice navigation in the Southern Ocean" by A.A. Romanov has been prepared for publication. Instructions have been prepared entitled "Ice observations on research ships of the USSR Goskomgidromet".

Ice conditions in Tugursk gulf in the Okhotsk Sea

(IWEP)
Aerial-visual observations, measurements and observations on fast ice, analysis of space images MSU-C and MSU-E over a period 1981–90 made it possible to identify dynamics of ice cover and spatial–temporal variability of ice conditions. Three types of fast ice were singled out depending upon morphology, occurrence of hummocks, and types of coast and littoral. Southern and northern zones of drifting ice differ by the consolidation ratio of ice, the state, sizes of floes, number and size of polynyas and clearings.

Salinity of fast ice fluctuates within the limits of 4–16‰ with the average value of 7‰. Structure and texture (aufeises, frazil ice, "normal" congelation ice, rafting of ice floes) influence on the salinity profile in fast ice was determined.

Ice cover on reservoirs of Kazakhstan

(M.M. Beilinson, KazPI)
Methods of calculating the growth of the ice cover on reservoirs in Kazakhstan were elaborated, taking into account meteorological, physical-geographical and hydromorphological peculiarities, conditions of ice formation, winter regime of exploitation of a reservoir and, for the first time, the important factor of heat advection.

Chemistry of bog ice

(A.V. Ivanov, IWEP)
The chemical composition of the ice of a bog massif in the region of Slavyanka settlement, Khabarovsky krai was studied. Its composition depends on several factors: origin (aufeis or "normal" freezing); abundance of organic acids and their complex compounds with metals in ice-forming bog waters; decomposition of these compounds during ice crystallization; precipitation of colloidal-dissolved forms of compounds of iron; silicon and other elements; differentiation of ions between ice and water.

ANTARCTICA

Driling at Vostok Station, Antarctica

(B.B. Kudryashov, LSU)
Within the framework of the joint Soviet–American–French programme, two boreholes 178 and 138 m deep were drilled with complete sampling of the core (January–February 1990). The core obtained was sent to the USA and France for further glaciological study (N.I. Vasiliev).

At the same time samples for analysis of the carbon dioxide content in air inclusions of the Antarctic ice cover were taken. Samples were taken from ice core obtained while drilling boreholes N 3G and N 47-2 within the depth intervals 100–2200 m every 15 m (A.M. Gusev).

In February–December 1990 at Vostok Station drilling of a new deep borehole N 5G was begun with heat drills TELGA-14M and TBZS-152M. By now the borehole has reached a depth of 1280 m and drilling is continuing. In borehole N 3G up to the depth of 1940 m thermometry, determination of drill-hole dip and direction and borehole gauging was made for the purpose of studying the dynamics and heat regime of the ice sheet in this region. Regular observations for many years of deformation in borehole N 1-2-bis were continued; this hole was drilled in 1972 for the purpose of studying the rheological properties of ice. In borehole N 3G acoustic logging was carried out in order to study the mechanical properties of ice directly in the ice massif. Petrostructural studies of the ice core with 20 m spacing included: macro description of the core, quantitative analysis of the spatial structure of ice aggregates, determination of orientation axes, estimation of the system of orientation of interface surfaces of ice crystals, and determination of density and total air content in ice. Samples were taken at 1 m intervals for oxygen-isotope analysis of the whole core of borehole N 47-2.

Isotopic analysis of oxygen in snow from shallow pits along the route Dome B–Mirny

(R. Vaykmyae, IG AS ESSR)

Variations of average annual accumulation were determined along the route depending on the distance from the sea.

Study of ice cores from Vostok Station

(N.I. Barkov, AARI)

Ice core studies show that structural parameters of ice in the Antarctic ice sheet are strongly related to the variability in the core sections with increased concentration of impurities are characterized by the small size of grains, the development of one-maximum orientation of *c*-axes and dislocation defects. This structure corresponds to shear deformation and can indicate internal slip planes in the ice sheet. A vertical profile of the gas content of Antarctic ice shows that a high frequency periodical component contributes greatly to the general variability of gas content with depth.

In summer seasons French, American and Soviet scientists worked together at Vostok Station. Electric conductivity of ice was measured; samples were taken for oxygen-isotope and beryllium analysis, and for geochemical investigation and for the determination of carbon dioxide and methane concentration in ice.

Dynamics of the marginal part of an ice cover

(AARI)

Satellite photography data on the coastal area of Antarctica (60° W–105° E), scale 1 : 1000 000 during 1975–86 were analyzed. The data show that the fronts of most of the ice shelves were stable. Considerable changes were noted on the fronts of Larsen, Filchner and Shackleton ice shelves. As the result of the calving of large icebergs their fronts retreated by 20–80 km, and their areas decreased by 26.6 × 10^4 km^2. Some parts of the front of Bellinghausen, Lazarev, Amery and Zapadny glaciers advanced towards the sea by 5–10 km.

Nourishment of the ice sheet by precipitation

(AARI)

Analysis of snow data from 1970–89 from Soviet stations along the Mirny–Vostok meridional profile (1420 km long) were made. Considerable inter-annual variability (up to 80–100%) accumulation in the coastal region was noted. At Leningradskaya Station there were three distinct maxima and three minima (every 5–6 years) on the background of a general tendency to decrease (by 30%). At Vostok Station the decrease of accumulation was 10%.

Absorption of electric waves in the ice sheet at Vostok Station

(AARI)

In the summer season 1989–90 at Vostok Station the absorption of pulse radio signals was measured at frequencies 310, 450, 780 and 1200 MHz in the upper 120 m layer using wide-angle reflection sounding. The results were used during the construction of a radio-wave neutrino telescope at Vostok Station.

Table. Absorption of pulse radio signals at Vostok (ice temperature –56°C) at various frequencies (λ)

λ (MHz)	*Snow*	*Firn*	*Ice*
310	0.058 ± 0.01	0.035 ± 0.01	0.045 ± 0.009
450	–	0.062 ± 0.012	0.055 ± 0.004
780	0.086 ± 0.031	0.076 ± 0.015	0.067 ± 0.015
1200	0.168 ± 0.023	0.127 ± 0.042	0.091 ± 0.044

Electric characteristics of Antarctic snow–ice formations

(AARI)

In 1990, a year's cycle of electrical properties studies was analysed, for shelf and continental ice in the region of Novolazarevskaya Station, for three different glaciological zones and along the route of scientific traverse Mirny–Komsomolskaya, where the structure of the glacier is characteristic for the centre of the continent. Considerable spatial inhomogeneity of the electrical properties of the ice shelf was noted; this is connected to variations in ice structure.

Radio-echo characteristics of the glacier ice of Antarctica

(AARI)

As a result of the study and generalization of experimental data in 1990, data on coefficients of backward scattering of glacier ice in the region of Molodezhnaya were received (frequency 10 HHz, horizontal and vertical polarization, angles of sight 0–55°).

Radio-echo survey of glacier thickness in the region of Progress Station, Antarctica

(AARI)

A map of subglacial relief was compiled, and characteristics of ice and underlying surfaces necessary for the construction of a runway were determined. The form of subglacial relief and the character of radar jitter fluctuation reflected from the lower boundary of a glacier make it reasonable to suppose that "dead ice" deposited beyond the glacier appeared as the result of the degradation of the Pleistocene ice sheet.

Investigations of Amery Glacier

(Yu.V. Raikovski, IG AS)

On the basis of the results of work on Amery Glacier during the 1988–89 season, theoretical investigations were made of freezing processes upon the lower surface of ice shelves due to the influx of fresh water from the central parts of the ice cover resulting from bottom melting near the bed of outlet glaciers.

Heat balance of a glacier surface, Antarctica

(P.P. Arapov, LSU)

Using improved methods of gradient measurements in the boundary air layer (a complex of actinometric measurements, a narrow band radiometer, heat flow meters and a snow–ice evaporator) a complete analysis of the daily change in the heat balance of a glacier surface was fulfilled. It was determined that a considerable factor in the heat balance relates to solar radiation penetrating the glacier thickness up to 80 cm. A numerical model of heat transfer in the upper glacier layer has been worked out. It made it possible to estimate quantitatively heat flows caused by molecular and radiation heat conduction.

THE ARCTIC

Investigations on Severnaya Zemlya Archipelago

(AARI)

On the basis of observations on Komsomolets Island, the previously discovered evidence from aerial photographs confirmed that there are ice caps leaning against ice sheets and ice domes, as well as independent ones which have a structure differing from that of domes and sheets. Snow survey and balance observations on Vavilov glaciers continued. Considerable accumulation of glacier mass balance during 1988–90 has been registered. Snow survey profiles which had disappeared due to intensive snow accumulation were restored.

Isotope composition of snow cover on Severnaya Semlya

(V.I. Nikolaev, IG AS)

Isotopic investigations of snow cover on Severnaya Zemlya showed a statistically important relationship of the oxygen-isotope composition of snow cover on ice domes to the altitude and aspect of slopes with regard to predominating winds.

Two-layered glaciers of Spitsbergen

(Yu. Ya. Macheret, IG AS)

On the basis of radio-echo sounding data, deep drilling and numerical modelling, a hypothesis was proposed that the two-layered glaciers of Spitsbergen, many of which are tidal and surging, can be in two different phases of development, characterized by small and increased water content (up to 1 and 5%) in the lower layer of warm ice.

Heat regime of subpolar glaciers

(Yu. Ya. Macheret, M.S. Krass, T.B. Larina, IG AS, MSU)

A new approach to the numerical modelling of the evolution of subpolar glaciers with climate changes has been suggested, based on the estimation of ablation as a function of summer air temperature, surface elevation and share of internal accumulation, depending on conditions of ice formation.

Investigations of Lunny Dome, Franz Josef Land

(P.A. Korolev, K.S. Smirnov, S.A. Sin'kevich, IG AS)

In spring 1990 on Lunny Dome, Alexandra Land, Franz Josef Land, winter accumulation was measured, thermal sounding to a depth of 53.6 m taken and glacier mass balance estimated.

Investigations of Hans tidal glacier and Amundsen Plateau, Spitsbergen

(A.F. Glazovsky, M.Yu. Moskalevsky, IG AS)

Jointly with the Silesian University, Poland, the mass balance of Hans tidal glacier 1989/90 was determined. On Amundsen Plateau and adjoining glaciers, winter snow accumulation was measured, a photogrammetrical survey made for estimation of elevation changes, and snow samples for chemical analysis taken from an annual layer.

Submitted by A. Glazovskiy

JOURNAL OF GLACIOLOGY

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

G K C CLARKE
Length, width and slope influences on glacier surging.
R D MOORE
A numerical simulation of supraglacial heat advection and its influence on ice melt.
P KALIFA, G OUILLON AND P DUVAL
Microcracking and the failure of polycrystalline ice under triaxial compression.
J A DOWDESWELL, G S HAMILTON AND J O HAGEN
The duration of the active phase on surge-type glaciers: contrast between Svalbard and other regions.
J Y GUIGNÉ, G B CROCKER AND P HUNT
Non-linear acoustic imaging of ice properties.
M LEPPÄRANATA, R KUITTINEN AND J ASKNE
BEPERS pilot study: an experiment with X-band synthetic aperture radar over Baltic Sea ice.
E M SCHULSON AND W D HIBLER, III
The fracture of ice on scales large and small: Arctic leads and wing cracks.
E BRUN AND E PAHAUT
An efficient method for a delayed and accurate characterization of snow grains from natural snowpacks.
A V KULKARNI
Mass balance of Himalayan glaciers using AAR and ELA methods.
R NARUSE, H FUKAMI AND M ANIYA
Short-term variations in flow velocity of Glaciar Soler, Patagonia, Chile.
V N NIJAMPURKAR AND D K RAO
Accumulation and flow rates of ice on Chhota Shigri glacier, central Himalaya, using radioactive and stable isotopes.
B HUBBARD
Freezing-rate effects on the physical characteristics of basal ice formed by net adfreezing.
C SCHØTT, E D WADDINGTON AND C F RAYMOND
Predicted time-scales for GISP2 and GRIP boreholes at Summit, Greenland.
D R MacAYEAL, J FIRESTONE AND E WADDINGTON
Paleothermometry by control methods.
M STURM, D K HALL, C S BENSON AND W O FIELD
Non-climatic control of glacier-terminus fluctuations in the Wrangell and Chugach Mountains, Alaska, U.S.A.
G KASER AND B NOGGLER
Observations on Speke Glacier, Ruwenzori Range, Uganda.
I D GOODWIN
Snow-accumulation variability from seasonal surface observations and firn-core stratigraphy, eastern Wilkes Land, Antarctica.
J -L TISON, E M MORRIS, R SOUCHEZ AND J JOUZEL
Stratigraphy, stable isotopes and salinity in multi-year sea ice from the rift area, south George VI Ice Shelf, Antarctic Peninsula.
J McDONALD AND I M WHILLANS
Search for temporal changes in the velocity of Ice Stream B, West Antarctica.
A G FOUNTAIN
Subglacial water flow inferred from stream measurements at South Cascade Glacier, Washington, U.S.A.
R B ALLEY
How can low-pressure channels and deforming tills coexist subglacially?
J F NYE
Thermal behaviour of glacier and laboratory ice.

ANNALS OF GLACIOLOGY

Work is currently under way on Volume **16**, 1992, *Proceedings of the Symposium on Mountain Glaciology relating to Human Activities* held in Lanzhou, China, 26–30 August 1991.

In 1992 there will be work on two volumes: Volume **17**, *Proceedings of the Symposium on Remote Sensing of Snow and Ice*, to be held in Boulder, CO, USA, 17–22 May, and Volume **18**, *Proceedings of the Symposium on Snow and Snow-related Problems (as part of an International Forum on Snow Areas)*, to be held in Nagaoka, Japan, 14–18 September.

1993 will also see work on two volumes: Volume **19**, *Proceedings of the Symposium on Applied Snow and Ice Research*, to be held in Rovaniemi, Finland, 18–23 April and Volume **20**, *Proceedings of the SCAR Fifth International Symposium on Antarctic Glaciology*, to be held in Cambridge, UK, 5–11 September 1993.

Glaciological Diary

** IGS Symposia
* Co-sponsored by IGS

1992

2-4 February
Seventh International Symposium on Okhotsk Sea and Sea Ice, Mombetsu, Hokkaido, Japan (The Secretariat, The Okhotsk Sea & Cold Ocean Research Association, c/o Department of Planning & Adjustment, Mombetsu Municipal Office, Saiwai-2, Mombetsu, Hokkaido 094, Japan)

12-13 March
Société Hydrotechnique de France, Section de Glaciologie, Meeting at Grenoble (L. Reynaud, Glaciologie CNRS, BP 96, 38402 St Martin d'Hères Cedex, France)

23-27 March
AGU Chapman Conference on Climate, Volcanism, and Global Change, Hilo, Hawaii. (Stephen Self, Department of Geology and Geophysics, The University of Hawaii at Manoa, Honolulu, Hawaii 96822, U.S.A.)

30 March-4 April
European 'International Space Year' Conference 1992: Space in the Service of the Changing Earth, Munich, Germany. (INTERPLAN, Convention and Visitor Service, Anton Kössel, Sophienstr. 1, W 8000 München 2, Germany)

6-10 April
XVII General Assembly of the European Geophysical Society, Edinburgh, Scotland (EGS Office, Postfach 49, 3411 Katlenburg-Lindau, Germany)

4-6 May
Second Circumpolar Symposium on Remote Sensing of Arctic Environments, Tromsø, Norway (The Roald Amundsen Centre for Arctic Research, University of Tromsø, N-9000 Tromsø, Norway)

12-15 May
1992 Joint Spring Meeting of the American Geophysical Union, Canadian Geophysical Union and Mineralogical Society of America, Montreal, Canada (AGU Meetings, 2000 Florida Avenue, N.W., Washington, DC 20009, U.S.A.)

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

7-11 June
OMAE 1992. 11th International Conference on Offshore Mechanics and Arctic Engineering, Calgary, Canada. (N.K. Sinha, Institute for Mechanical Engineering, National Research Council of Canada, Ottawa, Ontario, Canada K1A0R6)

15-19 June
IAHR 11th International Ice Symposium, Banff, Alberta, Canada (Conference Secretariate, IAHR Ice Symposium, c/o Mrs Yolande Matsusaki, Manager Conference Centre, 4 Lister Hall, University of Alberta, Edmonton, ALTA, Canada T6G 2H6)

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

2-14 August
XVII Congress, International Society for Photogrammetry and Remote Sensing, Washington, DC, U.S.A. (Lawrence W. Fritz, ISPRS Congress Director, GE Aerospace, P.O. Box 8048-10A26, Philadelphia, PA 19101, U.S.A.)

14-18 September
** Symposium on Snow and Snow-related Problems (as part of an International Forum on Snow Areas), Nagaoka, Japan. Co-sponsored by the Japanese Society of Snow and Ice and the City of Nagaoka (Secretary General, IGS, Lensfield Road, Cambridge CB2 1ER, U.K.)

1993

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

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, 730 000, 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.)

WORLD GLACIER MONITORING SERVICE (WGMS)

The service continues its efforts to
(1) collect and publish standardized data on glacier fluctuations at 5-yearly intervals;
(2) prepare a bulletin reporting mass balance results of selected reference glaciers at higher frequency;
(3) manage and upgrade the existing inventory of perennial surface ice masses;
(4) stimulate satellite observations of remote glaciers in order to reach global coverage; and
(5) periodically assess ongoing changes.
Main funding is through GEMS/UNEP, FAGS/ICSU and ETH Zürich.

Fluctuations of glaciers
Collection of data for preparation of Volume VI, *Fluctuations of Glaciers 1985–1990* started in January 1991. The same format and structure as in earlier volumes will be used to assure continuity of the published data series. In addition to earlier volumes, new contacts could be established with observational programmes in Chile, Mexico, Pakistan and India. Attempts to contact glaciologists in Turkey, Iran or Afghanistan, however, still remained without success. Data processing is now in full progress and publication of the volume is planned for winter 1992/93.

Glacier inventory
New detailed inventories were completed for New Zealand and West Greenland. A major step forward was achieved by reaching an agreement with USSR authorities to furnish coordinates of the already existing, detailed and very extensive USSR glacier inventory. Transfer of this important information is planned for winter 1991/92. Efforts were continued to develop computer programmes for using glacier inventory data with respect to glaciological, hydrological and geomorphological aspects, especially in view of modelling scenarios of possible future warming trends and their effects on environmental conditions in glacierized mountain regions.

Glacier Mass Balance Bulletin
Work for the *Glacier Mass Balance Bulletin* was completed. Bulletin No. 1 was printed and distributed in the first half of 1991. Results of mass balance measurements from the sample of 50 glaciers with values reported for both years 1987/88 and 1988/89 can be summarized as follows:

	1987/88	1988/89
Mean specific net balance	−602 mm	−57 mm
Standard deviation	±652 mm	±1138 mm
Minimum value	−2480 mm	−2590 mm
Maximum value	+520 mm	+3470 mm
Range	3000 mm	6060 mm
Positive balances	60%	38%

These values give a rough indication of mountain glacier mass balances in the Northern Hemisphere. Taking the two years together, the mean mass balance was negative by a few decimeters; the two considered years thus resemble the secular average quite closely and show a continuation of the long-term shrinking trend.

Satellite observations of remote glaciers
Contacts were established with recently started and ongoing programmes of satellite imagery analysis for monitoring ice margins and outlet glaciers of Antarctica and Greenland. At ETH Zürich, a working group on the application of remote sensing techniques was established in order to assist co-operation between specialists and users. WGMS is thereby actively involved in planning pilot programmes for monitoring glaciers in unaccessible areas. The main problem thereby consists in the trivial but fundamentally important fact that remote sensing specialists are generally interested in developing highly sophisticated image analysis techniques which are rarely of direct use for glacier monitoring. Application of already available techniques (measurements of glacier length and area) are considerably less attractive and have to be carried out by glaciologists with adequate technical knowledge and interest in environmental data rather than in technical details of the method. Some ongoing remote sensing monitoring programmes concentrate on phenomena with unfavourable signal-to-noise ratio (equilibrium line). The transfer of basic glaciological knowledge and of monitoring strategies must be improved between glaciologists and remote sensing specialists.

Periodical assessments
A manuscript about the development, strategy and results of international glacier monitoring was drafted on behalf of UNEP/GEMS. Efforts to build up standard curves of long-term glacier length measurements for global intercomparison with shorter and less complete observations had to be postponed due to an overload of work with other WGMS projects and because of limited funds. Plans are being developed to start a new WGMS publication series "World Glacier Monitoring — Updates and Assessments". The first issue could give the complete set of earlier mass balance data which form the basis for the graphs and statistics in the *Glacier Mass Balance Bulletin*. The second issue may contain a summary of the new New Zealand glacier inventory and the glacier inventory of West Greenland.

Wilfried Haeberli
Director WGMS

OPENING OF THE NORSK BREMUSEUM

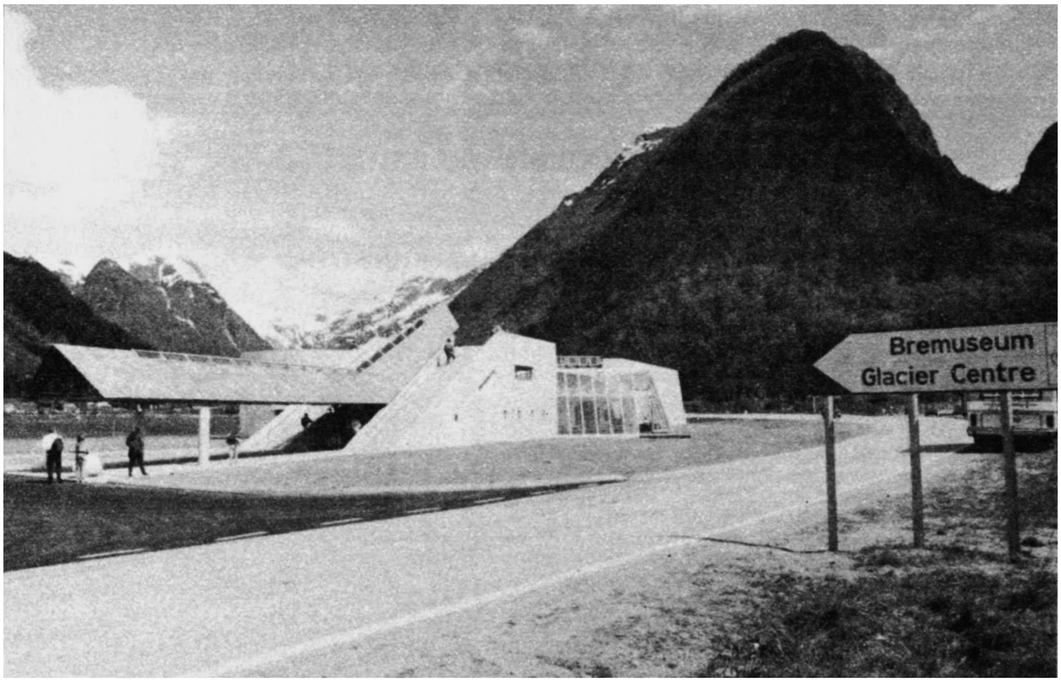
On 31 May 1991, Her Majesty Queen Sonja of Norway officially opened the Norwegian Glacier Centre at Fjaerland, on the southern end of the Jostedal Glacier. Several hundred people — invited guests, visitors and onlookers — were present at the ceremony, which was held in sunny weather on the upper terrace of the new building. Afterwards, the Queen toured the exhibits and saw a dramatic 3-D film in the theatre. A reception in the foyer area was then held and the success of the Centre toasted.

The Centre has the International Glaciological Society as one of its sponsors, the others being Norwegian universities and organizations. All the sponsors spoke at the reception. The IGS Secretary General congratulated the Board on its work, and on its intention to serve glacier research in several ways: as family entertainment and education through exhibits and films, as a showcase for glacier research, as a base for field work on the Jostedal Glacier, and as a teaching centre for students.

AWARDS

Dr Troy Péwé received an honorary doctor of science degree from the University of Alaska-Fairbanks in May 1991. He first came to Fairbanks in 1946 to study permafrost, a poorly understood phenomenon at the time. While working for the U.S. Geological Survey, he joined the University of Alaska faculty part-time to head and develop the UA Geology Department (1954–65). His research helped define permafrost and improved arctic engineering practices.

The Finnish Academy of Technology has elected GI professor **William Sackinger** a foreign member, an honor given to non-Finnish citizens for special merit in technical scientific research.



Photograph by I. Whillans

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Other members who are supporting the work of the Society through these higher rates of membership wish to remain anonymous. They are therefore not listed above.

We are grateful to all our Supporting and Contributing Members for their help.

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Private members	Sterling	£36.00	
Supporting members	Sterling	£136.00	
Contributing members	Sterling	£56.00	
Junior members (under 25)	Sterling	£18.00	
Institutions, libraries	Sterling	£110.00	for Volume 38 (Nos. 128, 129, 130)

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

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ICE

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

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