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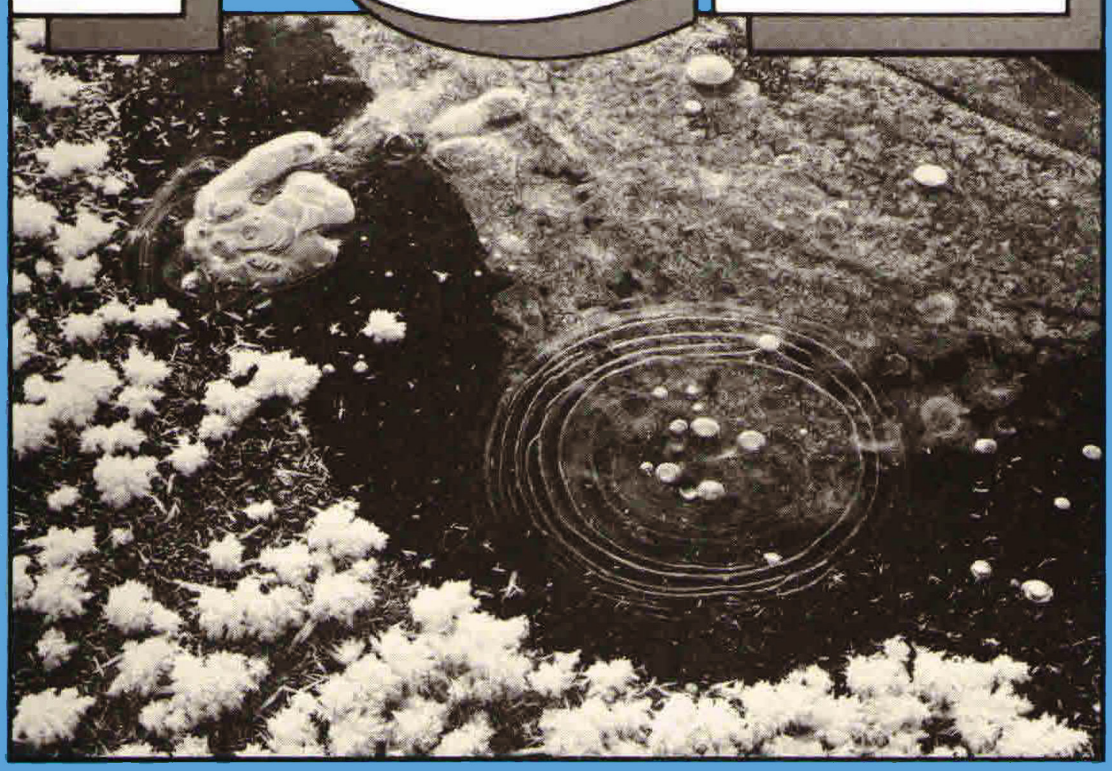

NEWS BULLETIN OF THE INTERNATIONAL GLACIOLOGICAL SOCIETY

INTERNATIONAL GLACIOLOGICAL SOCIETY

International Symposium on Glacial Erosion and Sedimentation	Representation of the Cryosphere in Climate and Hydrological Models
20–25 August 1995	12–15 August 1996
Reykjavík, Iceland	Victoria, B.C., Canada

Please note change of venue for the following meeting:

EISMINT

(European Ice Sheet Modelling Initiative)

18–22 September 1995

To be held in Chamonix, France by the European Science Foundation

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CONTENTS

COVER PICTURE: Frozen water rings on Davos lake (photograph by E. Wengi, Swiss Federal Institute for Snow and Avalanche Research).

ARGENTINA

Glaciology in the Central Andes

(Instituto Argentino de Nivología y Glaciología)
Research, begun in 1974, was mainly related to snow hydrology and glacier inventory. However, it now deals with glacier mass balance, glacier fluctuations and dynamics, avalanches and avalanche risk and climate change. Glacier studies in the Andes Centrales Argentinos (28–41°S) include the Piloto and Plomo River Glaciers, Rio Mendoza headwaters; mass-balance measurements on the former began in 1979.

Geocryology

(Instituto Argentino de Nivología y Glaciología)
Geocryological research is mostly centred on the origin, systematics and hydrology of rock glaciers. In one periglacial basin, 5 meteorological stations monitor conditions in the seasonal freezing zone, and in sporadic, discontinuous and continuous permafrost (over 4500 m). Winter flow from rock glaciers comes mostly from residual flows and from sub- and permafrost aquifers. Problems related to environmental change and industrial contamination are also studied.

Ice cores

(Laboratorio de Estratigrafía Glaciar)
Ice cores studies are supported by the Instituto Antártico Argentino and the Consejo Nacional de Investigaciones Científicas y Técnicas (CNICT) through their development of the Laboratorio de Estratigrafía Glaciar. The project began about 15 years ago and includes collaboration with the Laboratoire de Glaciologie et Géophysique de l'Environnement, Grenoble. It aims at high resolution reconstruction of climatic and environmental fluctuations in the Antarctic Peninsula (James Ross Island) over 2000 years, and in southern South America (Southern Patagonia ice cap) over the last 100 years.

Physical properties of ice

(Servicio Meteorológico Nacional and Facultad de Matemática Astronomia y Fisica, Universidad Nacional de Cordoba)
Work on understanding atmospheric processes associated with hail formation and cloud electrification has been carried out for many years with support from CNICT. It includes:

Ice accretion: Exchanges with Eidgenössische Institut für Schnee- und Lawinenforschung (Davos) and Institut FISBAT – C.N.R. (Bologna) have permitted collaboration on the analysis of crystal structure, morphology and density of ice accretions in a refrigerated wind tunnel. The results have been applied to hailstone structure.

Grain growth and grain boundary migration: These are studied using polycrystalline samples of pure and doped laboratory-grown ice. Theoretical representations of the phenomenon are obtained with a numerical simulation model. The anisotropy of boundary diffusivity for special grain misorientations has been evaluated through grain boundary migration in ice bicrystals.

Electrical properties: Special attention has been given to those ice properties responsible for charge separation due to particle impact in mixed clouds, partly in collaboration with the Laboratory of Atmospheric Physics, UMIST (Manchester, U.K.). The characteristics of ice as an ionic conductor are also being investigated.

Submitted by Laura Levi

BELGIUM

POLAR GLACIOLOGY: ANTARCTICA

Ice shelf/ocean/bedrock interactions (Victoria Land)

(J.-L. Tison, R. Souchez and R. Lorrain, DSTE-ULB; M. Meneghel and A. Bondesan, DG-UPa; V. Maggi, A. Lozej and I. Tobacco, DST-UM; C. Barbante, DSA-UVe; C. Baroni, MCSN; D. Ronveaux, DG-UVi; J. Jouzel, M. Stiévenard and C. Fléhoc; LMCE)
Processes of frazil ice generation at the base of ice shelves have been investigated in the Victoria Land area. Two different types of marine ice sampled at Hells Gate Ice Shelf (74°44′/74°53′–163°36′/163°57′) show contrasting properties that reflect different environmental conditions for deposition. Co-isotopic and chemical measurements indicate dilution and fractionation effects that provide a tentative explanation for the apparent contradiction between the very low salinity levels detected in marine ice and the comparatively minor salinity fluctuations in sea water profiles near ice shelves. Recent work, based on sea water CTD profiles in front of the ice shelf relates the spatial distribution of the two types of frazil ice to the peculiar characteristics of the water column in this area.

Marine ice is also found in floating ice tongues. High resolution co-isotopic measurements in the study case of the Campbell Glacier (south of Mount Melbourne), reveal different processes of marine ice accretion near grounding lines. Where large-scale basal crevasses or fissures open, intrusion of water from the bottom of the ice shelf is followed by active production of frazil ice that predominantly contributes to the filling and closing, as opposed to congelation from the sides. Where a subglacial water-filled sediment enters into contact with sea water, freezing under a double diffusion process occurs.

POLAR GLACIOLOGY: GREENLAND

Organo-lead in snow and ice from Greenland

(F. C. Adams and R. Lobinski, UIA; C. Boutron, LGGE)
The well-preserved and dated successive snow and ice layers deposited in the Greenland ice cap contain a unique record of past and present changes in large-scale atmospheric pollution of the Northern Hemisphere by heavy metals, especially lead. Alkyl-lead compounds are characteristic to gasoline which make them a unique indicator of automotive and aircraft pollution. In addition, they offer some interesting features for the climatologist such as a different composition of North American and European emissions with respect to the use of methyl- or ethyl-lead compounds, a year-to-year variable and known output since 1923, and different transport mechanisms of ionic (partly alkylated) and non-polar (fully alkylated) species.

The project has provided a comprehensive survey of concentration levels of ionic alkyl-lead species in Greenland snow and ice, which was carried out relying on ultraclean sampling, high-resolution separation of individual species, and ultrasensitive determination procedures. The seasonal variations are observed in concentrations of organo-lead compounds in the Dye 3 fresh snow and are interpreted in terms of backwards air mass trajectories. An indication of source regions influencing Dye 3 at different times is provided. Organo-lead concentration in precisely dated deep ice sheets at Summit shows an increasing trend since the early 1970s which is slightly blurred by seasonal variations. The results are correlated with the data on the distribution of organo-lead species in gasoline, the consumption levels of leaded gasoline in Europe and the U.S.A., as well as with concentrations and isotopic compositions of total lead in particular samples.

The goals for 1994 include analysis of ca. 40 samples from a snow pit on the Summit site, analysis of samples to be acquired at col du Dome (altitude 4300 m) near the summit of Mont Blanc in May–June 1994, and analysis of individual dust particles from selected samples of Greenland and Antarctic snow.

Greenland ice core project: basal ice at Summit

(R. Souchez, J.-L. Tison, R. Lorrain, M. Lemmens and L. Janssens, DSTE-ULB; M. Stiévenard and J. Jouzel, LMCE; J. Chapellaz, LGGE; A. Sveinbjörndottir, SI-UI; S. J. Johnsen, NBI-UC; T. Thorsteinsson and S. Kipfstuhl, AWI)
The GRIP ice core (Greenland Ice Core Project: a multinational project, carried out by eight European countries under the auspices of the European Science Foundation ESF) was drilled into silty ice close to bedrock at Summit (72°34′ N, 37°37′ W) on the main ice divide of the Greenland ice sheet in summer 1992 after having penetrated 3022.54 m of ice. The isotopic composition of the 6 m of basal ice recovered indicates that ice formed at the ground surface in the absence of the ice sheet largely contributed to its formation. Favourable circumstances, due to CO_2 and CH_4 production underneath the ice, have shown that flow-induced mixing within the basal ice has taken place at the scale of a few centimeters over a minimum vertical distance of 5 m. Ice fabrics retain the mark from the entrainment of locally formed ice by the growing ice sheet. This mark is only partly overprinted by the present-day stress configuration at the ice divide, suggesting that this basal ice is not presently subject to large cumulative strains.

Reconstruction of basal boundary conditions at the Greenland ice sheet margin

(R. Souchez, M. Lemmens, L. Janssens, R. Lorrain and J.-L. Tison; DSTE-ULB)
Previous co-isotopic studies yielded evidence for two zones of debris entrainment beneath the Greenland ice sheet, related to changes in boundary conditions at the ice-bedrock interface. Recent work on gas composition in basal ice from West Greenland (Qigssertaq, Russell Glacier) has shown that these changes are in fact transitional. First, slight melting of crystal boundaries and vein water squeezing occur in debris-free glacier ice, that could still be below the pressure-melting point. Then, where the melting point is reached and more meltwater produced, sliding by regelation and inclusion of fine particles to form the basal dispersed facies occur. Closer to the margin, partial freezing and ice accretion take place to form the basal stratified facies. These findings stress that since debris-free glacier ice is affected by this process when travelling close to bedrock, precautions have to be taken in interpreting gas composition of glacier ice near the bottom of an ice sheet for paleoclimatic reconstructions.

ALPINE GLACIOLOGY

Reactive carbonates in basal ice from limestone areas

(I. Fairchild, J. Berry; SES-UB; B. Spiro, IGL-NERC; R. Lorrain, J.-L. Tison and L. Janssens; DSTE-ULB)
Limestone alpine environments provide favourable circumstances to study drainage systems beneath glaciers, especially the water-film component. Earlier work has shown that basal ice forms in equilibrium with calcite precipitate, the chemical composition of which can be used to reconstruct the dynamics of the water film and its relationship to glacier sliding processes. The present collaborative (UK-Belgium) project investigates the possibility of in situ formation of calcite precipitate into the basal ice and how it affects the ice composition. Genesis and alteration of these precipitate inclusions are also studied both on experimental and natural ground in the Tsanfleuron area (Wallis, Switzerland).

MODELLING

Dynamics of the East Antarctic Ice Sheet

F. Pattyn, H. Decleir, Ph. Huybrechts and Ph. Vis; GI-VUB)
The project is two-fold:
1) Refined flow-law modelling is essential to link environmental data, from deep ice-core drilling on the Central ice dome, to glacier variations, as obtained from geomorphological–geological observations in the marginal mountains. For this purpose a comprehensive flow-line model is being developed with variable grid size to allow for the spatially inhomogeneous data input and to simulate the behaviour of outlet glaciers and ice streams.

The model is time-dependent and couples the two-dimensional ice flow to the temperature field. It takes account of longitudinal deviatoric stresses and basal sliding, both at the grounding line and in the inland ice sheet, to calculate the velocities. At the seaward margin, a freely floating ice shelf is coupled. Also included is bedrock adjustment and the effect of valley wall friction.

Starting from boundary conditions, provided by 3-D modelling, detailed flow-line modelling will be used to study the present imbalance of drainage basins, but mainly to investigate past glacierization of the coastal mountain ranges. The model is at present being implemented, in joint collaboration with Japanese scientists (NIPR, Japan), in East Dronning Maud Land (Sør Rondane Mountains) and Enderby Land (Shirase Glacier).

2) Extraction of glacier surface velocities from sequential SPOT imagery by computer-based image matching is being applied in the Sør Rondane Area (Dronning Maud Land), and in connection with the modelling experiment of the same area.

Modelling the Late Cenozoic Antarctic ice sheet

(P. Huybrechts, AWI & GI-VUB)

A study was performed to investigate the ice sheet in pre-Quaternary environments, particularly with respect to the ongoing speculations that East Antarctica may have been largely ice-free at times until as recently as the mid-Pliocene. A reduced version of a previously developed 3-D thermomechanical Antarctic ice-sheet model was used that does not include explicit ice-shelf dynamics, but still allows grounded ice to expand over terrain below sea level. Accumulation and ablation components were entirely parameterized. The results supported the concept of a stable East Antarctic ice sheet with respect to a climatic warming, and pointed to the glaciological difficulties involved in explaining an ice-free corridor over the Pensacola and Wilkes basins. The latter event is a crucial element in the "waxing and waning ice sheet hypothesis" and would require a temperature rise of 17 to 20°C above present levels for present topographical conditions and even 12–15°C if it were assumed that the Transantarctic Mountains were only elevated up to 500 m. For temperature rises below 5°C, the model actually predicted a larger Antarctic ice sheet than today, whereas the West Antarctic ice was found not to survive temperatures more than 8–10°C above present values. At present, work is in progress to make the model suitable for studies of a more regional character in an attempt to link the modelling with geomorphological and geological field studies in the marginal mountain areas. This involves the introduction of multigrid techniques and coupling with models for the development of the subglacial landscape.

3-D modelling of the Northern Hemisphere ice sheets

(P.Huybrechts, AWI & GI-VUB; S. T'siobbel, GI-VUB)

A three-dimensional time-dependent thermomechanical ice-sheet model is being used together with a simple mass-balance model to reconstruct the Quaternary ice sheets on the continents of the Northern Hemisphere. The model freely generates the ice-sheet geometry in response to specified changes of surface temperature and mass balance, and includes bedrock adjustment, basal sliding and a full temperature calculation within the ice. The mass-balance model makes a distinction between snowfall and melting, with the latter part based on the positive degree-day-method. Up to now, a steady-state study was made of ice sheet size versus summer temperature deviations, as well as a simulation of the last two glacial cycles using the GRIP $d^{18}O$ record. Most notably, the modelled extent for a summer temperature lowering of 8-9°C is in reasonable agreement with most reconstructions based on geological evidence, except for the presence of a large ice sheet stretching from Alaska across the Bering Strait to most of East Siberia. In addition, wet ice and basal sliding turned out to be always confined to the margin, whereas central areas in these reconstructions remained always cold-based. Further developments of the model will include a better treatment of the ice-bedrock interface and coupling with an atmospheric flow model.

Modelling atmospheric mesoscale circulations over Greenland and Antarctica

(H. Gallée , O. Fontaine de Ghelin, Y. Wang and G. Schayes; IAGGL-UCL)

To improve our knowledge of the meteorology and climatology of the polar regions, particularly at the mesoscale, a limited-area three-dimensional atmospheric model has been developed. It uses the primitive equations written in terrain-following coordinates. The katabatic jump, which is a sudden (and rather spectacular) wind speed decrease occurring sometimes in katabatic flow near the Antarctic coast has been studied with a two-dimensional version of the model. The model is also able to initiate mesocyclonic activity in relation to strong katabatic winds near the Antarctic Coast.

The alternance of katabatic and anabatic winds in Adélie Land during the summer is being studied. Cases observed during the IAGO (Interaction Atmosphère Océan Glace) campaign, are well simulated by the model.

A new study area is the Greenland ice sheet. Mesoscale circulations such as the tundra-ice breeze and the katabatic wind play an important role in the Greenland ice-sheet mass balance. The model has been successfully validated with the data from the GIMEX (Greenland Ice Margin Experiment) campaign. The next step consists of a simulation of the Greenland ice-sheet 1991 summer atmospheric circulation and surface energy balance with the model. The results of such simulation will be used to develop a new parameterisation of the Greenland ice-sheet mass balance.

In the standard model version, only the water vapor conservation is simulated. In a new model version, the cloud microphysics are taken into account by an explicit scheme, including the evolution of water vapor, cloud droplets, ice crystals, rain and snow. This version is currently tested by simulating Ross Sea mesocyclones.

Modelling sea ice — a global coupled sea-ice/upper-ocean model

(Th. Fichefet, M. A. Morales Maqueda and H. Goosse; IAGGL-UCL)

Sea ice is a critically important element in the world climate system, one that both affects present-day climate and responds sensitively to climatic changes. There are three principal processes by which sea ice acts upon climate. First is the direct effect it has upon the Earth's albedo, since snow-covered ice can have albedo as high as 0.9 compared to 0.1 for open water. Secondly, the ice cover acts as an insulating blanket, interfering with free heat, moisture, and momentum exchanges between ocean

and atmosphere. The third process is the change in surface-water salinity that occurs whenever the ice either melts, resulting in a freshwater lid that enhances the stability of the water column, or freezes, thus increasing the salinity and the surface density, often to the point of convective overturning responsible for the production of oceanic deep or bottom water. In view of these properties, it is of prime importance that sea ice be properly represented in global climate models. We have developed a new coupled sea-ice/upper-ocean model adapted for climate studies. The sea-ice model consists of a thermodynamic component and a dynamic component linked by advection processes. The thermodynamic part allows for sensible and latent heat storage in the ice. A parameterization of leads is also included. With regard to the dynamic part, the ice–ice interaction is modelled by a viscoplastic rheology. The upper-ocean model is made of an integral mixed-layer model and a diffusive pycnocline model. At the surface, the coupled model can be driven by different sets of atmospheric forcing, all of them derived from outputs of atmospheric general circulation models (AGCMs; EMERAUDE and ARPEGE from Météo-France, and NOGAPS from the US Navy). Temperatures and salinities of the upper ocean are restored to observed annual mean data in order to account for oceanic advection processes. Annual mean geostrophic currents are used as forcing in the sea-ice momentum balance. Several seasonal simulations performed both in the Arctic and the Antarctic Oceans have permitted us to validate the model and determine the importance of ocean/sea-ice interactions. The great sensitivity of the coupled system to the model-to-model varying characteristics of the atmospheric forcing fields points to the urgent necessity of a deeper analysis and understanding of AGCM outputs in high latitudes. Further experiments on the model response to atmospheric daily variability are now in course, the long-term goal of this work being the coupling of the sea-ice model to a general circulation model of the ocean. This coupling should improve the physical description of the ocean/sea-ice system and allow for studies of the impact of sea-ice covered regions on the global oceanic circulation.

Simulation of the Northern Hemisphere continental ice sheets with a latitude–longitude ice-sheet model coupled to a zonally averaged climate model

(I. Marsiat; IAGGL-UCL)

A two-dimensional (latitude–longitude) vertically integrated ice-flow model has been coupled to the 2D-LLN climate model to perform paleoclimatic simulations. Both models are coupled through a land surface model which computes seasonal cycles of surface temperature and precipitation at the real altitude of the surface and allows for the annual snow and/or ice mass budget.

The present day climate of the Northern Hemisphere is quite well represented considering the relative simplicity of the model. In particular, the Greenland mass balance and snowfield extension in space and time are well computed. During the last glacial to interglacial cycle, total ice volume and sea-level variations are well simulated. This suggests that the physical mechanisms that have been included in the model are sufficient to explain the ice-sheet buildings and terminations that are such a striking feature of individual ice-age cycles. However sensitivity experiments show that the amount of the simulated ice volume during the cold phases is quite dependent on some parameterizations and simplifications which are generally used in this kind of simple model. Due to the zonally averaged character of the atmospheric forcing, ice repartition between the different ice sheets differs from the geological reconstructions. Improvement of the glaciation pattern must be expected in the future using 3-D climate models.

Abbreviations used in the text:

AWI = Alfred Wegener Institute, Bremerhaven, Germany
DG-UPa = Dipartimento di Geografia, Universita' di Padova, Italy
DG-UVi = Department of Geography, University of Villanova, USA
DSA-UVe = Dipartimento Scienze Ambientali, Universita' di Venezia, Italy
DST-UM = Dipartimento Scienze della Terra, Universita' di Milano, Italy
DSTE-ULB = Département des Sciences de la Terre et de l'Environnement, Université Libre de Bruxelles, Belgium
GI-VUB = Geografisch Instituut, Vrije Universiteit Brussel, Belgium
IAGGL-UCL = Institut d'Astronomie et de Géophysique George Lemaître, Université Catholique de Louvain, Belgium
IGL-NERC = Isotope Geosciences Laboratory, National Environment Research Council, UK
LGGE = Laboratoire de Glaciologie et de Géophysique de l'Environnement, Grenoble, France
LMCE = Laboratoire de Modélisation du Climat et de l'Environnement, Gif sur Yvette, France
MCSN = Museo Civico de Scienze Naturale, Brescia, Italy
NBI-UC = Niels Bohr Institute, University of Copenhagen, Denmark
SES-UB = School of Earth Sciences, University of Birmingham, UK
SI-UI = Science Institute, University of Iceland, Iceland
UA = University of Antwerp, Antwerpen, Belgium

Submitted by J. L. Tison




CANADA

For key to abbreviations see ICE (1991) 97, 17–18, and list at end

GENERAL

CRYSYS: Understanding the cryospheric system and its role in global change in Canada

(B. Goodison, AES with T. Agnew, G. Flato, L. Stirling, A. Walker, AES; R. Brown, AESQ; J. Falkingham, CICE; D. Barber, GEOG/MAN; M. Bernier, INRS; M. Brugman, NHRI; C. Burn, GEOG/CARL; G. Clarke, GPHYS UBC; D. Delikaraoglou, TRILOGY Spacetech Inc., Ottawa; C. Duguay, GEOG/OTT; H. Granberg, Y. Moisan, T. Piekutowski, A. Tarussov, CARTEL; D. Holland, BOM; A. Judge, R. Koerner, TSDGSC; E. LeDrew, E. Soulis, ES/WATER; M. Lewis, OCEAN/DAL; D. Manak, Cdn Space Agency, Montréal; M. Manore, T. Pultz, V. Singhroy, CCRS; L. McNutt, ASF, UAk; S. Munro, GEOG/TOR; L. Mysak, B. Tremblay, CCGCR/McG; I. Rubinstein, Earth Obs. Lab., Inst. Space and Terrestrial Science, Downsview, Ontario; M. Woo, GEOG/McM)

CRYSYS is a program to monitor cryospheric systems from space. It is designed: (1) to develop capabilities for monitoring and understanding regional and hemispheric variations in cryospheric variables; and (2) to improve understanding of the role of the cryosphere in the climate system, and in global change.

CRYSYS was initiated in 1988 in response to NASA's Earth Observing System Program (EOS). It offers an opportunity to develop methods for extracting information on the cryosphere from conventional and remote sensing systems, a link to the data and information system of EOS (EOSDIS), and access to EOS satellite data. In 1993, AES became the principal sponsoring agency with Dr Goodison as the principal investigator.

CRYSYS investigators use in-situ, airborne, and satellite data, as well as modelling in their research on cryospheric variables (snow, sea ice, lake ice, glaciers, ice caps and permafrost). In snow research, CRYSYS scientists are developing techniques for mapping snow cover and snow water-equivalent from active and passive satellite microwave data; in permafrost, they have an active program to map and monitor the extent of permafrost from the new generation of radar-equipped satellites; radar and other satellite data provide more accurate data on the area, volume and mass balance of glaciers and ice caps; sea-ice research is focused on extracting information from satellite data to estimate the thickness and volume of sea-ice cover, and to model natural variability in the sea-ice system. CRYSYS also contributes to the objectives of other international programs (e.g. GEWEX and ACSYS).

Shallow groundwater investigations in granitic terrains, southeastern Manitoba

(G.A. Thorne, Whiteshell Laboratories, Manitoba)

AECL Research is investigating the suitability of granitic rock for nuclear-fuel waste disposal. In 1989, a fractured outcrop was chosen to evaluate the timing, processes and quantities of recharge, by measuring air and soil temperatures, snowmelt, groundwater levels and regularly observing snow cover. During the winter, when air temperatures rise and stay above freezing for extended periods, snowmelt and accumulation of meltwater at the snowpack base can occur and become available for infiltration and significant groundwater recharge into the rock fractures.

Gas hydrate distribution and contribution to climate change

(A. Judge and S. Smith, TSDGSC)

Evaluating the importance of gas hydrates requires an improved knowledge of their distribution. Analysis of thermal and geophysical logs from 369 wells in the Canadian Arctic Islands and the Beaufort Sea–Mackenzie Delta regions indicates that a maximum of 1900–3900 Gt of methane may be stored as hydrate here. The recent geological and climatic history of the area suggests that the volume of hydrate is variable with time. Decomposition of hydrates may be occurring beneath some 73 000 km^2 of the Canadian Beaufort Shelf. Approximately 10^5 m^3 hydrate km^{-2} may become unstable over a 100 years due to marine transgression. In contrast, cooling of sediments and hydrate formation is occurring in the Arctic Islands as new land emerges from the ocean in response to isostatic rebound.

GLACIERS – GENERAL

Laurentide ice sheet subglacial processes

(S. Marshall and G. K. C. Clarke, GPHYS/UBC; D. Fisher and A. Dyke, TSDGSC)

Models of subglacial physics are being developed to improve the realism and verification of large-scale ice-sheet models. Models of subglacial hydrology, erosion-deposition and bed thermal evolution are being developed and coupled with a thermo-mechanical finite difference model of the Laurentide ice sheet. Realistic bed geology, topography and geothermal fluxes are included as essential inputs to the basal process models. Rigorous application of continuum mechanics for the ice, water and energy components of the system, with as much bed detail as possible, will allow a physical treatment and sensitivity analysis of many intriguing aspects of glacier dynamics. For example, it should be possible to test the form and plausibility of episodic ice sheet surge events in the northeastern Laurentide ("Heinrich events") and on the southern margin.

Model of the Laurentide ice sheet

(S. J. Marshall and G. K. C. Clarke, GPHYS/UBC)

A three-dimensional time-dependent thermomechanical model of ice-sheet dynamics is being developed to study the formation and collapse of the Laurentide ice sheet. The model attempts to incorporate realistic subglacial physics, including hydrology and deformation processes, and will ultimately be incorporated in a coupled model of the atmosphere/ocean/cryosphere system.

Quaternary history and environments

(P. F. Karrow, ES/WATER)

Reconstruction of Great Lakes Quaternary history is being advanced through study of: bedrock topography; stratigraphy and palaeontology of sub-till fossiliferous

sediments; character and extent of glacial deposits; the stratigraphy, geomorphology, and palaeontology of glacial lake deposits; and palaeontology of post-glacial lake and bog deposits. Neotectonics is related to isostatic rebound and occurrences of bedrock stress-release features. Sea-level changes in Florida are being dated with amino-acid analysis.

Mechanical damage by ice loading

(H. H. Schloessin and W. C. Mahaney, ES/WEST)
Quasi-hydrostatic loading of an ice cylinder (equivalent to a 1–2 km thick glacial cover) containing individual and isolated alpha-quartz fragments or small spheres of fused silica, can produce fracture. Two previous tests could not demonstrate that any uncommon fractographic markings occurred in, or were mediated by, ice. Just as in natural settings of glaciation, where rock and mineral particles always enter the ice with a record of surface markings of mechanical, fluvial, aeolian, etc. origin, it is also difficult in laboratory experiments to be certain that new markings are specifically due to glacial influences. To identify mechanical damage done by exposure to ice new experiments are proposed using (a) small mineral single crystals with facets as grown or with polished surfaces emersed in ice under load, and (b) same as in (a) but with the application of very high pressures far exceeding those attained in glaciers. The crystal facets will be investigated, before and after the exposure to ice, by x-ray diffraction strain measurements, optical microscopy and etching techniques to unambiguously determine the effects, especially new fractographic markings.

GLACIERS – ARCTIC AND YUKON

Glacier mass balance and climate change

(B. Alt, J. C. Bourgeois, D. A. Fisher and R. M. Koerner, TSDGSC)
In 1993 and 1994 surface snow samples were collected in the Canadian Arctic Islands, from ice caps in Severnaya Zemlya and Franz Josef Islands and at 4 sites on Arctic Ocean sea ice between Russia and Canada. The mass balances of Meighen, Melville South, Devon Northwest and the northern Agassiz ice caps were measured. Balances differences between some ice caps in 1991/92 and 1992/93 were quite considerable.

A new intermediate drill was used to collect surface-to-bed cores and several 20–50 m cores for cooperative studies with WATER, QUEEN'S, EC and NRC. The drill is being modified for a 500 m 1995 drilling on Penny Ice Cap.

In cooperation with Campbell Scientific, remote autostations are running at three sites on Agassiz (top, equilibrium line, ablation zone) and Devon Ice Cap (top). The station established on Academii Nauk Ice Cap, Severnaya Zemlya in 1993, had a continuous record the following year; riming of sensors affected the results. The objective is to develop transfer functions for interpreting ice-core records.

Transfer functions are also being developed to interpret pollen concentrations in ice cores in terms of paleoclimate. In spring 1994, samples were collected along a 500 m transect at Pakitsoq, West Greenland, as part of an international collaboration to study Pleistocene ice emerging at the surface of the ice margin.

Organic pollutants and trace metals in glacial snow/ice, Ellesmere Island

(D. J. Gregor, ES/WATER; A. Peters, M. Alaee and J. Nriagu, NWRI; R. M. Koerner and D. Fisher, TSDGSC)
This study is quantifying: annual residue and historical deposition trends of trace organic contaminants and metals in Arctic ice caps; annual variability of deposition of these compounds as a result of variable atmospheric conditions; and major processes controlling the fate of these contaminants in glaciers that could influence the deposition trend, including revolatization to the atmosphere, transfer between annual layers by gas transfer and melt water, and photochemical degradation within the snow layers.

ΣPCB flux to the Agassiz Ice Cap for the last three decades shows no clear, continuing temporal trend due in part to the inter-annual variability, but there is some evidence of a pattern to the deposition. It was generally higher in the early 1960s, with a maximum of 930 ng m^{-2} a^{-1} in 1967/68, in 1968/69 there was a significant decrease which increased slowly and consistently until 1979/80 when a further decrease occurred with a period of record minimum of 91 ng m^{-2} a^{-1} in 1980/81. Subsequently, ΣPCB deposition again rose, with a local maximum of 848 ng m^{-2} a^{-1} in 1989/90 and a mean flux for the last three years of 465 ng m^{-2} a^{-1}, moderately higher than the period of record mean of 406 ng m^{-2} a^{-1}. In contrast, PAHs show a distinct decline over the 30 years which more or less corresponds to reductions in fossil fuel combustion. The PCBs on the ice cap are dominated by the lower chlorinated homologs which also account for a great deal of the inter-annual variability. Recent reports of PCB volatilization from temperate soils indirectly support this observation in that the PCB trend in Arctic ice caps is complicated by variable source and delivery functions, scouring and revolatization.

"Quviagivaa" Glacier, Ellesmere Island

(P. M. Wolfe and M. C. English, CRRC)
A study is nearing completion on the relationships between climate, runoff and mass balance on a small glacier in the Sawtooth Range. In the summer of 1993 data on superimposed ice, stream flow, snow accumulation/ablation, ice ablation and meteorological factors were collected. The mass balance for "Quviagivaa" Glacier for 1992–93 was highly negative; AAR = approx. 0.06. Glacier runoff and ablation will be related to meteorological parameters, and other mass-balance measurements in the Canadian High Arctic.

Mass balance of White and Baby Glaciers, Axel Heiberg Island

(J. G. Cogley, W. P. Adams and M. A. Ecclestone, GEOG/TRENT)
A comprehensive reassessment of the mass-balance records of the White and Baby Glaciers is about to be published as NHRI Science Report No. 6. The records extend from 1960 to date, with gaps. The balance of the White Glacier (38.7 km^2) is -100 ± 48 kg m^{-2} a^{-1} on average, ELA averages 975 m a.s.l. and AAR 0.65; that of the Baby Glacier (0.6 km^2) is -112 ± 91 kg m^{-2} a^{-1}. Attempts to identify trends in mass balance were inconclusive; conventional mass-balance measurements are not accurate enough to identify trends of climatologically plausible magnitude. White and Baby Glacier balances are shown to be representative of those measured

elsewhere in the Canadian High Arctic. The regional balance normal for the High Arctic yields an estimated contribution to eustatic sea-level rise which agrees with published values.

Science Report 6 also discusses related glaciological research, including: the digital elevation model of the White Glacier at 50 m horizontal resolution; and satellite remote sensing as a tool for estimating mass balance. In support of the latter, a detailed radiative transfer model for atmospheric correction of satellite imagery has been developed; it deduces glacier-surface reflectance with reasonable accuracy. Mass-balance estimates are in preparation for the balance years 1991–92 and 1992–93. In both years the balance was strongly negative.

Climatological studies, Barnes and Penny Ice Caps, Baffin Island

(J. D. Jacobs, GEOG/MUN; A. Headley, AES)
As part of a larger study of regional and mesoscale climates of Baffin Island, automated climate stations operating on the summits of the Barnes and Penny Ice Caps are providing the first year-round meteorological data. Snow-depth and density data are obtained during annual site visits. Records are being analyzed in relation to meteorological data from other stations in the region in order to develop statistical glacioclimatic models. Observation from 1989–92 provide the basis for assessing changes at the ice-cap margin, including climatology and substrate colonization by lichens. The summit data permit extrapolation of seasonal temperatures from the ice marginal station for equilibrium-line altitude estimates. Compared with data from the 1960s, retreat of the Lewis Glacier continues at about 25 m a^{-1}. Lower regional summer temperatures over the past three decades have not significantly slowed the recession that has been underway here for the past three centuries.

Cause and mechanics of glacier surging, Trapridge Glacier, Yukon

(G. K. C. Clarke, U. H. Fischer and J. L. Kavanaugh, GPHYS/UBC)
Trapridge Glacier lies on an unlithified bed. A long-term study of the surge cycle began in 1969 and will continue until completion of the next surge. Instrumenting the ice/bed interface with sensors to observe subglacial mechanical and hydrological processes should help to discover the glacier-surge mechanism.

Subglacial physical processes, Trapridge Glacier, Yukon

(U. H. Fischer and G. K. C. Clarke, GPHYS/UBC)
By instrumenting the bed of Trapridge Glacier with tilt cells, 'ploughmeters' and 'slidometers' as well as water-pressure and turbidity sensors, hydromechanical interactions between the glacier and its bed are being studied. There is evidence for time-varying sticky spots and for stick/slip sliding motion.

GLACIERS – CORDILLERA

Moving Glacier, Strathcona Provincial Park, Vancouver Island

(D. J. Smith, GEOG/VIC)
More than 200 alpine glaciers are scattered along the crest of the Vancouver Range; almost half are within Strathcona Provincial Park where they have received only peripheral attention. The Forbidden Plateau/Comox Glacier Nature Conservancy area contains 18 glaciers. Historical records and air photographs indicate virtually all have downwasted and retreated, particularly Moving Glacier. Its behaviour (1931–92) was described by integrating data from vertical aerial photographs taken in 1931, 1962 and 1981, from Landsat thematic mapper (TM) imagery obtained in 1992, and 20 m contour TRIM (Terrain Resource Information Management) files. Since 1931 Moving Glacier has steepened dramatically and decreased in size by over 75%. Its balance history for the last 60 years has been overwhelmingly negative.

Wedgemount Glacier, B.C.

(W. Tupper, BCIT; K. Ricker, RICK)
From September 1990 to September 1992, Wedgemount Glacier retreated from a lake-water snout position, with frontal ice cliff, to an onshore steeply tapered snout, with 50–60 m of retreat; the shaded southwest side was about 20 m closer to the lake. The very cloudy 1993 summer effectively masked the low-snowpack winter, to reduce snout retreat to only a few metres. However, the shaded appendage of ice, left in 1992, disappeared making the snout a geometrically even convex outline with uniform radiating steep slope and only minor surface irregularities. Two velocity profiles were lost in the ablation that accompanied the reshaping of the snout.

Overlord Glacier, B.C.

(K. Ricker, RICK; W. Tupper, BCIT)
Brief re-surveys were carried out in July 1992 and August 1993. The warm summers of 1991 and 1992, with lower winter snowpacks, yielded a 27 m retreat from 1990 and a bilobed ice-front. The 1993 survey showed a slight re-advance, 0.8 m on one lake and 2.7 m on the other. The summer was very cloudy, and close inspection of the glacier snout revealed that the 1992/93 winter position had been only a few metres away.

Assessment of waterways for salmonoid net pen aquaculture

(K. Ricker and J. McDonald, AXYS Group, Sidney, B.C. for B.C. Agriculture, Fisheries and Food)
Waterways are being evaluated for rearing salmon in net pens, in the area fronted by Queen Charlotte Sound (51°00′ to 53°00′ N). Behind them are the expansive ice sheets of the Monarch and Silverthrone ice fields, each several hundred km^2 in extent. To the north of the former are the heavily glacierized Kitimat Ranges between Bella Coola and Kemano, in a lower elevated but much moister climatic regime (> 4000 mm a^{-1}). This area has hundreds of small cirque and valley glaciers and ice sheets. Runoff from all areas generates large dilution plumes with accompanying turbidity. The study is analyzing the seaward extent of glacier-melt influences and weighing these long-season events against autumn rainfalls which generate shorter but similar impacts on waterway quality. In the Mathieson–Furlayson system, intense autumn rains (up to 250 mm d^{-1}) appear to have a more diluting effect on the waterways than does ablation; in neighbouring Dean Channel, the converse situation occurs.

High mountain hydrology

(G. J. Young, GEOG/WLU)

Remapping of Peyto (Alberta), Ram River (Alberta), Woolsey (BC) and White (N.W.T.) Glaciers has been undertaken in the last 5 years. Calculations of volumetric changes over the last 20 years is underway to fix long-term mass-balance measurements and help explain the glacier-melt component in high-mountain runoff.

Snowcover dynamics and runoff from glacierized basins

(D. S. Munro, GEOG/TOR)

Field work, remote-sensing methods and modelling will be used to develop a predictive model of meltwater runoff from glacierized basins. It will incorporate hourly in-basin measurements of global radiation and air temperature to force the modelling scheme; integrate field measurement with remote sensing to provide short-wave albedo measurements, both spatially continuous and sensitive to changing cloud conditions; and produce spatially complex patterns of snowcover change during the melt season, to compare with observed patterns.

Measurements have already revealed the importance of absorbed global radiation to the melt process, particularly in fair weather, when melt rates are greatest. A remarkable degree of correspondence is being found between field measurements of albedo and those obtained from LANDSAT images. It appears we are ready to move beyond a simple altitudinal snowline response in modelling to one which takes into account the variations introduced by topography. A spatially complex model of snowcover change implies the ability to generate spatially complex patterns of surface meltwater production.

Rae Glacier, Rockies

(C. P. Lawby, GEOG/SASK; D. J. Smith, GEOG/VIC; M. M. Brugman, NHRI)

Theoretical lag and response times for adjustment to a mass balance change were compared to field observations of terminus position, ice flow, glacier thickness and character, runoff and local meteorological parameters at Rae Glacier, Alberta. This glacier has experienced considerable terminus retreat and down-wasting since its Little Ice Age maximum in the 1880s. The stress gradient coupling theory indicated that the length of the glacier was equivalent to its coupling length. The lag time is somewhere between 5 and 10 years and computed response times range from 40 to 400 years. The block-type response, suggested by these time, is consistent with a longitudinal averaging length approximately equal to four to five times the mean depth of the glacier, and implies that basal sliding is probably important in the flow response of this small glacier.

Little Ice Age in Peter Lougheed and Elk Lakes Provincial Parks, Rockies

(D. J. Smith, GEOG/VIC; D. P. McCarthy, NCC)

Most glaciers in this region are restricted to summit, cirque or hanging-valley locations. Their termini lie between 2300–2500 m, with ELA above 2600 m. All have undergone significant downwasting and ice-front retreat from trimlines established during the Little Ice Age. Dendrochronological, lichenometric and ^{14}C studies at 14 glacier sites were used to develop a chronology of Little Ice Age (LIA) events. While three periods of moraine construction were recognized, only a few sites contain datable evidence.

The earliest indications of LIA glacial activity come from terminal moraines deposited in the early 1600s at three sites. Minimum surface dates for two moraines may correlate to an event in the early 18th century. Most recent moraines date from 1792 to the mid-1800s, with moraine formation complete everywhere by the late-1800s. Recessional moraines are rare and indicate ice-front retreat has been relatively continuous since the 19th century.

SNOW – GENERAL

Snowcover–climate relationships

(R. D. Brown, AESQ; B. E. Goodison, AES)

As part CRYSYS, the snow cover over southern Canada has been reconstructed for 1900–92, analysis of the spatial/temporal variability on completed, the long-term variability of snow-cover extent over the interior of North America characterized, and a study completed on the role of snowfall in the Arctic climate system.

Snow applications using ERS-1 SAR

(Y. Moisan, CARTEL)

Various snow parameters (e.g. wetness, surface roughness) are under investigation using multitemporal European Remote Sensing Satellite 1 (ERS-1) High Resolution Synthetic Aperture Radar (SAR) data sets and image processing and change detection techniques. Preliminary results should be available in early 1995.

Biogeochemistry of seasonal snow

(H. G. Jones, INRS)

This project will relate the chemical and biological dynamics of the seasonal snow cover to physical processes at the snow–atmosphere and snow–soil interfaces. Recent studies have shown that microbiological activity on boreal forest snow cover can deplete nutrients before the end of the snow season, that gaseous soil emissions can be transported rapidly through sub-Arctic snow cover by convective processes, that nitrogen fluxes at the snow–atmosphere interface are dependent on solar radiation, and that the use of artificial snow on ski slopes does not seem to influence the germination of certain indigenous species.

SNOW – ARCTIC

Circumpolar snow and ice hydrology

(T. D. Prowse, NHRI)

NHRI will release a report in the summer of 1994 entitled *Northern hydrology: international perspectives.* This multi-authored book is the third in a series on northern hydrology and reviews various aspects of snow and ice hydrology in Finland, Greenland, Iceland, Norway, Sweden, the United States (Alaska), and the former Soviet Union. The two previous books included *Northern hydrology: Canadian perspectives* and *Northern hydrology: selected perspectives.*

Tundra snow, Ellesmere Island

(M. K. Woo, GEOG/McM)

Field work will be carried out in a test area (Fosheim Peninsula, Ellesmere Island) to enable process studies and to provide ground observations against which remote sensing data can be validated. Satellite information will be used to scale up the results to enable application at the GCM scale. This is part of 3 year study to understand snow distribution and melt processes on a regional scale for the tundra environment and to develop an algorithm for remote sensing surveillance of regional snow cover during the melt period through a coupling of field and satellite data.

For the end-of-winter snow distribution, long traverses, about 20 km, will be made to obtain snow-cover information at a scale comparable to the pixel size of satellite data. This ground data will be used to calibrate satellite imagery to enable remote-sensing interpretation of the regional snow cover. The energy balance of the melting snow will be studied at two sites with different dust contents in the snow to permit modelling of snow melt. By coupling the melt model with the snow distribution, the changing extent of the snow cover can be estimated for the melt season, and the meltwater released from the region computed.

Runoff processes in permafrost basins

(P. Marsh, NHRI)

Results from comprehensive studies of snow cover in the continuous permafrost of forested and tundra regions (near Inuvik, N.W.T.) show it is possible to link a snow-accumulation model based on vegetation-terrain types with a snow-melt metamorphism/runoff model to estimate the spatial variability of runoff in a tundra basin. Other results, from an assessment of the delivery of nitrogen or inorganic contaminants to northern ecosystems by a snow cover, show the role of heterogeneous flow in controlling the concentration of meltwater runoff, concentration increasing with decreasing flow.

Snow cover determination using passive microwave data

(A. E. Walker and B. Goodison, AES)

Recent work has focused on improving the retrieval of snow-cover information from passive-microwave satellite data under limiting conditions such as wet snow, forest cover, and seasonal variations in snowpack structure. Development of a boreal-forest snow water-equivalent algorithm is currently under investigation using airborne microwave data acquired during February 1994 as part of the Boreas (Boreal Forest Ecosystem Atmosphere Study) winter field campaign. Since 1992, special snow surveys have been conducted by university cooperators at Arctic and sub-Arctic target sites in support of algorithm development for these landscape regions. This work is a major component of CRYSYS.

Snow water-equivalent from passive microwave data, N.W.T.

(T. Y. Gan, ENG/ALTA)

A nonlinear multi-regression algorithm has been developed to convert passive microwave data from the Special Sensor Microwave/Imager (SSM/I) and the Scanning Multichannel Microwave Radiometer (SMMR) to snow water-equivalent (SWE), for mapping snow distribution in the N.W.T. In addition to brightness temperature data, land-use data, mean weekly maximum temperature data and snow-course data were also used. A SPANS GIS aggregates the land-use data, prepared by the Manitoba Remote Sensing Centre using NOAA-AVHRR images, from 1 km resolution to a resolution compatible with that of SSM/I and SMMR, about 30 km. A weekly "space-lag" autoregressive (AR1) model of order-one was developed from 30 long-term climatic stations located in the north and used to generate the temperature data needed.

The temperature estimated by AR1 was cross-validated with several independent climatic stations located along the Mackenzie Corridor. The estimated SWE values were validated with snow field measurements from the McMaster River Basin near Resolute and at Hay River. The algorithm underestimated the field measurements by 20–25%, but on the whole did better than other algorithms.

Snow surface processes in models

(J. W. Pomeroy, NHRI; D. M. Gray, ENG/SASK; R. J. Harding, Inst. Hydrology, UK; R. J. Janowicz, DIAND, Whitehorse)

Hydrological models and GCMs presently ignore surface snow processes such as sublimation of blowing snow which return as much as 75% of the seasonal snowfall to the atmosphere before melt commences and sublimation of intercepted snow which returns 30–40% of seasonal snowfall. These processes are extremely sensitive to land cover and hence quite variable over even small scales. Field experiments to verify snow algorithms are being conducted at Trail Valley Creek near Inuvik, N.W.T. (rolling arctic terrain), Wolf Creek near Whitehorse, Yukon (sub-Arctic and boreal mountain terrain) and Beartrap Creek near Waskesiu Lake, Saskatchewan (southern boreal forest). Objectives are to improve and verify the representation of surface snow redistribution, energy exchange, phase change and water-vapour fluxes within Lumped and Distributed Hydrological Models and Global Circulation Models (GCMs).

Snow chemistry

(J. W. Pomeroy, P. Marsh, NHRI; H. G. Jones, INRS; T. D. Davies, Univ. East Anglia, Norwich, UK; N. E. Peters, USGS-WRD, Atlanta, Georgia; M. Tranter, GEOG/Univ. Bristol, UK)

The role of snowcovers in controlling the release of nitrogen to boreal forests is not well known. The long snow-covered year and processes of wind transport and snow interception provide ample opportunity for accumulation of chemicals in the seasonal snowpack. They lead to high loadings of inorganic pollutants in areas of wind deposition and intercepted snow deposition; sulphate loadings at the tree line near Inuvik are twice those for rural Michigan, just outside major industrial centres. Field experiments are being conducted near Inuvik, N.W.T. and Waskesiu Lake, Saskatchewan on impact of blowing snow and accumulation; time and concentration of release from snowpack; role of photochemical processes; and lab studies.

Contaminants in snow, Yukon Territory

(D. Gregor, ES/WATER; M. Alaee and B. Strachan, NWRI; M. Palmer and M. Swyripa, DIAND)

During the winter of 1992/93, 43 snow samples were collected from 3 collectors near Whitehorse, Tagish, and

at White Pass near the B.C./Alaska border as part of a Yukon winter-time project to: quantify annual deposition of trace organic contaminants; quantify weekly deposition of contaminants; determine spatial variability in contaminant deposition; and assess source areas and transport vectors for contaminant deposition through back trajectory calculations.

Due the highly variable amounts of snow received at the 3 sites, it is more appropriate to compare PCB deposition which factors in the amount of snow in the snow collector. Mean deposition of PCB at Tagish and Whitehorse, respectively, is 4.9 and 3.6 $ng\,m^{-2}\,d^{-1}$. These values compare with High Arctic sites. In contrast, the mean deposition at White Pass for 1992/93 was estimated at 100 $ng\,m^{-2}\,d^{-1}$. Relatively few organochlorine pesticides and related compounds were detected in the Yukon snow samples. Those with consistent hits include pentachlorobenzene, hexachlorobenzene, p,p-DDE, α-hexachlorocyclohexane, lindane, γ-chlordane, α-endosulfan, α-chlordane and dieldrin. Of these, hexachlorobenzene, α-chlordane and dieldrin have relatively high blanks suggesting that their presence may be due to contamination.

SNOW – WESTERN CANADA

Snowpack variability in British Columbia

(R. D. Moore, GEOG/SFU)

The spatial and temporal structures of spring snowpack anomalies in British Columbia are being characterized and anomaly patterns related to interannual and decadal-scale variations in atmospheric circulation over the Pacific Ocean and winter weather types over British Columbia.

Hydrologic recovery of logged forest

(D. L. Golding, FOR/UBC)

Forest harvesting guidelines often specify the fraction of a watershed that can be logged to limit the increase in peak streamflow resulting from forest harvest. However, information is needed to describe the effect of forest recovery on peak streamflows to provide guidelines as to when stands adjacent to previously harvested areas can be logged without causing "excessive" increases in peak flow. This study examines changes in snow accumulation, snow melt, and stream flow regime, as trees become re-established and stands develop on cutover areas. Factors related to snow accumulation and melt, such as energy balance, will be measured.

SNOW – CENTRAL AND EASTERN CANADA

Taiga snow cover, S.E. Manitoba

(W. O. Pruitt, ZOO/MAN)

Investigation of the variations in taiga snow cover, effects of wind and the effects of animal, human, and machine traffic continue.

Investigation of the effects of snow cover on subnivean and supranivean vertebrates and invertebrates and the effects of these organisms on the snow cover is also underway.

Runoff processes in a boreal forest

(R. Metcalfe, GEOG/QUEEN'S; J. Buttle, GEOG/TRENT)

Work is in progress to measure spatial distribution of snow water equivalent in small basins in the northern boreal forest, estimate spatially distributed melt rates in the basins from point measurements and remote sensing imagery, determine basin water balances during snowmelt and summer rainfall events, conduct isotopic hydrograph separations for basin streamflows during snowmelt and rainfall inputs, and test the ability of a spatially distributed hydrological model to simulate streamflow soil–water storage, groundwater levels and isotopic responses of the basins during snowmelt and rainfall inputs.

SNOWDRIFT program

(M. Perchanok, MTO; D. McGillivray and J. Smith, Environmental Software Consultants Inc., 64 Ferris Rd., Toronto, Ont, M4B 1G4; H. Granberg, CARTEL)

A computer program was developed which models snow drifting at 4 m intervals over a 1 × 1 km area at any location in Ontario, to assist highway design staff minimize snow-drifting problems. Inputs include topography, roughness and hourly met data. Outputs include snow depth as contours and as cross-sections. Treatment of sub-grid features, such as fences, hedges and small ditches is being improved.

Winter maintenance materials for highways

(M. Perchanok, MTO; G. Comfort, FLEET)

Tests were conducted in a FLEET cold room to compare the performance of abrasives, de-icers, and pre-wetting solutions for winter maintenance on highways.

Snowmelt infiltration in a balsam-fir forested watershed, Quebec

(J. Stein, INRS-Eau)

It is thought that night-time freezing of water ($< 10°C$) at the soil surface, when the snow cover becomes thin or discontinuous in the spring, changes the soil infiltrability index. To test this, transects were established and four plots instumented, in the Lac Laflamme basin, to follow the evolution of water-table fluctuations, snow-cover area, soil and air temperatures, and liquid and total water contents at different levels in the soil. A minimum nightly air temperature of $-5°C$ during snowmelt did not produce soil ice. At a basin scale, concrete frost, prevalent throughout the basin, is associated with forest floors dominated by sphagnum or hypnobryale mosses, and originates from winter meteorological events.

SNOW – AVALANCHES

Avalanche hazard forecasting

(C. D. Johnston and J. B. Jamieson, ENG/CAL)

Weak snowpack layers consisting of persistent weak grains such as surface hoar and facets form the failure plane for approximately 75% of fatal avalanche accidents in Canada. This work will evaluate the rutschblock stability test for assessing the stability of snow slabs overlying persistent weak layers, and refine and evaluate shear-

frame stability indices such as S′ (Föhn 1987) for assessing the stability of snow slabs overlying persistent weak layers. Findings thus far indicate that the S′ determined for persistent weak layers on avalanche slopes can predict about 75% of skier-triggered slabs, and that such stability indices determined on representative study slopes are often good indicators of the stability on avalanche slopes within 10–15 km of the study slope.

Avalanche snowmelt runoff

(F. de Scally, GEOG/Okanagan Univ. Coll., Kelowna, BC, V1V 1V7)
Two years of measurements in this study of the influence of avalanche-snow transport on the subsequent temporal pattern of snowmelt runoff from high-elevation basins in the Cascade mountains, southern British Columbia, indicate that a significant difference exists in the unit-area discharge in late spring and summer from adjacent avalanche-free and avalanche-prone basins. Much of this difference later in the summer appears to be attributable to the effects of delayed melting of avalanche snow, even after winters of only modest avalanche activity.

Avalanche prediction and control, B.C.

(D. McClung, ENG/UBC)
A numerical avalanche-prediction system was developed and tested at Kootenay Pass, B.C. It uses parametric and non-parametric discriminant analysis and Bayesian statistics. Test results 1992–93, 1993–94 show about 80% accuracy under rigorous testing. With the ARCS Lab, B.C.I.T., an expert system for snow-profile interpretation was developed. This was tested in 4 areas during 1993–94 with testing planned in 10 areas for 1994–95. Measurements of snow gliding, full depth avalanche release and radiation were made at the Coquihalla, B.C. from 1992–94 to understand avalanches that release by gliding in relation to meteorological and snow parameters.
A trial of the CROCUS model to simulate snow-pack development in two different climate regimes in British Columbia was initiated. This cooperative effort with the Centre d'Études de la Neige, Grenoble, began in 1993–94. Studies were initiated in 1994 on frequency, arrival rate and terrain parameters for avalanche runout and risk studies on high-frequency avalanche paths. *The avalanche handbook* was published by The Mountaineers, Seattle in 1993.

PERMAFROST – GENERAL

Multi-lingual index of permafrost terms

(R. O. van Everdingen, AINA)
The Terminology Working Group of the International Permafrost Association is preparing a multi-language index of the main terms and synonyms contained in the *Glossary of permafrost and related ground-ice terms* published by the National Research Council of Canada in 1988. The index covers some 650 terms and synonyms in English, with equivalents in French, German, Italian, Norwegian, Spanish, Swedish and Russian.

Effects of climate change on permafrost

(A. N. Headley and J. B. Maxwell, AES)
A methodology is being developed for incorporating climate warming in the design of pipelines, buildings and other structures where such construction is underlain by permafrost. Standards and guidelines will be initiated for all of Canada, related to changes in permafrost that may occur under climate warming, that may be used by various industries for design purposes.

Properties, distribution and testing of permafrost

(P. J. Kurfurst, TSDGSC)
Geotechnical (CPT) and geophysical (seismic, electromagnetic, radar, RUSCAN) techniques have proved valuable in determining lithology, material properties, geothermal regime and degree of ice-bonding of nearshore and onshore materials, as part of a study on the distribution, classification and properties of frozen soils and ground ice.

Frozen ground structure interaction

(B. Ladanyi and A. Foriero, CINEP)
Complete analytical and numerical solutions for stress redistribution with load and time in short and long, rigid and flexible, axially and laterally loaded piles embedded in permafrost were obtained and compared with laboratory and field test results. More recently, attention was focused on general frozen soil/structure interface behaviour. A new solution for pipe uplift resistance, involving frozen ground tensile cracking, was proposed and its validity checked against the results of full-scale pipe anchoring tests in frozen soil, carried out in Caen, France.

Frozen soils and ice creep properties, SCT method

(B. Ladanyi and graduate students, CINEP)
A method for determining creep properties of frozen soils and ice, based on borehole enlargement by means of a low-angle truncated cone with 3 levels of lateral pressure transducers, was developed and tested in situ. 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 pilot 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. Another version of the test, involving an instrumented cone, makes it possible to perform a continuous lateral pressure measurement during the cone penetration at a controlled rate.

Borehole dilatometer creep and relaxation testing

(B. Ladanyi and graduate students, CINEP)
The study comprised in-situ tests at two permafrost sites (CRREL Permafrost Tunnel, Alaska, and Longyearbyen, Svalbard) and a series of full-scale tests under well-controlled cold-room conditions. The values of creep parameters determined were found to agree well with other testing methods, such as triaxial compression and borehole creep tests.

Cone penetration testing

(B. Ladanyi, T. Lunne, P. Vergobbi, B. Lhuillier, R. Fortier and M. Allard, CINEP)
Field tests since 1988 have confirmed hat there is a unique relationship between the cone resistance and cone penetration rate. It possible to carry out either a continuous frozen soil strength profiling to a given depth,

or determine the frozen soil or ice strength vs. strain-rate behaviour within a selected soil layer. CPT results have been correlated with the salinity, the unfrozen water content and the electrical resistivity of a silty permafrost layer.

Coupled processes in freezing and thawing soils

(B. Ladanyi, M. Shen and A. Foriero, CINEP)
By taking into account the simultaneous phenomena of heat transfer with phase change, water migration through frozen and unfrozen soil, and the resulting internal stresses generated by freezing, the process of frost heaving in fine-grained soils can be simulated. The conceptual frost-heaving model, proposed by Shen (1991), was validated against laboratory test results, and against measurements made on a buried chilled pipeline in Caen, France. It is possible to predict the stresses acting on such a pipeline under any given longitudinal pipeline rigidity condition. More recently, a large strain thaw-consolidation theory has demonstrated the limitations of the conventional small thaw-consolidation theories.

PERMAFROST – ARCTIC AND YUKON

Massive ground ice, Canadian High Arctic

(W. H. Pollard, GEOG/McG)
Different types of massive ice are being categorized, particularly to distinguish between intrasedimental and buried glacier ice. The study is concerned with: detailed mapping of ground ice distribution and stratigraphic characteristics (ice content and cryogenic textures) in the High Arctic; analysis of ground ice fabrics, chemistry and isotopic characteristics; and analysis of carbon dioxide and methane in massive ice.

Massive ground ice, Eureka Sound Lowlands

(T. Bell, GEOG/MUN; W. H. Pollard, GEOG/McG)
Preliminary observations indicate a segregated ice origin, in response to permafrost aggradation following post-glacial emergence; consequently, a history closely paralleling the local emergence history. Marine sediments overlying the ground ice were deposited between 10 000–4000 BP. Hence, a wide range of climatic regimes should be reflected in the hydrologic and cryotic processes active during permafrost aggradation. Field mapping suggests that ground-ice degradation has had a significant impact on the geomorphic evolution of numerous valleys draining the lowlands. The likely response of ice-rich terrain to future climate warming in the High Arctic is being assessed.

Massive ground ice, Fosheim Peninsula, Ellesmere Island

(S. D. Robinson, QUEEN'S)
Geophysical surveys showed several regions cored with up to 17 m of massive ice. The original topography is poorly preserved except for ice-cores hills with a thick overburden. Slope failure and gullying has resulted in a thinner overburden with poor protection for the remnant ice bodies. There is a strong correlation between thaw slump headwall retreat and thawing degree days. Headwall retreat is currently between 5–14 m a^{-1}, and is strongly affected by slump morphology.

Permafrost areas and climatic change, Ellesmere Island

(A. G. Lewkowicz, GEOG/OTT)
Processes under study, primarily on the Fosheim Peninsula, Ellesmere Island, include solifluction, landsliding over permafrost and fluvial processes. All are influenced by snow distribution, ice-lens development and thaw within the active layer, and summer climate.

Thermal and hydrologic investigations

(C. Burn, GEOG/CARL)
Long-term investigations of permafrost and ground ice in Yukon and western Arctic Canada continue with projects such as: the determination of permafrost response to climate change via monitoring ground temperatures since 1985 at Mayo and Whitehorse, Y.T.; permafrost response to forest fire-induced changes in near-surface conditions near Whitehorse, Y.T.; investigation of the growth of permafrost in alluvial sediments following channel migration, Mayo, and the growth and decay of near-surface ground ice due to climate change, Mackenzie Delta area; examination of the influence of lakes on ground temperatures, Richards Island, N.W.T; and study of the winter hydrology of lakes in the Mackenzie Delta, N.W.T

Peatland morphology in discontinuous permafrost, MacKenzie Valley

(I. Kettles, TSD-GSC and S. D. Robinson, QUEEN'S)
Discontinuously frozen peatlands are a large poteential natural source of greenhouse gases. Ground-penetrating radar (GPR), supported by coring, was used to examine interrelationships between permafrost and peat in various landforms and the underlying sediment, and to assess peatland stability. Field work was conducted near Fort Simpson in 1993 and is near Norman Wells and Inuvik in 1994.

Electrical potentials at the freezing/thawing front

(V. R. Parameswaran, NRC; J. R. Mackay, GEOG/UBC)
Past work has shown that electrical potentials are developed during freezing of water and moist soils. This phenomenon is important in that such electrical gradients produced at the freezing front could cause moisture transport, leading to the formation of huge ice bodies and resultant frost heave. Measurements have been made for the past nine years in the freezing ice core of a pingo in the N.W.T.

PERMAFROST – ELSEWHERE

Thermal stress at the permafrost margins

(A. Judge, TSDGSC; J. Majorowicz, Northern Geothermal Consultants Ltd., 105 Carlson Close, Edmonton, Alberta, T6R 2J8)

High-precision temperature logging in 42 wells in central Alberta (in 1992) and recent measurements in northern and southern Alberta (32 sites) give evidence of a large regional-scale warming trend at the ground surface in the 1.5–3.0°C range. It is strongest in the northern areas, including the northern Prairies immediately south of the southern margin of permafrost. It has caused an observable inversion of temperature-depth profiles in the upper 100 m ± 30 m. The results correspond to findings from Alaska where warming as high as 3.5 ± 1.5°C was interpreted and in the Mackenzie Delta where warming as high as 3.7°C was found. The results roughly indicate a two to three times greater rise in ground temperature than the increase in air temperature over the same time interval, suggesting that our present predictions may severely underestimate the rate and magnitude of the impact of climatic change on permafrost.

Permafrost degradation and climatic warming

(Y. T. J. Kwong, NHRI; T. Y. Gan, ENG/ALTA)
Based on two field surveys of permafrost distribution conducted 26 years apart along the Mackenzie Highway south of Great Slave Lake, the southern limit of the sporadic discontinuous permafrost zone here has migrated northward by about 120 km. To substantiate that this is largely caused by climatic warming, a detailed trend analysis of monthly air temperature records from nine weather stations was performed using the non-parametric Kendall's test. The results show the region experienced a general warming trend for 1949–89 and that warming is more prominent in the minimum than the maximum temperature series. From estimates of the magnitude of warming trends on a monthly basis, the resultant increase in mean annual air temperature could readily lead to the observed northward migration of permafrost.

LAKE AND RIVER ICE

Ice types, early Canadian glaciology

(W. P. Adams, GEOG/TRENT)
Studies and observations of various types of ice appeared in Canadian scientific journals throughout the last half of the 19th century and well into the 20th. These do not appear to have fed into the mainstream of glaciology. Two papers have been published on such matters.

Lake ice freeze-up and break-up using passive microwave satellite data

(A. E. Walker and M. R. Davey, AES)
SSM/I brightness temperature data have been acquired in near real-time for Great Slave and Great Bear Lakes during ice freeze-up and break-up seasons since 1992. Results show it is possible to discriminate between areas of ice cover and areas of open water using the 85 GHz channels and therefore observe the process of ice formation and break-up over the two lakes. Observations of Great Lakes ice conditions during the 1993/94 winter were achieved using the same techniques. Current research is focused on the analysis of brightness-temperature time-series for determining the effects of atmospheric and ice surface conditions on the 85 GHz data. This work is a component of CRYSYS.

Frazil and anchor ice

(G. Tsang, NHRI; L. Y. Lau, NWRI)
Laboratory studies are being conducted to find the concentration distribution of frazil in water, the effect of frazil presence on the velocity profile, the statistical characteristics of frazil, the parameters that affect the formation of anchor ice, and the basic relationship between anchor ice and its affecting parameters.

RIVICE (river ice) model development

(S. Beltaos, NWRI; N. Marcotte, HQ; M. Sydor and K. Martinson, EC)
A numerical River Ice (RIVICE) model with applications in the areas of flood forecasting, ecosystem-risk analysis and response, climate change effects, effects on navigation and energy production and analysis of socio-economic impacts is being developed. Work to date includes the development and documentation of the model and further work on a dynamic heat-balance component that establishes the heat lost or gained at the water/air interface for open-water river sections and the water/ice interface for ice-covered sections. Individual ice modules will be reviewed and coupled with the hydraulic and temperature simulation modules. Complete development of the model will include verification through case studies and a complete series of technical notes.

Hydro-power ice problems

(N. Marcotte, HQ)
Several rivers with hydro-power stations experience problems such as frazil-ice accumulation, ice-cover breaking and mid-winter flooding. Ice conditions and water temperature are being observed and, using a modified version of mathematical model RIVHER, modelling of water temperature at the outlet of reservoirs and of the evolution of ice characteristics is in progress.

Environmental aspects of river ice

(T. D. Prowse, NHRI)
A report has been published by NHRI, with the Subcommittee on Hydraulics of Ice Covered Rivers, on the environmental aspects of river ice. The multi-authored report considers a myriad of physical, chemical and biological aspects and is to be followed in August, 1994, by the publication of a set of proceedings from a workshop of the same name.

Colour Lake, Axel Heiberg Island

(M. English, GEO/WLU; W. P. Adams, J. Buttle and M. Ecclestone, GEOG/TRENT)
Work on the quantity and type of ice on a naturally acid lake, Colour Lake, and on roles of ice growth and decay on lake and downstream chemistry continues.

River ice break-up and sediment/trace-element fluxes

(D. Milburn, Water Resources Division, DIAND; T. D. Prowse, NHRI)
The role of river-ice break-up in the transport of suspended sediment and trace elements has been evaluated for the Liard River, N.W.T. A unique set of field measurements, obtained by helicopter during the active break-up period, shows that the concentrations of suspended sediment and some trace metals far exceed those possible for comparable discharge under open-water

conditions. Higher concentrations are probably due to the enhanced turbulence, flow velocities and scour that accompany break-up activity.

Break-up, Mackenzie River at Fort Providence

(F. Hicks, ALTA; D. Andres, Trillium Engineering, Edmonton, Alberta)
There is typically a period of several weeks between decommissioning of the ice bridge just upstream of Fort Providence and the resumption of ferry operations, with limited access to Yellowknife and all points north. This study is developing a better understanding of the break-up processes on the Mackenzie River in this reach, with the ultimate objective of developing a forecasting tool.

Aeration of ice-covered lakes, British Columbia

(P. Hamblin, NWRI; C. K. Roger, ENG/UBC; R. Baddour and M. Helston, ENG/WEST)
Due to the barrier to natural replenishment provided by ice cover, oxygen levels can drop in winter to levels insufficient to support fish life. A solution is to create a polynya to admit oxygen and light. Two lakes in the interior of British Columbia were studied over a winter, one with artificial stirring and the other as a control. A model of the ice and snow cover and the water temperature was developed and included snowmelt due to rainfall, sediment heat transfer, snow-ice formation, and daily variations of snow density, conductivity and albedo. Sediment heat transfer was important in early winter while solar radiation dominated in the latter part of winter. The model, when modified for the stirrer, including polynya formation, and heat transfer through the open water and calibrated for the turbulent heat transfer to the ice cover, also agreed well. During the cooling period, the average heat loss due to turbulent transfer to the ice was three times that across the polynya in the stirred lake.

Mid-winter break-ups in mountains

(R. W. Costerton and P. F. Doyle, BC Environment)
Existing meteorological data-stations indices are being used to predict increases in discharge sufficient to cause imminent sudden break-up of river ice covers. The relationship between cold content of snowpack and start of runoff due to snowmelt leading to major discharge increases and break-ups is being explored.

Ice jam flooding, Peace–Athabasca Delta

(T. D. Prowse and M. N. Demuth, NHRI; M. Peterson, Wood Buffalo National Park, Fort Chipewyan, Alberta)
The effects of flow regulation and climate change on the occurrence and severity of river-ice floods are being evaluated for the Peace River, Alberta. Analysis of hydrometric records indicates that ice-jam floods have been responsible for historical inundation of the Peace–Athabasca Delta, one of the world's largest and most productive deltas. Hydrometeorological conditions have not been conducive to the formation of large ice jams since 1974. As a result, the Delta has experienced extensive drying and changes in, for example, the vegetation regime and the related small-mammal habitat. In an attempt to restore water to the high-elevation perched basins of the Delta, artificial ice jams are being designed/constructed using spray-ice technology.

Border-ice growth, Burntwood River, Manitoba

(D. H. Burn and T. M. Miles, ENG/MAN)
Border-ice growth and related measurements were obtained over a number of years for three sites on the Burntwood River. Reasonable results could be obtained with one of the models considered, but the meteorologic and hydrological/hydraulic data requirements for this model were quite extensive. A simpler border-ice growth model, that requires only the position of the ice edge and the degree-days of freezing, provided results that were nearly as good as the more detailed model. The model may be a viable alternative for other northern sites where detailed, site-specific, data are frequently not available.

Ice conditions, Upper Niagara River

(J. R. Rossiter, CANPOLAR; R. Crissman, New York Power Authority)
An assessment of available technologies for improving the real-time estimation of ice conditions above Niagara Falls has been completed, to optimize hydroelectric power generation. Trials of low-light-level television, marine radar, Doppler radar, and upward-looking sonar, are planned for 1995.

Ice management for flood control, lower Rideau River

(D. B. Hodgins and P. R. H. Schaap, Fenco MacLaren Inc., Atria N., Ph. II, 2235 Sheppard Ave. E., Willowdale, ON, M2J 5A6, with Rideau Valley Conservation Authority)
Ice clearing/blasting on the Lower Rideau River has been part of the ice-cover removal program to prevent ice-jam induced flooding of residential areas in Ottawa and Vanier for over 100 years. Despite its long-term success, the environmental implications of the program are largely unknown. On-site assessments of blasting effects on fish were conducted over five days in March, 1994 and fish-habitat assessment work is scheduled for the summer. Based on the findings, recommendations will be made to modify the current ice-removal program to minimize negative effects to fish and fish habitat. Biologists will contribute to the evaluation of alternatives to the current practice.

Saint John River ice and sedimentation

(S. Beltaos and K. Krishnappan, NWRI; B. Burrell, NBEPS; S. Ismail, NBEPC)
Forecasting/warning methods are being developed to help reduce recurrent ice-jam damage in the upper Saint John River during spring break-up, and possible long-term remedial measures are being identified. Direct and indirect effects of ice on sediment movement in rivers, are being studied. Suspended sediment concentrations increased from 5 to over 100 mg l^{-1} during the spring runoff of 1993 while the sediment load rose from 0.1 to 25 million kg d^{-1}. Results suggest that significant erosion occurs during the spring break-up, yielding a major part of the total annual sediment load; and that large amounts of aquatic contaminants can adsorb on to the suspended sediment and, in particulate form, travel much farther downstream than at other times of the year.

Mechanics of icing and seasonal frost mound formation

(W. Pollard and X. Hu, GEOG/McG)

In the North Fork Pass area, northern Yukon Territory, several environmental variables associated with icing activity are being monitored in an attempt to model various stages of the icing formation process. Research on the Expedition Fiord area of Axel Heiberg is concerned with icings and frost mounds associated with a series of mineral springs and the influence of water chemistry on icing formation. Another component of this research is concerned with the analysis of seasonal and perennial frost-mound formation and structure.

SEA ICE

Arctic sea-ice and ocean circulation

(D. M. Holland, L. A. Mysak and J. M. Oberhuber, CCGCR/McG)

Studies focused on where and how the waters and the sea ice of the Arctic Ocean circulate. First, a sensitivity study was carried out on the sea-ice model, the first time a systematic and comprehensive investigation of this kind was performed. A snow model was implemented in a GCM that allowed for a realistic simulation of both Northern and Southern Hemisphere ice characteristics without having to tune the model parameters for each hemisphere. The coupled ice–ocean model was used to investigate the general circulation of the Arctic Ocean and its connection with the North Atlantic. The counter-clockwise motion of the deeper waters within the Arctic was correctly simulated for the first time. A sensitivity study of the surface waters of the Arctic showed that salt, in effect, drives the circulation of the water and not the wind.

Forecasting Arctic sea-ice cover

(H. R. Kivisild, HRK Consultants Ltd., 1420, Premier Way S.W., Calgary, Alta, T2T 1L9)

The probability of floating and over-ice periods for operations in selected Arctic waters was estimated. Data on various types and thickness of ice were processed.

Ice mechanics, Allen Bay, N.W.T.

(D. M. Farmer and Y. Xie, IOS)

The physical processes involved in mechanical failure of sea ice in a natural environment are being determined. Field studies, using artificial impacts, have measured the seismic and acoustic radiation from sea ice, along with relevant environmental parameters. Mathematical models describe the observed signals. Observations of natural ice-cracking and other failure mechanisms in Allen Bay, N.W.T. have been described and explained. Elastic wave propagation through a pressure ridge showed severe attenuations of flexural waves; these have been explained with a flexural wave model.

Ice subsurface characterization

(H. Melling, D. R. Topham and R. G. Bowen, IOS)

Detailed thickness and topographic cross sections of Arctic sea ice are being acquired for engineering and climate applications, to understand deformational features in sea ice better, and to compare surface observations with remotely sensed data, particularly by radar. Detailed surveys of both upper and lower surfaces on two extensive areas of deformed sea ice have been completed and analyzed. Year-round observations of ice thickness and topography have been obtained by subsea sonar in the Beaufort Sea since April 1990.

Beaufort Sea oceanography

(R. W. MacDonald and E. C. Carmack, IOS)

Data and samples have been collected in the spring and summer since 1986. Research is conducted on the sources, sinks and distribution of natural hydrocarbons and related compounds, and multivariate models developed to understand the hydrocarbon geochemistry. Other work has related the water-mass structure of the Beaufort shelf to sources and residence times of water on the shelf. Models are now being developed to account for salinity and fresh-water budgets on the shelf and the role of the Mackenzie River in supplying buoyancy to the shelf. Oxygen-isotope measurements in the annual ice were used to determine the rate of spreading of the surface plume in the nearshore in winter and have accounted for the fresh-water budgets both in the water column and in the ice. The program terminated in March 1994; findings will be published over the next several years.

Beaufort Sea ice-load data base

(G. W. Timco, NRC)

The NRC has established a Centre of Ice/Structure Interaction. Based in Ottawa, it houses a large collection of reports, videos, films and data related to the development of the Canadian Beaufort Sea. It is the major repository of information obtained by Gulf Canada using the Molikpaq and Tarsiut structures. It also contains extensive contributions from Imperial Oil (Esso) and the Canadian Government. The collection will be catalogued in NRC's national science library (CISTI).

Numerical ice prediction model

(C. C. L. Tang, BIO)

A Hibler-type ice model coupled to a Mellor-type diagnostic baroclinic ocean model with an Ekman layer under the ice has been developed and used to simulate ice and oceanic conditions of the Labrador and Newfoundland shelves. The input of the model is 6-hourly surface wind produced by the European Centre for Mid-range Weather Forecast. With given initial ice conditions, the model computes ice velocity, ocean current, ice concentration and thickness. If the input wind field is forecast wind, the model can be used for short-term forecast of ice distribution. Extensive tests of the model are underway to tune the ice and ocean parameters, and to validate the model against available ocean and ice data.

X-band radar detection of growlers

(T. J. Nohara and S. Haykin, CRL)

Studies of growler detection in sea clutter using methods such as coherent radars and Gaussian Spectrum Models continue.

Melt rates of bergy bits and growlers

(G. Crocker, C-CORE; M. Williams, IMD)

Experiments have shown that ice size, water temperature, wave height and period, and to a lesser extent ice temperature are critical in determining the melt rates of bergy bits and growlers. Dimensional analysis shows that heat transfer can be determined from wave Reynolds

number, wave steepness, and an ice/wave length ratio, an analysis supported by laboratory data. The melt-rate information will be incorporated into a bergy bits and growlers model, critical in risk-analysis studies for offshore operations in iceberg-infested waters.

C-CORE iceberg impact study

(G. Crocker, K. Croasdale and G. Cammaert, C-CORE)
To identify the relationship between ice-crushing pressure, contact area and shape, and to advance the understanding of the kinematics involved in iceberg collisions with structures, full-scale iceberg impact loads (up to 10 000 tonnes) and pressures resulting from impacts of icebergs, and contact areas up to approximately 30 m^2 are being measured. In particular, full-scale information on loads and pressures resulting from iceberg/structure interactions with contact areas 3–30 m^2 (or larger is required). These represent a significant increase over the largest contact areas achieved to date (via indentor tests), and will therefore provide important new information on the nature of the pressure/area relationship in the range contact areas of real significance to vessels and offshore structures in ice-infested oceans. A test site has been found in southern Labrador, and a preliminary load panel designed and produced. Load-panel construction and deployment and the actual impacts test are scheduled to take place over the next two years.

Icebergs in the marginal ice zone

(S. Venkatesh, AES)
During the Labrador Ice Margin Experiment (LIMEX) of March–April 1989, the International Ice Patrol (IIP) of the United States Coast Guard deployed two satellite-tracked TIROS Arctic Drifter (TAD) platforms on two medium-sized tabular icebergs. The icebergs were drifting in sea ice of about 9/10 concentration east of Newfoundland. The TAD data provide a unique set for modelling the deterioration of icebergs as they emerge from the marginal ice zone and travel in open water. It is clear that a good knowledge of environmental conditions, particularly water temperature and sea state, is critical to modelling the deterioration and calving of the two icebergs.

Ice and iceberg studies

(J. R. Marko, D. B. Fissel and D. Haller, ASL Environ. Sciences Inc., Sidney, B.C., V8L 3S1)
Iceberg numbers south of 48° N are controlled by ice extents off Labrador (in the spring) and Davis Strait (in mid-winter) through two separate mechanisms whereby the ice reduces berg dissipation by coastal trapping and free-drift melt. Model evaluations suggest that sea-ice extent variations, responsible for this, are determined by winds over the great East Coast region. Empirically based techniques using spatially and temporally extensive wind inputs appear to provide the best present basis for operational ice forecasting.

Ice-keel scour studies

(C. Woodworth-Lynas, C-CORE)
An ice-keel-disturbed seabed is being studied to determine deformation processes and effects on benthic epi- and infauna/flora and rates of recolonization. Ancient glacio-marine sedimentary sequences are being re-examined for evidence of ice-keel scour in order to recognize fossil scour marks, and of ice-keel turbate facies to quantify sub-scour deformation and mechanisms in different grain sizes, and to validate centrifuge model studies of ice scour being carried out to develop pipeline design guidelines.

Iceberg impact modelling

(F. M. Williams, IMD)
Iceberg impact forces on subsea or offshore structures are under investigation and a series of flexural strength experiments on iceberg and glacier ice has been completed.

Validation of ice ERS-1 SAR data

(S. J. Prinsenberg, BIO; M. Manore CCRS; M. Shokr, AES; C. Stewart, CCG; T. Carrieres, CICE; S. Holladay, GEONEX)
The CCG's helicopter-borne, electromagnetic, laser-sensor system measured ice-plus-snow thicknesses and surface roughnesses at 1.5 m intervals along 1400 km of track. Another helicopter collected surface ice and snow samples, ice cores and deployed ice beacons; cores being used to obtain surface temperature profiles and brine contents from sites of different SAR reflectance; surface roughness measurements and snow salinities were also collected. Frost-flower salinities up to 80 ppt were measured in an area of high reflectance. SLAR data were compared to ERS-1 SAR and Ice Probe data. 16 ice beacons were deployed to measure drift and realign the Ice Probe and SAR data.

Interpreting SAR imagery of sea ice

(D. L. Hagen and S. Thomas, NORLAND)
Tools for mapping and monitoring sea ice are being developed to facilitate the use of existing radar data, those to come from RADARSAT. A Computer-Based-Tutorial (CBT) that teaches users how to interpret radar imagery for sea ice runs on any 386 or 486 PC.

Sea-ice field trials

(F. M. Williams, IMD)
Methods are being developed to characterize and measure the engineering properties of ice features. Recent work includes measurements of Northumberland Strait ice properties, studies of the strength and fracture toughness of first-year arctic sea ice, and development of a database on the flexural strength of ice over five parameters.

Rapid ice data collection system

(CANPOLAR; G. Timco, NRC)
A two-part system has been developed to determine the thickness and strength of sea ice from onboard an icebreaking vessel. The system features a remotely controlled core-auger that can retrieve a full sea-ice core 1.5 m thick and a snow sample in less than 5 minutes. The system also includes a calibrated video system that continually records the ice thickness and stores it on a video tape along with the date, time and ship position. This work was initiated by the Canadian Coast Guard and funded by PERD.

Environmental measurement science

(N. K. Sinha, IERT)
A method was developed for textural analysis of ice. Crystal area, feret diameter, shape factor, compactness, major axis slope and *c*-axis orientation of the grains can be determined as a function of depth. The technique involves a 'similar double-microtoming' method of thin-section preparation and image digitizer and image analyser/

statistics software. Other work includes examination of ice cores to detect the history of contaminants and collaborative studies on sea-ice microstructure relevant to SAR and ground truthing.

Boundary-layer stability and vertical exchanges through a first-year sea ice

(E. Hudier, UQAR)

Work is aimed at developing a model of the global flux through sea ice that would consider the local variability of exchanges processes and the large-scale characteristics of the ice cover. Research has focused on the influence of pressure-ridge keels on the salinity structure at the ice–water interface. Results indicate that the boundary layer was well mixed all over the ice floe except a small area downstream of the pressure ridge in which a melt layer developed during half of the tidal cycle. Our representation suggests a variability of the intensity of vertical exchanges with a minimum in the vicinity of ridges and a maximum in the wake regions. It follows that, depending on ridge density which typically range from 0.5 to 6.8 pressure ridges per kilometre, the region where vertical exchanges are diminished could cover between 1 and 13% of the sea ice surface which, added to rubble fields and pressure ridges, may represent up to 50% of a sea-ice sheet.

Medium-scale uniform pressure tests on first-year sea ice

(D. M. Masterson and P.A. Spencer, SANDWELL; R. M. W. Frederking, NRC)

A field program in first-year sea ice recorded ice failure pressures in a geometrical situation, allowing interpretation in terms of a "global" loading situation. The data are applicable to ice-breaking vessels and bottom-founded structures. The similarity between the pressure/displacement data for the flatjack tests permitted estimation of the maximum or plateau for tests which did not reach that point. Adjustments were also applied for stress/strain rate and ice porosity effects. Pressures from straight slots were consistently higher than for "H"-shaped slots. They are essentially independent of the contact area, indicating that, for "intact" ice at these stress rates, there is no size effect.

Hull loading of first-year sea ice

(S. J. Jones and B. Gagnon, IOT)

The International Northern Sea Route Programme (INSROP) is a five-year multi-disciplinary and multilateral research programme that commenced on 1 June 1993. The three principal cooperating partners are Central Marine Research and Design Institute (CNIIMF), St. Petersburgh, Russia; Fridtjof Nansen Institute (FNI), Lysaker, Norway; and Ship and Ocean Foundation (SOF), Tokyo, Japan. An initial study demonstrated the feasibility of using gas-filled, flat jacks with stiffened facing-plates to simulate first-year sea-ice loading on a ship's hull and a full-scale test program may be undertaken in the Russian Arctic in the winter of 1995.

In previous work, a series of large-scale loading experiments were conducted at Resolute, N.W.T. Vertical slots were cut in the top segment of the 1.8 m first-year ice sheet and the ice loaded using thin-walled metal flatjacks. Pressures in the 5–15 MPa range were sustained by the ice sheet. It was postulated that because the flatjacks were compliant no "hot spots" were generated in the interaction, resulting in high pressures. The new tests used the same loading apparatus but "rigid" indentors were inserted between the flatjack and the ice. Results showed similarly high pressures, except in previously damaged ice.

Sensitivity of deterministic ice-load model

(G. W. Timco and M. B. Irani, NRC)

Gulf Resources Canada Ltd. deterministic and probabilistic ice-load calculation models have been used to investigate the relative sensitivity of various parameters in an ice-loading event. For this, a realistic ice-interaction scenario of an impact on a structure by a large ice floe with embedded ridges was identified. The influence of floe size, ridge length, thickness and width, etc. was determined using the deterministic model.

Interaction with ice-control booms

(G. W. Timco and A. Cornett, NRC)

A test program for the Canadian Coast Guard investigated the behaviour of ice booms in Lac St. Pierre in the St. Lawrence Seaway. Tests were performed at model scale to assess different boom/cable connection systems and at full-scale to test the effectiveness of different beam shapes and sizes in containing the ice.

Flexural strength equation for sea ice

(G. W. Timco, NRC; S. O'Brien, MUN)

The measured flexural strengths of freshwater ice and sea ice have been compiled with the intention of correlating the measured results. 2495 data points from 19 investigators have been used. The correlation has been done as input for a new system being developed to characterize sea-ice properties rapidly. The results indicate a very good correlation between the flexural strength (σ) and the brine volume (v_b) with a functional form $\sigma = 1.76\, e^{-5.88\sqrt{v_b}}$ where the flexural strength is in MPa, and the brine volume is expressed as a brine volume fraction. The value of 1.76 MPa for zero brine volume is in excellent agreement with the average value (1.73 MPa) measured for freshwater ice.

Characteristics of crack formation in ice

(L. W. Gold, NRC)

Information on the characteristics of cracks formed in columnar-grain ice during loading in uniaxial compression is being gathered and analysis of statistical aspects is in progress.

Propeller/ice interaction

(S. Newbury and S. Jones, IMD)

Methods are being developed to calculate ice loads and ice-induced hydrodynamic loads on marine propellers operating in a full range of ice conditions. The conclusions are to be applied to the formulation of propulsion system loads for Canadian and Baltic ice class machinery protection regulations.

Shipboard ice properties system

(J. R. Rossiter, CANPOLAR; M. Mitch and R. Ritch, AR Engineering, Calgary; G. Timco, NRC)

An ice corer which can be deployed remotely from a ship (without requiring personnel on the ice) and a calibrated, computer-controlled, video system for estimating ice thickness from broken pieces of ice were designed and built.

Ice detection – East Coast

(J. R. Rossiter, CANPOLAR)

A team of experts has been assembled to determine the capabilities of instrumentation currently available, or expected to be available over the next 5–10 years, to detect and characterize sea ice and icebergs.

Ice flaking tests using a gas activator

(D. M. Masterson and P. A. Spencer, SANDWELL)

The use of a flatjack, a thin-walled, flat envelope of steel fitted into an ice slot and into which fluid or gas is pumped, makes it possible to load relatively large areas (up to 4.5 m^2) at relatively low cost. This method was used for strength tests on fresh-water ice at a high rate of loading, by using a gas filled activator/accumulator to supply the power. Stiff, 75 mm thick aluminum plates were used in conjunction with the flatjacks to examine the effects of "soft, compliant" and "stiff" systems. Undamaged ice and ice predamaged by loading with flatjacks only before testing were loaded to failure and very interesting and useful results for interpreting ice/structure interaction behaviour were obtained.

Ice–snow thickness monitoring system

(C. C. L. Tang, BIO)

An automated system to measure the change in ice and snow thickness of land-fast and drifting ice and obtain long-term data of ice/snow growth/melt rates for sea-ice distribution studies has been developed. It consists of two acoustic range finders, one in the air above the ice surface and one under the ice in the water. It can also be used in land-fast ice and inland lakes.

Sea-ice and snow thickness sensor

(J. R. Rossiter, CANPOLAR; J. S. Holladay and L. A. Lalumiere, GEONEX; S. J. Prinsenberg, BIO)

Work has been underway since the early 1980s to develop an fully operational helicopter-borne electromagnetic induction (EM) sensor to measure sea-ice thickness. The technology has been tested over a variety of ice types in the Canadian Arctic and off the East Coast, with uniform results. Typical snow- and ice-thickness accuracy is ± 0.1 m or $\pm 5\%$, measured at speeds up to 50 m s^{-1} and altitudes of approximately 30 m.

A ground-penetrating radar (GPR) system has been used to estimate snow thickness alone. Two successful trials have been conducted over dry Arctic snow and wet maritime snow. Absolute accuracy is limited to about $\pm 30\%$ because of the wide range of speeds of the radar signal through different snow types. Integration of this system into an EM sensor package is on-going.

ATMOSPHERIC ICING

Creep properties of spray ice

(L. Domaschuk, ENG/MAN)

Creep properties of samples of spray ice under isotropic and deviatoric components of stress are being investigated in the laboratory using triaxial compression tests.

Atmospheric icing of structures

(J. A. Druez, UQAC)

Work includes studies of the mechanical properties of glaze, rime and spray-ice and of the icing of structures, cables and transmission lines.

Abbreviations not listed in ICE (1991) 97, 17-18.

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MTO = Ministry of Transportation, 1201, Wilson Avenue, 3rd Floor, Downsview, Ont, M3M 1J8
NBEPC = New Brunswick Electric Power Commission, 515 King Street, Fredericton, NB, E3B 4X1
NCC = NW Community College, 130 First Avenue West, Prince Rupert, B.C., V8J 1A8
NORLAND = Norland Science and Engineering Ltd., Shaunavon, SK, S0N 2M0
QUEEN'S = Queen's University, Kingston, Ont, K7L 3N6
SANDWELL = Sandwell Inc., 10 Fl., 940 6 Ave. S.W., Calgary, Alta, T3B 4H7
SFU= Simon Fraser University, Burnaby, B.C., V5A 1S6
UAk = University of Alaska, Fairbanks
UQAR= Université du Québec à Rimouski, 310 Allée des Ursulines, Rimouski, PQ, G5L 3A1
VIC = University of Victoria, P.O. Box 3050, Victoria, B.C., V8W 3P5

Submitted by T.D. Prowse

SOUTH AFRICA

(J.N.J. Visser, Dept. Geology, Univ. Orange Free State, Bloemfontein 9300)

A spatial and temporal reconstruction of the Permo-Carboniferous glaciation (265–310 Ma) in southern Africa has been completed. Up to 800 m of glacial sediment was deposited during the marine glaciation in the south and a highland glaciation towards the north. The Gondwana Ice Sheet is being reconstructed for this period.

(C.A. Lewis, Dept. Geography, Rhodes Univ.)

Protalus ramparts, formed during the Quaternary on the Drakensberg Plateau, by small permanent snow fields, have been positively identified.

FINLAND

PHYSICS OF ICE

Friction on ice and snow

(L. Makkonen, P. Paasivuori and S. Liukkonen, Technical Research Centre of Finland (VTT))

A new theory, based on surface energy considerations, to explain some basic mechanisms of friction on ice and snow has been developed. Relationships between the friction coefficient of skates and the mechanical properties of ice have been studied under laboratory conditions. The effect of electric current on friction on ice has also been studied. The frictional component of ice resistance to ice-breaking vessels has been modelled numerically.

Surface of ice

(L. Makkonen, VTT)

It has been shown experimentally that the contact angle of water on ice is very much greater than 0° in contrast to earlier beliefs. A consequence of this finding is that the conventional theory on the origin of the liquid-like layer on an ice surface becomes obsolete. A new mechanism, unique to ice, for the existence of the liquid-like layer has been proposed.

Freezing and icicle growth

(L. Makkonen, VTT)

A theory that quantifies the spacing of primary dendrites growing into super-cooled liquid has been developed. Using this theory it is possible to show that the liquid fraction of spongy ice (mushy zone) in ice growth is quite insensitive to the conditions of growth.

Development of understanding and modelling icicle growth has continued by improving the model parameterizations and including a theory of icicle spacing. Measurements of icicle growth in cold rooms and a wind tunnel have been made together with Hokkaido University (ILTS) and Hokkaido Electric Power Co. in Japan.

Sea-ice morphology and dynamics

(M. Leppäranta, Dept. of Geophysics, University of Helsinki)

Basic research is undertaken on the morphology and dynamics of sea ice. The work is experimental as well as theoretical. Morphological studies have concentrated on sea-ice ridges, their physical properties, evolution, and spatial statistical characteristics; the experimental data are from the Baltic Sea. Dynamics has been studied as theoretical background research for the development of sea-ice dynamics models. the role of various possible ice rheologies and the ice–ocean coupling problem have been the main considerations.

ICING

Ice adhesion

(L. Makkonen, E. Lehmus and P. Paasivuori, VTT)

Testing of potential ice-phobic coating materials has continued. The results have been applied to practical problems in navigation channels, road signs and wind turbines. The effects of electric current and surface roughness on ice adhesion had been studied by laboratory experiments.

Measurement systems

(P. Lehtonen, Finnish Broadcasting Co. and L. Makkonen, VTT)

Atmospheric ice loads have been measured in the field on a full-scale TV-mast, a specially constructed test mast and automatic ice detectors. The measurements include determination of wind-drag coefficients on iced structures. Video camera systems have been improved by including night-time recordings using infrared lights. The rotating multicylinder method to measure drop size and liquid water content in icing clouds has been developed and used. A new numerical method to analyse these data objectively has been derived. Comparisons betweeen icing rates on full-scale structures and ice-detectors have shown low correlations. Further tests on ice-detection instruments are planned.

Techniques to model atmospheric icing at a small scale have been developed together with NRC, Canada. Scaling laws have been derived. Preliminary results from wind-tunnel tests suggest that small-scale modelling can be very useful in practical design of structures for icing conditions.

Icing of wind turbines

(L. Makkonen, E. Peltola, VTT; M. Autti and J. Kaas, Kemijoki Oy)

Development of wind energy production technology for Arctic conditions has continued as a part of the Finnish National Programme of Advanced Energy Systems and Technology (NEMO). Icing of turbines is a major problem area. Solutions have been sought by developing climatological estimation methods for icing risk and by studying the potential of ice-phobic coatings and heating systems. A numerical model to simulate icing and ice shapes on wind turbine blades has been developed.

A small test turbine was mounted on a hill with a severe icing climate and tested in 1990–91. After analyzing the results a full-scale 220 kW wind turbine (blade length 12.5 m) was installed in October 1993 on the same hill. This machine is heavily instrumented with load cells, vibration sensors, video cameras, etc. and includes blade heating and ice-phobic coatings. The aim of this project is to demonstrate the technical and economical feasibility of wind energy production in Arctic conditions.

Ice detection on aircraft

(L. Makkonen, VTT; J. Eloranta, Finnair; J. Ekman, TKK)

Ice formation on aeroplane wings while on the ground has resulted in severe accidents due to ice-induced engine failure or aerodynamic penalties at take-off. Experiments were made in Finland during the winter of 1992–93 to develop and test a new ice-detection system by VibroMeter SA, Switzerland. In addition to ice detection, the system showed potential for monitoring the change in the properties of a mixture of ice and de/anti-icing fluids on a wing. The system is planned to give a cockpit warning if there is ice or adhered snow on the wings, or if the hold-over time of the de/anti-icing liquid is exceeded.

SEA ICE

Baltic Sea ice climatology

(M. Leppäranta, Dept. of Geophysics, University of Helsinki)

The variability of ice seasons in the Baltic Sea is quite

large. In the last 100 years the maximum annual ice coverage has ranged from 12% to 100% of the total sea area and the length of the ice season has ranged from 3 to 7 months. This variability is examined in a numerical modeling project in 1993–95 funded by the Academy of Finland. An advanced coupled ice–ocean model has been constructed for the Baltic Sea. The model is calibrated with historical data and used for climatological forecasting for the future ice conditions in the region, based on various possible scenarios for future atmospheric climate conditions.

Impact of pollutants on Arctic sea-ice biota

(J. Weissenberger, Arctic Centre, Rovaniemi, Finland)
This work examines the role of crude oil, heavy metals and organic pollutants in the life cycle of Arctic sea-ice communities. Field experiments are carried out using enclosed ecosystems filled with sea water and plankton organisms from the Arctic Ocean. It is planned to develop a model of the impact of polluted ice on the Arctic food web.

ICE COVER

Analysis of north Greenland climate over the last 1200 years

(J. C. Moore and A. Friedmann, Arctic Centre, Rovaniemi, Finland)
This project is a multinational collaboration between AWI, Germany, AC, Finland and BAS, UK. Four ice cores (100 and 150 m deep) were drilled along a line running north from Summit, Greenland to 78° N in 1993. Dielectric conductivity measurements were made in the field and have been used to identify dated volcanic horizons in the ice. These horizons have been used to construct accumulation rate values at about 50 year resolution for the last 1200 years. The records have been compared with climate records from Scandinavia and other northern areas using proxy climate indicators such as tree-ring widths, and sea-ice conditions. The data from this part of Greenland represent the first from this previously poorly studied area. Preliminary results suggest a significant modification to accumulation rate maps of north Greenland, and the distinctiveness of northeast Greenland climate from the rest of Greenland. More cores are to be drilled in the 1994 season.

Analysis of dielectric conductivity stratigraphy on the GRIP ice core

(J. C. Moore, Arctic Centre, Rovaniemi, Finland; colleagues from GRIP)
The dependence of the electrical conductivity (ECM and DEP) on chemistry for the GRIP ice core has been calculated. The two electrical methods can be used as a proxy for ice acidity in the Holocene, and for concentration of salts and acids during the Wisconsin. Spectral analysis of 2 cm resolution DEP profile is being undertaken. Early results seem to show the existence of century-period cycles at similar periods to those previously observed in ice cores and tree rings spanning more recent times than are available in the high-resolution GRIP ice core.

MISCELLANEOUS

Sediment cores in Svalbard

(H. Österholm, Åbo Akademi University, Vaasa)
Sediment cores were obtained from Lake Tvillingvatnet near Ny-Ålesund, Svalbard, in 1991. The altitude of the lake is 29 m a.s.l. The longest obtained sediment core was 64 cm. The bottom part of the core is about 8900 ^{14}C years BP. The diatom compound and the chemical characteristics of the sediments indicated lacustrine circumstances since the sedimentation of the bottom layer of the core. A layer of till, dated to the period 7700–5800 ^{14}C years BP, indicate a glacial advance. This conclusion is supported by a significant compaction of the sediments below the layer of till. The front of Austre Brǒggerbreen is only 1 km distant from the lake. The glacial advance over the lake was probably caused by surges of Austre Brǒggerbreen.

Sea-ice Summer School

An international summer school "Physics of Ice-covered Seas" was arranged in Savonlinna, Finland, 6–17 June 1994. The summer school was sponsored by local organizations, IAPSO, SCOR and NSF. About 150 people took part representing 23 countries. There were 30 lecturers, 70 undergraduate or postgraduate students, and 50 other active scientists. The lecture programme consisted of the basic physical theory, mathematical modelling and related disciplines; also evening seminars were arranged where the students could give brief presentations of their research work. A text book based on the lecture material is presently in preparation.

Submitted by Matti Leppäranta

B S WADDINGTON AND G K C CLARKE
Hydraulic properties of subglacial sediment determined from the mechanical response of water-filled boreholes

R S W VAN DE WAL AND J OERLEMANS
Response of valley glaciers to climate change and kinematic waves: a study with a numerical ice flow model

D J WINGHAM
A method for determining the average height of a large topographic ice sheet from observations of the echo received by a satellite altimeter

K W BIRKELAND, K J HANSEN AND R L BROWN
The spatial variability of snow resistance on potential avalanche slopes

T KONZELMANN AND R J BRAITHWAITE
Variations of ablation, albedo and energy balance at the margin of the Greenland ice sheet, Kronprins Christian Land, eastern north Greenland

S HASTERNRATH AND A AMES
Recession of the Yanamarey Glacier in Peru's Cordillera Blanca during the 20th century

J L FASTOOK, H H BRECHER AND T J HUGHES
Derived bedrock elevations, strain rates, and stresses from measured surface elevations and velocities: Jakobshavns Isbræ, Greenland

R B ALLEY, A J GOW AND D A MEESE
Mapping *c*-axis fabrics to study physical processes in ice

J KOHLER
Determining the extent of pressurized flow beneath Storglaciären, using results of tracer experiments and measurements of input and ouput discharge

C R WARREN, N F GLASSER, S HARRISON, V WINCHESTER, A R KERR AND A RIVERA
Characteristics of tidewater calving at San Rafael Glacier, Chile

JANSSON, P
Water pressure and basal sliding on Storglaciären, northern Sweden

Recent meetings (of other organizations)

MIDWEST GLACIOLOGISTS

The 3rd annual Midwest Glaciology Meeting was held at the Byrd Polar Center, the Ohio State University, 22–23 April 1994. It was organized by Gordon Hamilton and Christina Hulbe. It is often uncertain where the U.S. "midwest" is. Judging from the participants, it includes Wisconsin, Minnesota, Illinois, Ohio, Maryland, West Virginia, Virginia, Pennsylvania, New York, Massachusetts, Colorado, and California.

The 32 presentations covered a variety of subjects. A favorite topic, that led to spirited discussions, was deformation and mobility of till beneath the Pleistocene Laurentide and modern West Antarctic ice sheets, modern Storglaciären (Sweden), and Burroughs Glacier (Alaska). Everyone was enthralled by robot-recorded videos of moraine deposition in Glacier Bay (Alaska) and beneath Mackay Glacier (Antarctica). Recent progress towards understanding the West Antarctic ice sheet was also a popular topic. Presentations on that theme included ice-stream mechanics, the risks of approximations made in mathematical modelling, mass balance, ice-crystal fabric from hot-water drilled ice cores, radar polarization studies, subglacial till structure, temperatures in an interstream ridges, passive and active seismic studies, stream/ridge margin migration, and the possibility of horizontal variations in ice strength within an ice stream. While Antarctic questions were being answered, new puzzles arose in Greenland. Peculiarities in the new ice core and ice-penetrating radar profiles at Summit, and Synthetic Aperture Radar (SAR) observations of a possible ice stream in northern Greenland are mysteries waiting for solutions, An exciting new technique, SAR interferometry, may help answer modern ice-motion questions in Greenland and Antarctica. Climate change, as always, was a favorite subject. Of particular interest to MGM attendees was evidence of past changes in equatorial glaciers. All presentations were oral with no abstracts or manuscripts submitted.

Friday evening was spent socializing in a traffic jam and at the home of Ian and Emily Whillans, enjoying a buffet and a selection of beers from local micro-breweries. The 4th annual meeting is planned for late April 1995, and will be hosted by the Department of Geophysical Sciences at the University of Chicago, Chicago, Illinois.

Christina Hulbe

Glaciological Diary

1994

23-24 September
Inaugural meeting of the Polish Branch of the International Glaciological Society in conjunction with 21st Polar Symposium and the Polish Polar Club, Warsaw, Poland (Dr Jacek Jania, Katedra Geomorfologii, Wydzial Nauk o Ziemi, Uniwersytet Slaski, ul. Bedziska 60, Sosnowiec, 41-200 Poland)

26-28 September
Snowsymp '94, International Symposium on Snow and Related Manifestations, Manali, India (Lt.Col. S.G. Nair, HQ Snow and Avalanche Study Establishment, Manali, Distt Kullu (HP), India)

30 October-3 November
International Snow Science Workshop, Snowbird, Utah, USA (L. Fitzgerald, ISSW '94, P.O. Box 49, Snowbird, Utah 84092, USA)

1-6 November
3rd International Symposium on Glacier Caves and Cryokarst in Polar and High Mountain Regions, Chamonix, France (M. Griselin, GDR Recherches Arctiques, 70150 Bonboillon, France)

7-10 November
Dynamics of the Arctic Climate System, Gothenburg, Sweden (Prof. Leif Anderson, Inst. of Analytical and Marine Chemistry, Chalmers University, S-412 96 Gothenburg, Sweden)

7-9 December
XVII Symposium on Polar Biology: Sea-ice ecology, Tokyo, Japan (Dr Mitsuo Fukuchi, Nat. Inst. of Polar Research, 9-10, Kaga 1-chome, Itabashi-ku, Tokyo 173, Japan)

1995

5-8 February
10th International Symposium on Okhotsk Sea and Sea Ice, Mombetsu, Hokkaido, Japan (Secretariat, Okhotsk Sea and Cold Ocean Res. Assoc., c/- Dept. Planning and Coord., Mombetsu Municipal Office, Saiwai-2, Mombetsu, Hokkaido, Japan)

18-24 March
NATO ARW on Processes of Chemical Exchange between the Atmosphere and Polar Snow, Tuscany, Italy (Eric Wolff, British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET, U.K.)

mid April
Midwest Glaciology Meeting, University of Chicago, USA (D. R. MacAyeal, Dept. of Geophysical Sciences, University of Chicago, IL 60637, USA)

11-16 June
5th International Offshore and Polar Engineering Conference, The Hague, The Netherlands (ISOPE, P.O. Box 1107, Golden, CO 80402-1107, USA)

3-14 July
Symposium on Biochemistry of Seasonally Snow-Covered Catchments (ICSI/ICWQ/ICT) (K. Tonnessen, US National Park Service, Air Quality Division, P.O. Box 25287, Denver, CO 80225-0287, USA)

20-25 August
** IGS International Symposium on Glacial Erosion and Sedimentation, Reykjavík, Iceland (Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, UK)

18–22 September
* EISMINT International Symposium on Ice-sheet Modelling, Chamonix, France (P. Pirra, EISMINT, European Science Foundation, 1 quai Lezay Marnésia, F-67080 Strasbourg Cedex, France)

1996

24-28 June
Interpraevent 1996: Protection of Habitat against Floods, Debris Flows and Avalanches, Garmisch-Partenkirchen, Germany (Interpraevent 1996, c/o Bayerisches Landesamt für Wasserwirtschaft, Lazarettstr. 67, D-80636 Munich, Germany)

12-15 August
** Representation of the Cryosphere in Climate and Hydrological Models, Victoria, B.C., Canada (Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, UK)

27-31 August
* IX International Symposium on the Physics and Chemistry of Ice, Dartmouth College, Hanover NH, USA (Victor Petrenko, 8000 Cummings Hall, Dartmouth College, Hanover, NH 03755-8000 USA)

1997

14-18 July
** Antarctica and Global Change, University of Tasmania, Hobart, Australia (Secretary General, International Glaciological Society, Lensfield Road, Cambridge, CB2 1ER, UK)

** IGS Symposia
* Co-sponsored by IGS

NOTE FROM HILDA RICHARDSON

If you wish to communicate with me by letter, please use my home address which is:

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Assisted by D.M. Rootes and S. Stonehouse

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