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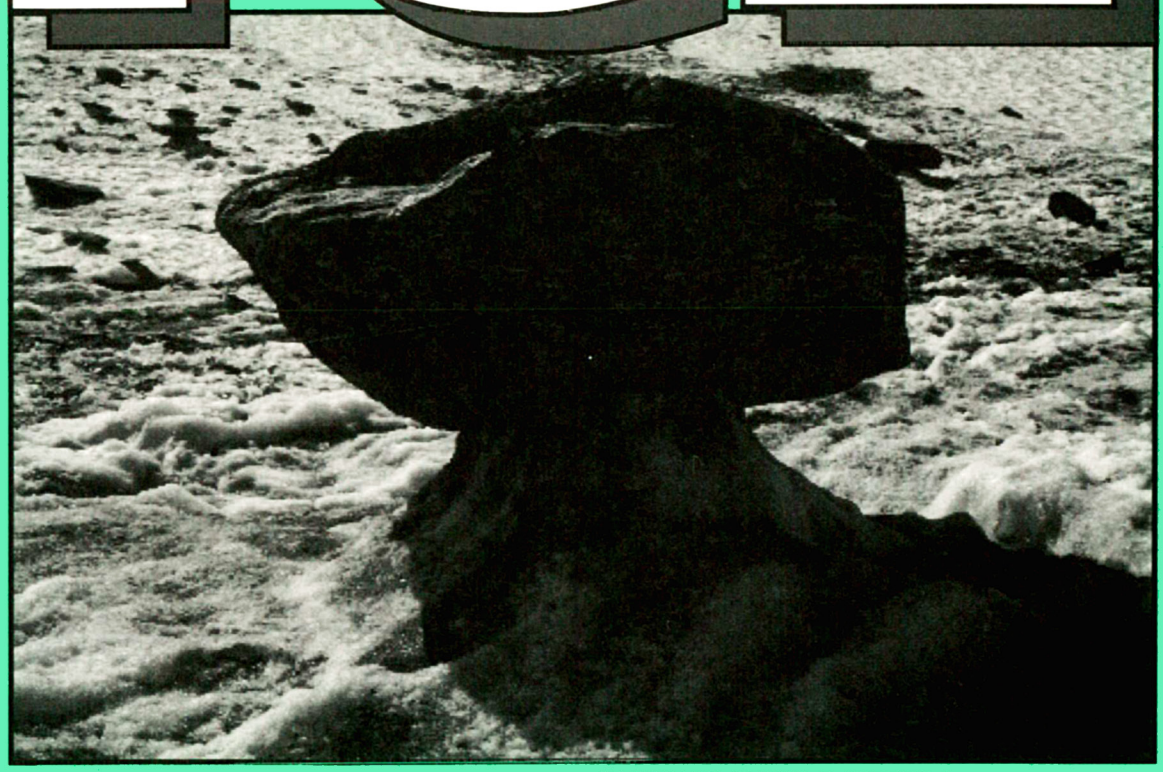

NEWS BULLETIN OF THE INTERNATIONAL GLACIOLOGICAL SOCIETY

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ICE

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COVER PICTURE: Glacier table on Griesgletcher, Vallis, Switzerland (Photograph by Françoise Funk-Salamí).

Scanning electron micrograph of the ice crystal used in headings by kind permission of William P. Wergin, Agricultural Research Service, U.S. Department of Agriculture

RECENT WORK

CANADA

(For abbreviations used see page 17)

SNOW — GENERAL

Reconstruction of Northern Hemisphere historical snow-cover extent, 1915–97

(R.D. Brown, MSC)

Historical and reconstructed snow-cover data from stations in Canada, the United States, the former Soviet Union and the People's Republic of China were used to reconstruct monthly snow-cover extent (SCE) fluctuations over mid-latitudinal (~40°–60° N) regions of North America (NA) and Eurasia back to the early 1900s using an areal snow-index approach. The station distribution over NA allowed SCE to be reconstructed back to 1915 for six months (November–April), along with estimates of monthly mean snow water equivalent (SWE) from gridded daily snow-depth data. Over Eurasia, SCE could be reconstructed back to 1922, but major gaps in the station network limited the approach to three months (October, March, April). The reconstruction provided evidence of a general 20th century increase in NA SCE, with significant increases in winter (DJF) SWE averaging 3.9% per decade. The results are consistent with an observed increasing trend in winter snow depth over Russia and provide further evidence for systematic increases in precipitation over NH mid-latitudes. NA spring snow cover was characterized by rapid decreases during the 1980s and early 1990s, with a significant long-term decrease in April SWE averaging 4.4% per decade. Eurasia was characterized by a significant reduction in April SCE over the 1922–97 period, associated with a significant spring warming. The snow-cover reduction was statistically significant at the hemispheric scale.

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Canadian snow data CD-ROM

(R.D. Brown, MSC)

A CD-ROM compilation of Canadian daily snow-depth and snow-course data has been made available by the Climate Processes and Earth Observation Division of the MSC. The snow-depth data consist of daily ruler measurements of snow depth taken by MSC observers and archived as daily element 013 in the Canadian National Climate Data Archive. Also included are a substantial number of daily and weekly snow-depth observations digitized through a data-rescue effort supported by the CRYSYS project of EC. The depth data extend from the late 1800s to mid-1998, although most data are in the period after 1950. The data have been quality controlled and missing values filled.

The CD-ROM also includes snow-course data from snow surveys by more than 20 agencies at weekly, bi-weekly or monthly frequencies. The data cover the period from the mid-1950s to the mid-1990s, with a pronounced peak in the 1976–85 decade. It contains bi-weekly estimates of SWE derived by interpolating observed snow-course density information to MSC snow-depth observing stations. The CD-ROM is available free to universities, research institutions and government agencies for RESEARCH PURPOSES ONLY by registering at: http://www.msc-smc.ec.gc.ca/crysys/snow_CDROM_Registration.html

SNOW HYDROLOGY

Prediction technology for contaminant migration in ground-water systems

(J.M. Buttle, Geog/TrentU)

Fate of applied de-icing salt (NaCl) was determined from salt retention and loss in snow cover adjacent to a 14 km section of highway in southern Ontario during the 1994–95 winter. Total winter salt application was ~530 Mg (29 to 74 kg m^{-1} length). Salt retention in snow cover in the highway right-of-way (ROW) decayed as a power function of distance from the highway, although melting of proximal snowbanks with high salt loads disrupted this pattern. Peak concentrations reached 6506 (Na^+) and 9916 (Cl^-) mg L^{-1} in snowbanks adjacent to the road near the end of winter. Wind transport of Na^+ and Cl^- out of the ROW was minor and restricted to relatively exposed sites. Almost all applied NaCl reached the soil surface in the ROW via (1) direct runoff and infiltration of saline water from the road into the shoulder and ROW, and (2) transfer of salt to snow cover adjacent to the highway and release during snowmelt. Total salt flux along the two pathways during a 49-day period was similar. Salt transfer via road runoff occurred during or shortly after NaCl application, unlike the intermittent fluxes from snow to soil surfaces in the ROW during this period. The latter were relatively uniform along the highway (3–5 kg m^{-1} length of highway), and accounted for 39 to 65% of applied NaCl. However, magnitude and timing of water and salt fluxes from snow to soil varied within the ROW. Cation exchange with Ca^{2+} in near-surface soils most likely resulted in preferential retention of Na^+ relative to Cl^-, although total storage of NaCl in upper soil horizons by winter's end was <15% of de-icing salt applications.

An environmental tracer (^{18}O) was used to trace movement of saline meltwater through the unsaturated zone underlying the highway. Average meltwater particle velocities at a site underlain by loam soils were 0.02 m d^{-1}, and ~280 mm of water was displaced below a depth of 1.86 m over a 78-day period in the spring and summer of 1995. Na^+ and Cl^- concentrations in water sampled in late summer 1995 at depths >2m exceeded 500 and 1000 mg L^{-1}, respectively. Approximately 75% of the net flux of NaCl below the upper soil was retained in the 0–2.8 m depth interval at this site, and results

from more permeable soils traversed by the highway indicate an even greater penetration of the annual NaCl application into the unsaturated zone along the moraine. This saline water likely recharges ground water in this portion of the Oak Ridges Moraine.

http://ivory.trentu.ca/~jbuttle/

SNOW/ICE ECOLOGY

Dissolved oxygen declines in ice-covered rivers

(P.A. Chambers, A. Pietroniro, NHRC)

Downstream declines in dissolved oxygen (DO) occur in ice-covered rivers as a result of limited re-aeration, inputs of oxygen-depleted ground water and oxidation of organic matter. Municipal and industrial development decrease under-ice DO concentrations due to high biochemical oxygen demand. The start-up of a bleached kraft mill beside the Athabasca River in 1957 was associated with the lowest late-winter (February–March) DO concentrations ever recorded. Improvements in mill technology since 1977 coincided with increases ($P<0.05$) in late-winter DO concentrations and an amelioration in both the magnitude and downstream extent of the DO sag. Application of a 1-D steady-state river water-quality model (DOSTOC), using historic data, simulated observed DO well for most years, with coefficients of determination (r^2) ranging from 0.51–0.92. A review of oxygen conditions in ice-covered rivers throughout the world showed DO concentrations decreased linearly with distance below effluent outfalls for most river reaches with effluent concentrations >1%. DO depression in ice-covered rivers increasing with distance downstream raises concern about safeguarding oxygen levels in northern rivers, especially with increasing development there.

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Organochlorine transport to glacier-fed lake

(M. Lafrenière, M.J. Sharp, EAS/UAlb; D. Schindler, Biol/UAlb; J. Blais, Biol/UOtt)

Industrial pollutants and agricultural pesticides, carried long distances in air masses, are being deposited in alpine lakes in the Canadian Rocky Mountains. Especially high concentrations of these organochlorine contaminants (OCs) are found in glacier-fed lakes. Bow Lake, Banff National Park, is the most highly contaminated of the lakes surveyed in the Rockies. The nature and concentration of contaminants transported to the lake depend on water sources and flow routing, so contaminant fluxes should vary between glacial and non-glacial catchments. The influence of water sources and hydrological processes on the transport of organochlorine contaminants is being determined by comparing water sources and hydrologic flow routing in the glacial and non-glacial stream catchments around Bow Lake.

http://arctic.eas.ualberta.ca

SNOW AVALANCHES

Snow-slab mechanics, avalanche forecasting

(Bruce Jamieson, Civil/UCal)

Field studies at Rogers Pass and near Blue River, B.C. are identifying index properties associated with the strength of surface-hoar layers based on analysis of shear strength, photographs of disaggregated grains, in situ microphotographs and preserved specimens. The measurements will be used to model change in the strength of surface-hoar layers. The resulting strength-change model will be incorporated into the *Crocus* snowpack-evolution model. The necessary conditions for fracture initiation and propagation through weak snowpack layers will be identified. A finite-element model for slab and weak layers will improve the skier-stability index which will be assessed with field measurements from skier-triggered slab avalanches.

http://www.eng.ucalgary.ca/Civil/Avalanche/

Avalanche Research Group, UBC

(D. McClung, Geog/UBC)

The work is focused in three areas: (1) interaction of avalanches and forest cover; (2) avalanche forecasting techniques, and; (3) avalanche engineering. For (1), information on 300 avalanches connected with clear-cut logging have been collected; British Columbia has >10,000 clear-cuts estimated to have been affected. Risk-based methods are used to minimize or eliminate the environmental damage. For (2), forecasting and decision techniques are being addressed for large scales, as encountered by helicopter-skiing operations. Fine-grid (2–3 km) weather forecasts are being verified to link improved weather forecasts to avalanche forecasts. For (3), risk-based methods have been assembled for avalanche mapping in land-use planning and methods developed to estimate return period far into the runout zone from empirical/statistical methods of runout prediction.

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RIVER ICE

Streamflow variability in ice-covered rivers

(R.D. Moore, Geog/UBC; A.S. Hamilton, MSC; T. Ouarda, INRS)

A quantitative understanding of the nature and causes of streamflow variability under an ice cover, and improved methods based on hybrid conceptual–statistical models for operational estimation and forecasting of winter hydrographs under ice cover, are being developed. A regional analysis of archived Water Survey of Canada discharge measurements under ice conditions has been conducted for Yukon. One conceptual hydrologic model has been applied to the M'Clintock River near Whitehorse. When updated with two winter measurements per year, the model output gives good estimates of winter streamflow, based on comparisons with measurements not used in the updating.

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LAKE ICE

Climate sensitivity of thaw lakes, Yukon

(C. Duguay, LTMEF)

Old Crow Flats (68° N, 140° W) lies north of Old Crow, Y.T., near the northern limit of the Taiga Cordillera Ecozone. The basin contains ~2,000 lakes 0.5–4700 ha in size. The lakes are extremely shallow, 1–1.5 m deep

to a maximum of ~4 m. The entire basin is underlain by permafrost ~60 m thick, except for unfrozen zones (taliks) under most of the larger lakes. The sedimentary basin is underlain by massive ground ice.

Time series of remotely sensed images and ancillary ground-truth data are used to quantify contemporary changes in the areal extent and water level of the thaw lakes, and the spatial and interannual variability of those lakes that freeze completely to the bottom each winter and those that do not.

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Climate response of lake-ice parameters

(C. Duguay, LTMEF)

The response of lake-ice parameters (freeze-up/break-up dates and ice thickness) to climate variability and change in Canada is being described, explained and predicted by: (1) determining whether there are consistent interannual and long-term changes in lake-ice parameters; (2) assessing determinants of mean freeze-up/break-up dates and ice thickness, and identifying determinants of temporal coherence of lake freeze-up/break-up for selected regions; (3) predicting potential impacts of projected climate change on lake-ice parameters, particularly in Arctic Canada, and; (4) developing remote-sensing methods for determining lake freeze-up/break-up dates and ice thickness for climate monitoring.

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SEA ICE

Numerical modelling of pack ice

(M. Sayed, A. Barker, G. Timco, CHC)

The Kulluk, a moored, floating vessel used for drilling in the Beaufort Sea, was numerically simulated in moving pack ice under varying conditions (pack-ice velocity, ice thickness and surrounding ice concentration). The angle of internal friction and a reference ice-strength parameter were varied to investigate the effects of these two modelling parameters on peak loads. The numerical results were compared, with good agreement, to the measured loads obtained on the Kulluk.

http://www.chc.nrc.ca

Centrifuge modelling of sea ice

(S.J. Jones, IMD; R. Phillips, R. McKenna, M. Lau, C-CORE)

A project is underway to determine the success of a centrifuge in modelling the interaction of sea ice with a structure. Both sea ice and fresh-water ice have been grown successfully in the C-CORE centrifuge and their strength properties measured. A model cone has been towed through an ice sheet and the forces acting on it measured. Results compare favourably with those from model cone tests in IMD's ice tank.

http://www.nrc.ca/imd/

ICE TUTOR — a tool for ice forecasting

(S. Bourque, R. Chappell, CIS; S. Thomas, NRI)

The Canadian Ice Service worked with Noetix Research Inc. to develop the first 2 modules of a multimedia learning tool for training new personnel in visual recognition and SAR imagery interpretation. CIS has now partnered with Noetix Research and the National Naval Ice Centre to produce 3 additional modules — ice physics, remote sensing (AVHRR, SSM/I and OLS) and geography.

Automated ice-tracking algorithm

(K. Wilson, CIS)

The Tracker algorithm has been running automatically on CIS operational areas since the fall of 1999. Its near-real-time turnaround (under 2 hours after reception of RADARSAT data) provides a useful resource for operations and a powerful input into the CIS ice model. To date ~1200 ice-motion products have been generated and archived. Tracker products are valuable as a research tool in regional Arctic climate studies. For the International North Water Polynya experiment, the Tracker algorithm produced >148 ice-motion images in the Baffin Bay region from January–December 1998. The annual ice dynamics in the region are being mapped to determine if the polynya is maintained by wind-driven ice motion. Tracker products are being used in a study on the state of the Arctic cryosphere during the extreme warm summer of 1998 and to monitor the flow of ice through the Queen Elizabeth Islands, which may have a significant impact in shipping in more southerly latitudes in summer seasons with an increase in mobile ice.

Monitoring decay of first-year sea ice

(R. De Abreu, CIS; D. Barber, CEOS; R. Frederking, M. Johnston, CHC)

The Canadian Ice Service is defining the seasonal decay of first-year sea ice to support current and future operational activities. Of special interest are changes in the physical properties of the ice volume and the resultant appearance within optical, thermal and active microwave remote-sensing imagery. Techniques will be developed whereby the seasonal decay of sea ice can be reliably monitored and reported on within CIS products. To date, seasonal decay of first-year sea ice has been categorized and characterized by the University of Manitoba. CIS, working with CHC, is relating these categories to change in ice strength and developing techniques whereby these categories can be reliably related to sea-ice remote-sensing signatures.

Operational ice modelling

(T. Carrieres, D.H. Tran, CIS; T. Yao, S. Prinsenberg, C. Tang, BIO; M. Sayed, CHC; S. Savage, McGU.; G. Crocker, BC)

The Canadian Ice Service is upgrading its operational ice-forecast models. Through the Community Ice–Ocean Model Framework, coupled dynamic–thermodynamic sea-ice and ocean models run routinely in several regions. Data assimilation efforts are being led mainly by BIO. A new sea-ice module, developed at CHC and McGill using particle-in-cell methodology, is being tested and refined and will replace the standard Eulerian module. A new iceberg model is also under development. This builds on the existing operational model, developed by the International Ice Patrol, adding and refining a number of key physical parameterizations and environmental forces. The CIS product suite is being improved and expanded with particular emphasis on Canada's East Coast.

Canadian Archipelago fluxes

(S. Prinsenberg, J. Hamilton, G. Fowler, D. Greenberg, BIO)

Heat and freshwater fluxes passing through channels of Canadian Archipelago are being studied. The fluxes will be quantified in order to better understand their contribution to the total fluxes leaving the Arctic, and to the water-mass and heat budgets of the Arctic Ocean itself. The fluxes will also serve as a calibration dataset to validate regional and global climate models of atmospheric–pack-ice–ocean coupling and simulate the variability and global-warming effect of the Arctic perennial ice-cover extent and the North Atlantic circulation and fisheries.

Moorings: The mooring arrays deployed in August 1998 in Lancaster Sound were all recovered and redeployed. Arrays consist of ACDPs (2) monitoring the total 200 m water column and 5 self-contained CTD units monitoring water properties at 5 depths (30, 40, 100, 150 and 185 m). Special high-accurate 3-axis flux-gate compasses had to be installed within the ADCP float packages due to the proximity of the magnetic pole. For the 1999–2000 deployment, the ADCPs and flux-gate compasses were electronically connected to synchronize their sampling routines. Since the freshwater and heat fluxes increase towards the surface, much of the total water-column flux is missed with the present instrumentation. To overcome this, a subsurface mooring housing a CTD profiler is being designed to profile surface (0–50 m) water properties. Upward looking sonars (ULS) will also be used to monitor ice flux. The 1999/00 instruments were recovered and redeployed for a third time. Results from 1998–99 show that tidal and mean currents are similar to those measured to the west in Barrow Strait in the early 1980s. There is a strong seasonal cycle in the current, salinity and temperature fields from open-water to land-fast ice conditions. Atmospheric forcing (5–6 day period) is felt over the total water column, but weakens during winter when the area is ice-covered.

Modelling: A finite-element model has been used to simulate barotropic transports through the Archipelago in response to a 10 cm surface setup of the Beaufort Sea relative to Baffin Bay. The simulated transports correspond well to the values known. The simulated transports are 0.6 Sv for Lancaster Sound and Nares Strait, and 0.2 Sv for Jones Sound. Tides in the Archipelago are affected both by Arctic and Atlantic tides. Model tidal-height simulations compare well with observations and show that the stronger Atlantic tide affects the Archipelago water level past the shallow sills and interferes there with the weaker Arctic tide.

http://www.maritimes.dfo.ca/science/ocean/seaice/home.htm

Labrador/Newfoundland Shelf ocean and pack-ice variability

(S. Prinsenberg, Ingrid Peterson,T.Yoa, BIO)

Some elements of a program to monitor freshwater and heat fluxes in the ocean and pack ice moving southwards along the Labrador coast at Hamilton Bank are being implemented. They are thought to be important components of the North Atlantic Oscillation and the Atlantic Thermohaline Circulation. The location coincides with the southern end of the WOCE CTD line to Greenland.

Winter surveys obtained CTD profiles through the ice across Hamilton Bank to monitor variability in the cold intermediate layer that reaches its maximum extent at the end of the ice-growth period. Helicopter-borne sensors are acquiring statistics on ice thickness, surface roughness and ice concentration; all used to enhance RADARSAT SAR classifications. Pack-ice extent variability has been studied using CIS's weekly composite ice charts, related to atmospheric and ocean parameters. Numerical models are being developed to forecast short-term ice properties for CIS, to study seasonal evolution of the pack ice under present and global-warming atmospheric conditions, and to assess the interaction of surface waves and ice. Instruments are being acquired or developed to monitor ice drift and ice draft through moored arrays at selected stations

COLD OCEAN AND POLAR ENGINEERING

Ice loads on Confederation Bridge

(R. Frederking, I. Kubat, CHC)

The Canadian Hydraulics Centre has developed a simple and reliable system for measuring the response of the Confederation Bridge piers to ice and wind loading. The system deploys 2 tiltmeters — one at the waterline and the other close to the top of the pier. The CHC measured and recorded pier tilts over 83 days. Information on wind, current and ice drift was also obtained. A method to separate load components, due to wind and ice loading, has been developed. An analysis was carried out to investigate the pier response due to ice loading. These data, together with the magnitude of the wind and the current velocity, enabled the evaluation of pack-ice pressure in ice adjacent to the bridge.

http://www.chc.nrc.ca

NRCC ice-load catalogue

(G. Timco, M. Johnston, R. Frederking, CHC)

The CHC has developed an "Ice Load Catalogue" that contains the full details of over 500 events of ice loading on offshore and coastal structures. It contains information on the time-based behaviour of the load, as well as details of the ice conditions during each loading event. A complete range of structures is included in the catalogue, including bridge piers, light piers, wharves, dams, offshore structures and natural islands. This Ice-Load Catalogue is by far the most comprehensive source of information on actual ice loads on offshore and coastal structures.

http://www.chc.nrc.ca

Bergy-bit impact

(R. Gagnon, S.J. Jones, A. Derradji, B. Hill, IMD)

A major study is underway at IMD to understand the impact of a ship with a small iceberg or bergy bit. Oil tankers, taking oil from the Hibernia development on the Grand Banks of Newfoundland, traverse an area where bergy bits are common in spring/summer and may not be visible due to fog or high seas. The project

involves: (1) hydrodynamic tests of artificial bergy bits and a tanker in the IMD towing tank; (2) impact tests of a real growler with an instrumented plate in the ice tank, and; (3) a full-scale impact experiment with a ship and bergy bit. Phases (1) and (2) have been completed and the data are being analyzed. In addition, uniaxial compression tests on iceberg ice have been conducted over a wide range of strain rates. Historical records of sea-ice extent and iceberg numbers have been compiled, as well as records of ice–ship collisions.

http://www.nrc.ca/imd/

USCGC *Healy* ice trials
(S.J. Jones, C. Kirby, C. Meadus, IMD)
IMD participated in a major international project to measure the performance in ice of the new American icebreaker, USCGC *Healy*. The ice properties, thickness and strength, encountered by the ship were measured in collaboration with scientists from CRREL.

FROZEN GROUND

Behaviour of fine-grained frozen soils close to the melting point
(B. Ladanyi, CIN/EP)
At temperatures close to fusion, the rheological behaviour of frozen and unfrozen clays is often quite similar, especially in the primary-creep range. In ice-rich frozen soils, as long as the strength is governed mainly by pore ice, the so-called "long-term strength" will tend to zero with time, or disappear at an infinitely slow strain rate. In ice-poor frozen soils, containing large quantities of unfrozen water, and in unfrozen normally consolidated undrained clays, the long-term strength has a finite value, supplied by friction and mineral cohesion. In the latter case, it is logical to expect that the Cam-Clay model, not ice/metal creep theories, will govern the creep, long-term strength and relaxation behaviour in both types of materials. The basic similarities and differences in the creep and strain-rate behaviour of frozen and unfrozen soils are being explored, and sound geomechanical principles for the prediction of the long-term behaviour of frozen clays and silts at temperatures close to the melting point are being established.

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Deep-seated hill-slope creep in permafrost
(A. Foriero, Civil/ULav; B. Ladanyi, CIN/EP; S.R. Dallimore, P.A. Egginton, F.M. Nixon, GSC)
Attempts have been made to simulate hill-slope creep at a site near Tuktoyaktuk, N.W.T. This site is unique in that the deformations occur within a massive ice body, forming the core of a 30 m high concentric hill approximately 1200 m × 700 m. The simulation model is based both on an extension of a closed-form solution originally proposed by Haefeli for 2- and 3-D ice caps and a finite-element creep analysis. The solution covers cyclic temperature fluctuations and incorporates spatial variations of the temperature-dependent creep parameters. Results of simulations are compared with in situ measurements of creep displacements in the hill.

Frost-heaving stresses acting on a pile
(B. Ladanyi, CIN/EP; A. Foriero, Civil/ULav)
Foundation piles embedded in frost-susceptible soils can be subjected to large uplift forces resulting from frost heaving of soils. These forces can cause an upward vertical displacement of piles that are not embedded sufficiently deep below the frost depth, or do not have sufficient resistance to counteract the heaving forces. It is important to be able to predict the magnitude and distribution along the pile of these frost-heaving forces. This study proposes an approximate, but closed-form, solution for calculating the magnitude and the development with time of adfreeze frost-heaving forces acting on a pile, that combines the effects of frost-penetration rate, heave rate and soil temperature at any depth along the pile and at any time.

Permafrost field tests and their use
(B. Ladanyi, CIN/EP)
Several types of test most frequently used in permafrost have been reviewed and evaluated in terms of their respective advantages and drawbacks in performance and application. In particular, the scope and the value of data each test is able to furnish have been evaluated, and their potential use in the design of foundations in permafrost addressed. The tests are: the cone-penetration test; the pressuremeter test; and the sharp-cone test. Possible correlations between these direct field methods and some non-destructive ones, such as the apparent electrical-resistivity method, are being explored.

Frozen-soil mechanical-properties database
(B. Ladanyi, CIN/EP)
A literature review reveals that although a number of experimental studies of frozen-soil mechanical-properties have been published in the last 25 years, the data are presented in many different forms, so are difficult to compare and apply to various frozen-ground problems. Some recently published data on mechanical properties of frozen soil are being presented in a standard form, making it possible to express, for a given soil type, the combined effects of temperature, density, ice content and confining pressure. Eventually, the results of each experimental study currently published will be presented on user-friendly standard data sheets, each containing only essential information on the tested soil and the tests performed.

Rheology of ice/rock mixtures
(B. Ladanyi, CIN/EP)
This project deals with: (1) the effect of ice/rock interface roughness on adfreeze strength and creep of glaciers. It combines the rheology of ice with information on the shear along irregular rock surfaces, available in rock mechanics literature, and; (2) the large-scale shear strength of ice/rock mixtures. The project will combine all available information on shear of frozen granular materials to improve the knowledge base.

Active-layer monitoring, Mackenzie Valley
(M. Nixon, F. Wright, GSC)
In 1993 and 1994 the Geological Survey of Canada augmented about 30 active-layer monitoring sites established

between 1990–92 on a transect in the Mackenzie River Valley from Fort Simpson to the Arctic coast with automated, paired air- and ground-temperature instrumentation. In 1994, 1997 and 1999, several ground-temperature cables were installed near Fort Simpson and Norman Wells to refine modelling of permafrost in these important areas. Loggers record temperatures several times each day, allowing calculation of *N* factors for each site relating air to ground temperature. These values, along with other data, can be used in quantitative models to map the distribution and thickness of permafrost and to investigate the impact of various climate-change scenarios on permafrost. Over 60 sites are presently active, spanning the entire transect, and up to 9 years of data are available. Ten representative sites have been accepted by the international permafrost community as part of the Circumpolar Active Layer Monitoring System (http://www. geography. u c.edu/~kenhinke/ CALM/). Current activities include data collection, site maintenance, and ground-temperature profile measurement to refine modelling in the discontinuous permafrost zone.

http://sts.gsc.nrcan.gc.ca/permafrost/index.html

Permafrost research in northern Quebec

(M. Allard, R. Fortier, CEN)

In July 2000, 20 holes were drilled through permafrost near Umiujaq, Nunavik, to obtain cores and install geophysical instruments. The aims are to: (1) observe the cryostratigraphy in permafrost that aggraded in marine sediments following land emergence (from isostatic rebound) and interpret the sequences of ground-ice layers and sediments in terms of the processes of permafrost formation; (2) obtain samples of ice and trapped gases for chemical and isotopic analysis; (3) obtain temperature records along thermistor arrays that provide 3-D temperature fields in permafrost and obtain groundwater-pressure measurements at the base of permafrost in order to calibrate heat- and mass-transfer models of permafrost growth and regime; (4) provide open-access holes for determining geophysical properties, namely acoustic and electromagnetic, of the permafrost, and for long-term monitoring of those internal properties in parallel with climate-induced thermal changes; (5) interpret and model the process of formation of palsas and like permafrost mounds, and; (6) explain permafrost characteristics and features now found in sea-bottom conditions, as the recent emergence of these marine sediments may be an analogue for early glacial emergence of marine sediments in other Arctic regions.

Three sites were drilled and instrumented: (1) a (mineral) palsa consisting of a circular mound 50 m in diameter and 3 m high (the surface is pitted with mud-boils, and ice lenses up to 50 cm thick were found to 11.5 m depth in homogenous marine silts); (2) a 14 m high permafrost mound that probably formed when permafrost invaded a spur between two pre-existing gullies (consisting of silt sediments with scattered boulders and some sandy layers, ground ice of lenses and reticulated ice and soils grading into stratified sand near the permafrost base, about 21 m deep), and; (3) a 2.5 m high sandy mound with thick ice beds (up to 35 cm) at depths from 5 m to 14 m in silty layers and at the stratigraphic contacts between sand and silt layers. The permafrost grew in a sequence of glaciomarine sediments.

Glacier–permafrost interaction, Bylot Island

(B. Moorman, ES/UCal)

The investigation on Bylot Island involves examining the linkages between glacial and permafrost hydrological systems, the burial and preservation of glacier ice, and the stability of permafrost under changing environmental conditions. Several new techniques are used including combining differential GPS and ground-penetrating radar surveys to create 3-D maps of glacier thickness, englacial- and subglacial-drainage systems and buried ice. Electrical-resistivity imaging techniques are being developed for mapping the 3-D thermal structure of the ground and the distribution of massive ice. A low-temperature experimental facility has been constructed at the University of Calgary to enable numerical and physical modelling of field conditions. The facility includes a walk-in freezer, currently housing a scale model (1.5 × 3 × 2 m) of permafrost, massive ground ice and a buried pipeline. Two pumping constant-temperature baths enable precise control of the pipe temperature and the thermal field surrounding it. The facility also has an automated control and monitoring system that enables experimentation under controlled dynamic conditions. Currently, a number of experiments are being undertaken in the facility to test the scalability of geophysical techniques.

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Illisarvik bibliography

(C. Burn, Geog/CU)

An internet bibliography of the nearly 50 reports and published papers covering research at Illisarvik is available at: http://www.nwtresearch.com/illisarvik. Illisarvik is the experimental drained lake on Richards Island in Canada's western Arctic. The experiment, conceived by Ross Mackay, began in 1978 and is continuing. The bibliography lists the full citation and abstract of all articles. It was compiled by Margo Burgess (GSC), Ross Mackay (UBC) and Chris Burn (CU), and is hosted by the Aurora Research Institute, Aurora College, N.W.T.

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National permafrost databases

(S. Smith, M. Burgess, GSC)

The Geological Survey of Canada has published a ground-temperature database for northern Canada (Open File 3954) providing a baseline summary compilation of data acquired over the last 30 years. The national database includes information from published and unpublished sources for 656 sites, 526 of which are in the permafrost region. Most sites are abandoned and currently inactive. Site characteristics, such as air temperature, snow cover and vegetation that influence the ground-temperature regime, have also been compiled. The entire database is presented as an Excel spreadsheet. Maps and graphs illustrate site distribution, near-surface ground temperatures and other attributes. The web-based version is currently under development and Phase I of the project is available at http://sts.gsc.nrcan.gc.ca/tsdweb/geoserv_new.asp/. Upon completion, access will be through the GSC permafrost web site.

http://sts.gsc.nrcan.gc.ca/permafrost/

GSC High Arctic permafrost observatories

(S. Smith, M. Burgess, GSC)

Ground temperatures to 60 m depth have been measured regularly since 1978 at five sites at Alert, Nunavut (82.5° N, 62.4° W). These are the most northerly permafrost monitoring sites in the world and the 22-year dataset is one of the longest records of permafrost temperatures in Canada. An analysis incorporating the last decade of observations is being undertaken and the instrumentation and sites are being serviced and upgraded. Ground-temperature cables were connected to data loggers and air and ground surface temperature sensors were installed at three sites. Preliminary analysis indicates that air temperatures have generally increased since 1986, accompanied by an observed rise in permafrost temperature in the upper 15 m. Snow cover is generally thin to absent here, but exhibits high spatial variability which may be an important influence on the response of shallow permafrost temperatures to changes in air temperature. Data were also recovered from data loggers near Eureka and on Lougheed Island. The record of permafrost temperatures to depths of 60 m from 1991–1997 is now available for analysis.

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Coastal studies in permafrost environments

(S. Solomon, GSC)

The Geological Survey of Canada has been examining the effects of environmental forcing on rates of coastal erosion on the Beaufort Sea coast. Historical data have revealed decadal-scale cycles in storm events which cause storm surges and wave-induced erosion. Ice-chart data over 30 years reveal a trend towards increased open-water periods, especially during the past decade. During the last field season, a late-summer storm resulted in a 2.2 m storm surge (return period of about 10 years). The surge was especially interesting in light of the abundance of ice in the region. Despite the construction of new shore protection at Tuktoyaktuk, flooding and localized severe erosion took place. At nearby Tuktoyaktuk Island, a thermo-erosional notch, 2 m high and 10–15 m deep, was cut at the base of the cliffs over the 24 hours of the storm.

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Permafrost/Glaciers/Ice Caps Monitoring Network Workshop, Ottawa, January 2000

(M. Burgess, S. Smith, GSC)

The GSC convened a National Permafrost/Glaciers/Ice Caps Monitoring Networks Workshop in Ottawa, 28–29 January 2000 to provide input for Canada's Global Climate Observations System (GCOS) plan for the cryosphere. The workshop was attended by some 50 participants and focused on requirements for coordinated national networks to observe the climate-change signal, assess its regional variability, and evaluate its impacts in permafrost . The final report of the workshop will be available on the GSC's permafrost web site and released as a GSC Open File. See also report below by Demuth and Koerner.

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GLACIER DYNAMICS/ICE-SHEET MODELLING

Cause and mechanics of Trapridge surges

(G.K.C. Clarke, EOS/UBC)

The Trapridge Glacier study is tracking changes that occur as the glacier enters its next phase of surge activity. Emphasis is on year-round continuous observation of subglacial mechanical and hydrological processes. At present, more than 250 sensors are installed in and on the glacier. Winter 1999–2000 was marked by a dramatic, but short-lived, mechanical event occurring in mid-December.

http://www.geop.ubc.ca/Glaciology/Trapridge.html

Dynamics and environmental controls of glaciers and ice sheets

(S.J. Marshall, Geog/UCal; G.K.C. Clarke, EOS/UBC)

We are studying the dynamics of glaciers, ice sheets, and ice–climate interactions, with a focus on subgrid process description in continent-scale models. This includes: (a) the development of a continuum mixture framework for portraying ice-stream thermomechanics in large-scale models; (b) development of surface hydrology routing schemes to simulate continental runoff in the Quaternary; (c) development of subgrid mass-balance and ice-dynamics schemes to describe regional ice fields and alpine glacier distributions in a continent-scale model, and; (d) algorithm development for incorporating longitudinal stress coupling in ice-sheet models, to improve their skill in simulating regional ice fields.

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Greenland ice sheet modelling studies

(S.J. Marshall, Geog/UCal; K.M. Cuffey, Geog/UBC)

We are examining the paleoclimatic and ice-sheet history in Greenland by testing and reinterpretating ice-core climatic records, and modelling implications for the ice sheet. Conversely, ice-sheet modelling can be used to examine flow characteristics (e.g. strain rates) at the ice-core sites. These are needed for accumulation-rate reconstructions. Work has concentrated on the Eemian ice sheet and the Last Glacial/deglacial transition in Greenland; following up the studies by Huybrechts and Ritz, but incorporating new insights from the ice cores.

Atmosphere–ice interactions, High Arctic

(T.M.H. Wohlleben, M.J. Sharp, A.B.G. Bush, EAS/UAlb)

Quantitative estimates of the magnitude of the ice–albedo feedback have been obtained for a High Arctic glacier catchment (isolated from surrounding ice caps) using a 2-way coupled ice–atmosphere model, where the ice beneath is static (not flowing) and the annual evolution of this areal feedback has been calculated. Secondary ice–albedo feedbacks have been identified, and non-linear interactions between the primary ice–albedo feedback and other processes are being noted. Repeat experiments using a dynamic glacier, instead of static ice, in the model will be carried out next. This research will provide a baseline against which to compare the warming amplifications predicted by global GCMs for the polar regions.

http://glacier.eas.ualberta.ca/trudy

ICE-CORE STUDIES AND PALEOGLACIOLOGY

Glacier-climate history: human remains

(E. W. Blake, IIInc.; A. Mackie, MSBTC; G. Hare, R. Gotthardt, AB/YG)

In August 1999, a group of sheep hunters discovered human remains on a small alpine glacier in northwestern British Columbia. With winter snow beginning to fall, a two-day recovery effort was launched and most of the archaeological material was collected. Radiocarbon dating of the hat and robe found with the body indicates an age of AD 1415–1445, which predates known direct contact with European or Asian peoples.

The remains were found in what appears to be a stagnant area of ice behind a series of bedrock bumps (exposed as nunataks today). Air-photo records suggest large amounts of melt since the 1950s. Investigations of ice-depth flow regime and melt rates are ongoing.

http://www.icefield.yk.ca/

Climatic history of the southwest Yukon using organic artifacts

(E. W. Blake, IIInc.; R. Farnell, RR/YG; G. Hare, R. Gotthardt, AB/YG)

In early September 1997, a pair of sheep hunters discovered an alpine ice patch covered with fecal pellets. One of the hunters was a caribou biologist who identified the feces as caribou. Since no caribou are currently found in the area, further investigations were made and a small wooden shaft fragment discovered. Since the site is well above treeline, this indicated human involvement. Shallow coring revealed layers of pellets within the ice. Radiocarbon dating of a pellet and the shaft gave uncorrected dates of 2450 BP and 4360 BP, respectively.

Subsequent investigations have revealed over 60 such sites in southwestern Yukon. Sampling at four sites has found fecal pellets ranging in age from modern to 8300 BP (uncorrected) and archaeological artifacts as old as 4700 BP (uncorrected). The artifacts are some of the oldest and best-preserved organic artifacts found in North America. Investigations of melt rates, radiocarbon dating, isotopic ratios, and structure are ongoing.

http://www.icefield.yk.ca/

Ice-core, climate, chemical, pollen, biological and other records, Canadian Arctic and Yukon

(D.A. Fisher, R.M. Koerner, M.N. Demuth, J.C. Bourgeois, C. Zdanowicz, J. Zheng, J. Sekerka, M. Parnandi, NGP)

The NRCan glaciology groups' ice-core programme dates back to the 1970s and provides information about the climate history of northern Canada on time resolutions of seasonal to millennial that extend to the Last Glacial/interglacial cycle. The ice-core studies add an important time dimension to more recent in situ and satellite-based climate monitoring, and place the modern trends in the context of past variability. The multi-proxy, multi-variable approach of ice cores allows cause and effect relationships to be established and provides, along with the records from tree rings and other climate-sensitive stratigraphies, a way of reconstructing the history of the Earth's climate in great detail over the last few thousand years. This information is critical for developing an understanding of the integrated response of the cryosphere to climate. A collaborative ice-core program, planned for Mt. Logan and surroundings, will throw light on the importance of the Pacific Northwest and the contrast between the Eastern and Western Arctic. Drilling programs are being planned for the Barnes Ice Cap (Baffin Island) and Mt. Oxford (Ellesmere Island). Two recent surface-to-bed cores from Devon Ice Cap are being analyzed.

Ultra-clean electro-mechanical drill

(D. Fisher, J. Zheng, NGP; E. W. Blake, M. Gerasimoff, IIInc.)

An ultra-clean drill, modelled on the Danish UCPH and GSC Hilda/Simon drills is being developed. The goal is to decrease by orders of magnitude the trace-metal contamination of the core by the drill. This will reduce the amount of cleaning required and increase the amount of core available for study. The drill uses pure titanium, HDPE, and tungsten-carbide components for those parts in contact with the ice core. The core is drilled into a pre-cleaned HDPE sleeve that also serves as a shipping tube. Field tests in 1999 and 2000 at Eclipse Dome, Yukon and Devon Ice Cap indicate improved core quality.

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Ultra-clean ice-core analysis

(J. Zheng, D. Fisher, C.M. Zdanowicz, NGP; W. Strachan, V. Cheam, G. Lawson, CCIW; Erik Blake, IIInc.; C. Ferrari, LGGE)

Accurate measurement of trace elements (e.g. metals) in ice cores requires that the contamination level of the cores prior to analysis be minimized. Existing in-laboratory decontamination procedures, although workable, are time-consuming and inefficient in terms of core utilization. A new ultra-clean, titanium-made ice-core drill was developed by GSC and Icefield Instruments Inc. to reduce trace-metal contamination resulting from ice-core drilling operations (see previous). Sample processing of the Devon Ice Cap core will be carried out by the NGP in a new Class-100 facility and samples will be co-analyzed jointly through several laboratories for quality control. This technology will be of interest to all researchers interested in the accurate measurement of trace-level impurities in ice cores.

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Holocene pollen records from Arctic ice caps

(J.C. Bourgeois, R.M. Koerner, D.A. Fisher, NGP)

A continuous Holocene record of pollen deposition was obtained from an ice core from Agassiz Ice Cap, Ellesmere Island. The pollen provides a record of primarily long-range atmospheric transport to the ice cap. Pollen concentrations, particularly tree pollen, were highest in the early Holocene, decreased in the mid-Holocene, and changed relatively rapidly after ca. 3500 years ago. In

the early Holocene, the pollen profile parallels the $\delta^{18}O$ and ice-melt records from the same ice core, indicating that the warmest summer temperatures occurred very early in the Holocene.The high concentration of tree pollen in the early Holocene, when large parts of Canada were still ice-covered and forest zones were generally farther away, implies that atmospheric circulation was stronger than now. The ice-core pollen records from Penny (Baffin Island) and Devon (Devon Island) Ice Caps (analyses in progress) could be of significant value to comprehensive studies of atmospheric dynamics and vegetation changes in the Arctic.

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Barnes Ice Cap, central Baffin Island

(C. M. Zdanowicz, D.A. Fisher, NGP, I. Clark, D. Lacelle, Geol/UOtt)

The Barnes Ice Cap is a remnant of the Laurentide Ice Sheet, to which it was joined about 8500 years ago. Pleistocene-age ice is known to outcrop along its margin. A stable-isotope ($\delta^{18}O$) chronology for the late Pleistocene–early Holocene history of Barnes Ice Cap is being developed by sampling basal ice layers along transects normal to the ice margin. Work began in July 2000 along the southwestern edge of the ice cap; 450 samples were collected for $\delta^{18}O$ analysis. The ease of access to the Barnes Ice Cap margin offers unique opportunities for sampling Laurentide ice for a variety of paleoenvironmental indicators (e.g. biological particles, trace gases, microparticles). Interested researchers are invited to contact the P.I. to discuss collaborative projects.

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Anthropogenic sulfate and nitrate trends

(K. Goto-Azuma, NIPR; R.M. Koerner, NGP)

Ice-core studies have shown that sulfate and nitrate concentrations in Arctic snow increased significantly since the end of the 19th Century due to the influx of anthropogenic pollutants from industrialized regions. Increasing sulfate and nitrate concentrations are evident in all the ice-core data from Greenland, the Canadian Arctic and Svalbard. Temporal patterns, however, show spatial variation. Around Dye 3, South Greenland, significant increases in sulfate begin in the 1890s; those in nitrate begin about 50 years later. A similar pattern is seen at Penny Ice Cap in the Low Arctic. In contrast, both sulfate and nitrate concentrations started to increase significantly in the 1940s on Agassiz Ice Cap, in the High Arctic and Snøfjellafonna, in Svalbard. At Summit, central Greenland and sites in North Greenland, sharp sulfate increases occur at about the turn of the 20th century and again about 1940 or 1950, where the latter increase is the greater of the two. At these central and North Greenland sites, significant increases in nitrate began about 1940 or 1950. The difference between the magnitude and timing of increasing trends of the sulfate ions at these sites can be attributed to the different source regions and pathways for these pollutant ions. The sources appear to be North America for South Greenland and Baffin Island, Eurasia for Ellesmere Island and Svalbard, and both North America and Eurasia for Central and North Greenland.

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GLACIER MASS BALANCE AND CLIMATOLOGY

Mass balance of White and Baby Glaciers, Axel Heiberg Island

(J.G. Cogley, M.A. Ecclestone, P. Adams, Geog/TrentU)

Annual mass-balance measurements continue on White Glacier and Baby Glaciers, extending records which date back to 1960. On White Glacier, the average balance during the 1990s, -278 ± -126 mm a^{-1}, was the most negative of the four decadal averages now available. This figure may be compared with the mass-balance normal of -100 ± -48 mm a^{-1} for 1960–1991. In support of the mass-balance programme, the history of retreat of the White Glacier terminus is being reconstructed from airborne and satellite imagery. Incomplete results show a stillstand during the 1970s, with retreat rates of a few m a^{-1} before and after. The adjacent terminus of Thompson Glacier has been advancing at least since 1948, but its rate of advance has slowed steadily.

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Global glaciology

(J.G. Cogley, P. Adams, Geog/TrentU)

A dataset containing annual mass-balance time series is being maintained. The data, obtained by direct or glaciological measurements, come from some 270 small glaciers around the world. Electronic files are available from ftp@trentu.ca/pub/gghydro. Statistical analysis suggests that, after the correction of biases, the mass balance of the small-glacier part of the cryosphere was slightly negative during 1960–1991 and may, in fact, have been at equilibrium. Supplementary datasets are in preparation for geodetic measurements of mass balance and for fluctuations of glacier length.

Field studies for mass-balance modelling of High Arctic glaciers

(D. Lewis, M.J. Sharp, EAS/UAlb)

Extension of mass-balance field results demands numerical modelling of glacier responses to climate change. However, a lack of datasets relating to processes critical to mass balance, such as refreezing of meltwater in the snowpack, often means the processes are incorrectly parameterized, leading to incorrect estimates of mass losses from glaciers. To provide the necessary datasets, field studies on processes controlling the mass balance of John Evans Glacier, Ellesmere Island (internal accumulation and effects of wind distribution on patterns of snow accumulation) are being conducted. Studies on Prince of Wales Ice Cap, Ellesmere Island, will determine whether recent surface-elevation changes, detected by airborne laser altimetry, are due to long-term climate trends, short-term climate-related mass-balance variability, or long-term trends in ice dynamics.

http://arctic.eas.ualberta.ca/

Climatology of Arctic islands ice caps

(C. Labine, EAS/UAlb, CSC; B. Alt, BEA; R.M. Koerner, NGP)

Previously, ice caps in the Canadian High Arctic were visited once a year and mass-balance analysis performed.

A project to establish a long-term climatology for the ice caps in the Canadian High Arctic Islands and understand the climate regime during the entire year was started in 1988. Initially, automatic monitoring stations were established on Agassiz Ice Cap and visited and serviced annually. Subsequently, they have been established on the Devon, Meighen and Melville Ice Caps. The project is focused on retrieving, quality controlling and archiving the data. Associated with the project is an ongoing evaluation of measurement techniques and sensors to solve the problems associated with automatic monitoring in these remote and harsh environments.

Canadian Glacier Variations Monitoring and Assessment Network

(M.N. Demuth, R.M. Koerner, NGP; D.S. Munro, Geog/UTorE; R.D. Moore, Geog/UBC; J.G. Cogley, W.P. Adams, M. Ecclestone, Geog/TrentU; M. English, C. Hopkinson, CRRC; John Taggart, WSB/AE; R. Drurey, TAU; F. Weber, BCH)

The Canadian Glacier Variations Monitoring and Assessment Network (CGVMAN) is a government-university-private sector effort centered on observing three glaciers in the Cordillera (Peyto, Place, Helm) and six glaciers and ice caps in the eastern Arctic (Devon, Agassiz, Meighen, Melville, White and Baby). Field sites provide infrastructure and support for university researchers.

Data reports and assessments for the CGVMAN glaciers are provided through the WGMS's Internet site (annual), Glacier Mass Balance Bulletins (biennial) and the Fluctuations of Glaciers reports (quinquennial). An internet page for the network is being finalized.

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Mass wastage of Peyto Glacier in relation to North Pacific synoptic climate influences

(M.N.Demuth, NGP; A.Wallace, C. Hopkinson, CRRC; B.H. Luckman, Geog/UWO; R. Keller, WSB/AE)

The Pacific Decadal Oscillation (PDO) has been associated with North Pacific climate variability and the advection of moisture over the Cordillera. It appears to modulate climate over similar spatial scales to ENSO, but over markedly different temporal scales. Coherence between circulation anomalies, the PDO and the winter balance of Peyto Glacier is noteworthy. The PDO warm phase appears to manifest meridonal flow of dryer air into the Cordillera in winter and generally warmer summers. The cold phase corresponds with strong moisture advection over the Cordillera in winter and summers that are generally cooler. The instrumental record (e.g. temperature) for the central Canadian Rockies extends back to the late 1880s. Coupled with the strong PDO relationship to winter-balance variability, it should be possible to reconstruct seasonal and net mass-balance time series back to 1896 when Walter Wilcox first photographed Peyto Glacier. This would complement data on past-century mass wastage derived from morphostratigraphic information and historical maps and photographs.

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Wedgemount and Overlord Glaciers, B.C.

(Karl Ricker, RC; W. Tupper, Consultant, BC)

Glacier variations and volumetric fluctuations of Wedgemount Glacier have been monitored annually by terrestrial and aerial stereophotogrammetry since 1976, and from 1991 by field baseline measurements. Observations of Overlord Glacier (13 km southeast), surveyed biennially to annually from a baseline, began in 1996. Recent studies have focused on the impact of El Niño/La Niña cycles. Wedgemount retreated 30.9 m during the 1997/98 El Niño and Overlord 13.3 m. Thinning of Wedgemount exposed an underlying riegel below the equilibrium line. During the 1999/2000 La Niña, Wedgemount's recession slowed to 15.6 m, whereas Overlord showed a scant 1.6 m retreat. In 1999, Wedgemount retreated 5.6 m, while Overlord advanced 1.2 m. The total recession of Wedgemount Glacier from the Little Ice Age climax to 2000 is ~1314 m; for Overlord (300 m lower with the same aspect) it is ~1036 m. The latter is closer to Pacific maritime air masses, so the snowpack may be thicker and denser than that of Wedgemount.

Permafrost/Glaciers/Ice Caps Monitoring Network Workshop, Ottawa, January 2000

(M.N. Demuth, R.M. Koerner, NGP)

See also report above by Burgess (Permafrost). The final report of the glacier/ice cap working group will be released as a GSC Open File and available on the GSC's glaciology web site: http://sts.nrcan.gc.ca/glaciology/

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GLACIER HYDROLOGY AND HYDROCHEMISTRY

Biogeochemical transformations of organic carbon in glacial systems

(J. Barker, M. Sharp, EAS/UAlb)

Glacial sediment contains organic carbon incorporated from soils and vegetation overridden during glacier advances. Organic carbon provides the substrate for heterotrophic microbial respiration in subglacial and tundra environments. The CO_2 flux to the atmosphere from microbial respiration in the active layer of tundra is significant and is implicated in global warming. This contribution could be enhanced by continued warming and glacier retreat. The organic carbon budget and net CO_2 flux in Arctic and alpine glacier systems is being investigated and quantified and the significance of glaciated, deglaciated and recently deglaciated terrain for the terrestrial CO_2 flux assessed.

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Strontium in runoff from glacierized terrain

(M. Sharp, R.A. Creaser, M. Skidmore, EAS/UAlb)

The relationship between subglacial chemical weathering processes and the Sr-isotope composition of runoff from Robertson Glacier, Alberta, has been investigated. The glacier rests on predominantly carbonate bedrock of Upper Devonian age. The provenance of solute in meltwaters varies systematically with solute concentration and subglacial-water residence time. In dilute waters, it is principally calcite dissolution fueled by protons from the dissolution of CO_2 and subsequent dissociation of

carbonic acid. At higher solute concentrations, dolomite dissolution coupled to sulfide oxidation is more important. Contrary to the global riverine trend, both Sr concentration and $^{87}Sr/^{86}Sr$ increase with total solute concentration. This indicates both an absolute increase in the amount of Sr derived from carbonate weathering, and a proportional increase in the contribution of radiogenic ^{87}Sr from weathering of K-silicate minerals, in the more concentrated waters. Although the ammonium acetate exchangeable Sr in tills is enriched in ^{87}Sr relative to local carbonate bedrock, only the more concentrated meltwaters display a similar enrichment. The most dilute waters, which probably transport the bulk of the dissolved Sr flux from the glacier, have $^{87}Sr/^{86}Sr$ characteristic of local carbonate bedrock. Results suggest that although enhanced weathering of silicate minerals with high levels of radiogenic ^{87}Sr occurs in glaciated carbonate terrains, it is unlikely to contribute significantly to the proposed enhanced flux of ^{87}Sr from glaciated continental surfaces to the oceans.

http://arctic.eas.ualberta.ca

Composition of meltwaters draining a polythermal glacier

(K. Heppenstall, M.J. Sharp, EAS/UAlb)

Natural ionic and isotopic tracers are being used to monitor the seasonal evolution of the subglacial drainage system within a polythermal glacier (John Evans Glacier, Ellesmere Island) and its relationship to the behaviour of the ice-marginal and supraglacial drainage systems. This will provide the hydrological context for ongoing studies of the flow dynamics of the glacier and their relationship to the basal thermal regime. Regular samples were collected from the snowpack, several supraglacial channels, ice-marginal lakes and the subglacial outflow. They were analyzed for major ions and for tritium and cosmogenic sulfur-35. Chemical data suggest the supraglacial and subglacial drainage systems are closely interconnected, and that the subglacial drainage system becomes more efficient throughout the melt season, with reduced residence times and different dominant chemical signatures. Provisional results from tritium analysis indicate an increasing contribution from ice melt as the season progresses. Sulfur-35 results are awaited at present.

http://arctic.eas.ualberta.ca/

Hydrometeorology of a High Arctic glacier

(S. Boon, M.J. Sharp, EAS/UAlb)

Field studies of the glacier drainage system at John Evans Glacier, Ellesmere Island, are being used to guide the development of a melt–runoff model for a polythermal glacier. The model will be used to investigate glacio-hydrological response to climate trends and variability of the last 50 years, and to predict the hydrological impact of future climate trends. Summer meltwater drainage is initiated by a subglacial outburst flood fed by pulsed inputs of stored water from the supraglacial system. Over the past six years, it seems that a sequence of unusually warm summers has resulted in progressive evolution in the efficiency of the subglacial drainage system and in the proportion of the supraglacial drainage network connected to it. This behaviour may provide an analogue for the possible impact of global warming on the drainage systems and runoff behaviour of Arctic glaciers.

To date, we have collected two seasons of hydrological data, and six years of meteorological data from 3 stations on the glacier. Preliminary results have clarified the mode of drainage-system evolution and demonstrated the crucial role of the filling and draining of surface depressions and pits in controlling the delivery of water from the glacier surface to the glacier bed. Modelling these processes will be a major challenge for the creation of the lumped hydrological model.

http://arctic.eas.ualberta.ca/sarah

Effects of glacier changes on streamflow and water quality

(R.D. Moore, Geog/UBC; M.N. Demuth, NGP)

Monitoring sites for discharge and water quality (temperature, suspended sediment and water chemistry) have been established on Place Creek and on adjacent Eight Mile Creek. The two catchments have similar aspects, drainage areas and elevation ranges, but Place Creek is headed by Place Glacier whereas Mile Creek is not glacier-fed. Place Glacier is monitored for mass balance. Over the longer term, Eight Mile Creek will serve as a reference for interpreting the effects of changes in Place Glacier on Place Creek.

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Melt impacts on ocean salinity

(Karl Ricker, RC; for Legacy Fish Foods Ltd. and Entech Environment Consultants Ltd.)

Glacier and snowmelt runoff from Vancouver Island's highest mountains (2200 m a.s.l.) was evaluated by analyzing 40 years of oceanographic data for Nootka Sound, and adjacent fjords and hydrometric records from the Gold and Zeballos Rivers, for an aquaculture project in Muchalat Inlet. Halibut and sablefish can only tolerate limited fluctuations in sea-water salinity and thrive at temperatures below 11°C. Copious runoff suggests the Inlet is not ideal for this venture.

Climate change impacts on glacier hydrology

(M.N. Demuth, NGP; A. Pietroniro, NHRC; T.B.M.J. Ouarda, INRS; N. Crookshank, J. Yetter, CHC; J.-G. Zakrevsky, WSC/MSC)

Using a transect of basins within the North Saskatchewan River basin with a range of glacier-cover/climatological regimes, and accounting for variability in precipitation, it has been determined that catchment yields for the annual recession period (Aug–Nov) have been reduced significantly over the period of record (ca. 1950-present) and are commensurate with observed headwater extension (glacier retreat). Moreover, this reduction is observed despite general increases in the vertical flux of meltwater released by the glacier over the last several decades. The available morphostratigraphic evidence (e.g. moraines, trimlines) suggests the leeward-slope glaciers are accelerating towards a reduced stage not attained since the early Holocene warm interval. In any case, it appears that glacier-fed rivers are already experiencing the medium-to-long-term impacts of climate variability predicted by the IPCC. The entire annual hydrograph for the remaining catchments in the transect, and their meteorological variables, are being studied using statistical (classical and Bayesian) analysis and distributed hydrological modelling (WATFLOOD; EnSim-Hydrologic).

Quaternary geology, Coquihalla Mountain to Merritt, Cascade Mountains, B.C.

(K. Ricker, RC; for Forest Renewal B.C., Ministry of Forests)

Periglacial, glacial and other deposits for an area (~2300 km^2) straddling the Similkameen, Nicola and Coquihalla basins were mapped at 1:20,000. Deposits were linked to Glacial Lakes Quilchena,Tulameen, Similkameen, Juliet, Maka, Brodie, Tulaineen, Hamilton and Merritt. There are two withering glacierets on Coquihalla Mountain and glacierets have recently disappeared from nearby Yak Mountain; both active and inactive rock glaciers and other periglacial features were noted throughout the region above 1700 m a.s.l.

Catastrophic overtopping of a moraine-dammed lake, southern Coast Mountains

(S. Evans, GSC; J.J. Clague, Geog/SFU)

Proglacial Queen Bess Lake, southern Coast Mountains, British Columbia, partially drained on 12 August 1997 when its Little Ice Age moraine dam was overtopped and breached by a huge displacement wave. The wave was triggered by a large ice avalanche from Diadem Glacier, which clings to a steep rock slope above the lake. The ice avalanche (ca. 2.3 Mm^3) occurred during a warm period when large amounts of water were discharging from the base of Diadem Glacier. About 6.5 Mm^3 of water escaped from the lake, producing a flood that devastated the valley below the moraine dam. The flood wave was recorded 112 km downstream before entering the ocean. Diadem Glacier has undergone dramatic retreat since 1949 and, by 1996, had receded onto a steep rock slope above Queen Bess Lake.

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ATMOSPHERIC ICING

Ice properties and structural interaction

(J.A. Druez, ERIGS)

The following aspects of atmospheric icing are being investigated: (1) atmospheric icing measurements at the Mount Valin natural icing test site; (2) atmospheric icing simulation and tests in an environmentally controlled laboratory; (3) establishment and analysis of a database on icing; (4) mechanical behaviour of atmospheric ice, and; (5) icing of structures (ice accretion, persistence and shedding; ice and wind loads; statistical analysis and modelling; mechanical strength, design and reliability).

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REMOTE SENSING

SAR coherence images for terrain and environmental monitoring

(P. Budkewitsch, M.A. D'Iorio, P.W. Vachon, CCRS; W.H. Pollard, Geog/McGU)

Data from tandem ERS-1/2, repeat-pass ERS-1 and RADARSAT-1 from islands in the Canadian Arctic Archipelago were processed and scene coherence images generated from data pairs. Coherence images hold great potential for monitoring and mapping uneven distribution and changes in the snow cover. Although changes in the snowpack are different from year to year, general snow accumulation and wind patterns can be recognized. Phase decorrelation is also identified with areas where small amounts of ground movement have likely occurred. Mass wasting and processes in the active layer causing expansion or cracking are likely sources of temporal phase decorrelation. This important observation raises the possibility that coherence images can be used to closely monitor the freeze and thaw behaviour of the active layer in cold climates.

http://www.ccrs.nrcan.gc.ca

Operational detection of icebergs from SAR

(D. Flett, CIS; D. Power, C-CORE; R. Desh, IIP)

The CIS provides ice and iceberg information to marine users in Canadian waters. RADARSAT data are used as the primary operational data source for ice monitoring: although it is evident that icebergs (and vessels) can be seen, it is only used in an ad-hoc manner for extracting iceberg information. In 1999, the CIS initiated a three-year project, with C-CORE and the IIP, to use RADARSAT SAR to routinely detect and monitor icebergs off Canada's East Coast. C-CORE has developed an algorithm to automatically detect icebergs in RADARSAT imagery and discriminate them from vessels.

Previous RADARSAT iceberg detection work at C-CORE was limited to high-resolution fine-beam mode imagery (9 m resolution) which, although capable of detecting icebergs of roughly 10,000 tons and smaller, covers only a 50 km wide swath. It is desirable to detect icebergs over a larger area and, therefore, necessary to determine the detection capabilities of the wider-swath, but lower-resolution, RADARSAT modes. Validation programs are collecting detailed ground-truth observations and measurements of icebergs as near coincident as possible with RADARSAT acquisitions.

CICE-2000

(D. Barber, CEOS; K.W. Asmus, K. Wilson, R. DeAbreu, CIS; R. Frederking, M. Johnson, CHC)

The CIS participated in the University of Manitoba CEOS Collaborative Interdisciplinary Cryospheric Experiment (CICE-2000) from May–July 2000. This multi-year study in the Arctic Archipelago near Resolute Bay, Nunavut, has been ongoing since 1980. The recent focus was the evolution of melt ponds and their effect on the thermogeophysical properties of the snow and sea-ice cover as related to microwave scattering and emissions. The MSC Surface Based Radiometer (SBR) system was deployed in McDougall Sound to provide continuous measurements of the microwave emissions of the sea-ice/snow cover during the transition from winter to summer conditions. The SBR is a dual-polarized (vertical and horizontal) 19, 37 and 85 GHz radiometer system designed to be deployed on ships or terrestrial platforms and has been used in numerous sea-ice research campaigns. Data are being analyzed by UMAN graduate students, supervised by D. Barber.

Members of the CIS, in a collaboration with CHC and Transport Canada (TC), used a borehole jack system to measure the mechanical strength of sea ice during CICE-2000. This work was in support of the TC project to incorporate sea-ice decay information into the Arctic Ice Regime Shipping System (AIRSS).

http://www.chc.nrc.ca

ICETANK 2001

(M. Shokr, MSC; K.W. Asmus, CIS)

Starting in November 2000, CIS will be undertaking a collaborative research activity with M. Shokr of the Data Assimilation and Satellite Meteorology Division (MSC, Downsview) at the NRCC Ice Tank facility to measure microwave radiation/emission and physical properties from artificially grown sea ice. This is a follow-up project to one undertaken during the winter of 1998–99. The MSC SBR System will be deployed from mid-November –January 2001 to collect passive-microwave data at 19, 37 and 85 GHz (vertical and horizontal polarization). CIS personnel will collect data on the physical properties of the ice and snow cover. The objective is to develop empirical relations between microwave brightness temperature of thin ice vs ice thickness and salinity, to use in a model to estimate the thickness of thin ice by combining observations from SSM/I and AVHRR under cloud-free sky.

Validation and correlation of RADARSAT imagery with ground-truthed sea-ice ridges

(M. Johnston, G. Timco, R. Frederking, CHC)

The feasibility of using RADARSAT ScanSAR scenes to identify first-year ridges was investigated for the CIS. Scenes of the northern Gulf of St. Lawrence were validated using CHC field measurements of seven first-year ridges off the west coast of Newfoundland, sampled in March 1999. Results show small areas of ridged ice can be identified on ScanSAR imagery when the immediate surroundings consist of relatively undeformed ice, level bay ice or calm, open water. However, individual ridges could not be distinguished from the surrounding deformed ice. The effects of ridge orientation and incidence angle upon the ice microwave signature were investigated. For the examined incidence angle range, ridge orientation has a greater effect upon the ice signature than small differences in incidence angle. For larger differences in incidence angle, ridges were more clearly identified in the far range than in the near range.

http://www.chc.nrc.ca

Augmenting the temporal resolution of remote-sensing data-driven snowmelt models

(D. Gratton, UQATR)

To enhance the potential of site measurements, particularly in inaccessible (high-mountain environments) or large areas, we are linking the point values to a radiation exchange model based on surface radiative parameters (albedo and thermal emission) using the spatial, spectral and temporal sampling potential of multispectral remote sensing. It permits a synoptic analysis of the radiation field and identifies crucial energy-exchange areas, particularly, how local topographical elements play a critical role in both shortwave and longwave radiation exchange processes. Unfortunately, the time span between image acquisition can be too long for weekly monitoring of surface-radiation exchange and meltwater production. To solve the temporal problem, we propose a "spatialized" model adapted to coarse spatial resolution heterogeneous pixels which have a high daily acquisition rate (e.g. NOAA-AVHRR imagery). The model would consider a pixel region covered with various homogeneous net-radiation surfaces computed once from the fine-spatial resolution imagery, and estimate the individual parameters required for modelling the net radiation at the coarse spatial resolution.

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Ice strain rates from interferometric SAR

(L. Gray, A. Khananian, CCRS)

It is being ascertained whether interferometric SAR data can be used to calculate and map ice strain rates.

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Uncertainty in glacier mass balance

(M.N. Demuth, NGP; E. Morris, SPRI; A. Pietroniro, NHRC;, Y. Arnaud, IRD; Th. Toutin, CCRS, J. Zwally, GSFC/G)

The confidence ascribed to recent assessments of global mass-balance variations has been questioned because of various size, hypsometric and situational biases, and the errors and limitations inherent in classical field approaches and documentation. An observation strategy is being developed, based on remote-sensing tools that will include an assessment of errors and calibration/validation requirements.

Airborne LASER mapping of Wapta Icefield

(M.N. Demuth, NGP; A. Pietroniro, NHRC; C. Hopkinson, CRRC; M. Sitar, Optech & CRRC)

Using an Optech LiDAR system, LASER-ranging data were collected and processed for a 5 km × 20 km area over Wapta Icefield from 4000 m a.s.l. LASER scans were configured for ±20 off nadir at 28 Hz and a LASER trigger repetition rate of 25kHz.

Research is being conducted to determine whether repeat ALTM, interferometric SAR (InSAR) surveys and glacier-dynamics modelling can be applied to smaller glaciers and ice caps for measuring mass balance and related glacier–climate parameters, and whether LASER intensity fields allow glacier-surface facies delineation.

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Airborne passive microwave and polarimetric radar remote sensing of snow cover

(J. Sokol, NRI; T.J. Pultz, CCRS; A.E. Walker, MSC)

Coincident airborne polarimetric C-band synthetic aperture radar (SAR) and microwave radiometer data at 19, 37 and 85 GHz were collected on 1 December 1997, 6 March 1998, 12 March 1998 and 9 March 1999, over two study areas in Eastern Ontario. Field measurements of snowpack properties and weather conditions were gathered along flightlines on bare agriculture fields during each flight. The multitemporal, multisensor data were analyzed with respect to changes in the SAR polarimetric signatures and microwave brightness temperatures as a function of changing snowpack conditions. Snow state and structure can be identified by comparing SAR and passive microwave values of derived snow parameters. Flightline profiles were generated for each acquisition, which show details on the fluctuation of brightness temperatures and radar backscatter due to variations of land-cover and snow conditions. Results indicate certain microwave parameters are more sensitive to changes in snowpack parameters and respond differently to various snow conditions.

http://www.ccrs.nrcan.gc.ca/ccrs/tekrd/radarsat/r2demo/demo7/oviewe.html

RADARSAT-1 "Stereo Advisor"

(T. Toutin, I. Cyr, CCRS)

The selection of a stereo pair from RADARSAT-1 is a challenging process for most users because various beams and modes (look angles and spatial resolutions) are offered The CCRS web-based "Stereo Advisor" helps users decide, based on recommendations of stereo images, explanations and comments related to the proposed application and study site.

http://www.ccrs.nrcan.gc.ca/ccrs/imgserv/advisor/advpg1e.html

Glaciers of the Canadian High Arctic

(J.G. Cogley, Geog/TrentU)

Glacier terminus fluctuations are being reconstructed from airborne and satellite imagery dating back to 1947. The initial focus is Axel Heiberg Island, where there are over 1100 glaciers. Early work is concentrating on the technical challenge of achieving rapid coverage of a large sample of terminuses. The aim is to provide a spatial context, at low temporal resolution, for mass-balance measurement records and for paleoclimatic time series from ice cores. A second project aims to exploit active-microwave (RADARSAT) and passive-microwave (SSM/I, SMMR) satellite imagery to estimate mass-balance components, particularly the duration and intensity of melting at regional scales.

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Dynamics and volumetric changes of ice caps

(D. Burgess, M. Sharp, D. Mair, EAS/UAlb)

Recent volumetric and areal changes of the Prince of Wales Ice Field and Devon Ice Cap are being measured and interpreted in terms of observed ice-flow dynamics and mass-balance estimates. Synoptic-scale changes will be obtained by comparing air photos from the late 1950s with measurements from recent satellite imagery. Velocity fields will be derived and calibrated from a network of differential GPS point velocity measurements. Features indicative of ice-sheet instability (e.g. ice streaming or glacier surging) will be analyzed from optical satellite imagery. Volume changes inferred from mass imbalances will be estimated by comparing ice flux towards the margins with accumulation measured across the ice-cap surface. The study will quantify changes of Prince of Wales Ice Field and Devon Ice Cap over the past 40 years and predict any potential contribution to sea-level rise based on observed patterns of ice-mass response to recent climate trends. Progress to date includes: orthorectification and mosaicing of 1999 Landsat 7 imagery; ice margins for Devon Ice Cap mapped from 1999 Landsat 7 imagery; orthorectification of 1/3 of the 1960's airphotos of the Devon Ice Cap margin.

Peace River ice monitoring

(F. Weber, D. Nixon, BCH)

In Spring 2000, BC Hydro, with RADARSAT International, conducted a capability pilot project for ice monitoring the Peace River near the town of Peace River. Information on the ice front, intensity of frazil-ice production, open-water leads, and snow and ice melt is required to operate the Williston Reservoir effectively and to reduce the risk of ice-jam-related flooding. In the past, ice information was collected from small airplanes.

Methodologies have been developed for deriving ice information and the operational use of near real-time products of RADARSAT satellite imagery. Six RADARSAT fine-beam scenes were acquired during the freeze-up and break-up period; four of which coincided with flights to provide "air truthing" of the ice characteristics supplemented by video and photo images. The most promising results were achieved by visual analysis of the RADARSAT images. The ice front and border ice are clearly visible. Open-water leads >6 m diameter, as well as shear lines, can be identified. Ice pans and floes can be detected, their concentration derived, and conclusions drawn on the intensity of frazil-ice production. Juxtaposed and secondary consolidated ice cover can also be distinguished. However, problems were experienced with the scheduling, as forecasting the ice-front location for the time of image acquisition is critical. Due to the morphology of the Peace River, backwater upstream of the ice front could not be derived from the imagery, but was detected by an experienced observer. RADARSAT imagery is highly suited for collecting a data library of ice information on a long-term basis. However, the logistics of scheduling and image processing still limit the real-time use of the data.

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ANTARCTICA

Velocities of Filchner Ice Shelf and tributaries from speckle-tracking interferometry

(L. Gray, CCRS; K. Jezek, BPRC)

Velocities of the Filchner Ice Shelf and its tributary glaciers have been derived using speckle-tracking interferometry. The method requires interferometric SAR data, a digital elevation model and an estimate of the height difference due to the tidal influence on the floating ice. Speckle-tracking interferometry has the advantage that ice speed and direction can be estimated from one interferometric pair and, with adequate coherence, is suitable for areas of high velocity and long repeat cycles. Flux rates for the ice shelf and its tributary glaciers have been calculated using the velocities and ice-thickness data derived from a hydrostatic equilibrium model. Filchner Ice Shelf is close to equilibrium with an output of 75.3 $km^3\ a^{-1}$. The flux rates indicate that Recovery Glacier is the largest contributor to the ice shelf (38%) and the Slessor Glacier the next (33%). Shackleton Ice Fall, Support Force Glacier and Foundation Ice Stream contribute 9%, 7% and 7%, respectively. Local accumulation accounts for the remaining 5%.

http://www.ccrs.nrcan.gc.ca/ccrs/tekrd/rd/apps/map/amm1e.html
http://www.ccrs.nrcan.gc.ca/ccrs/tekrd/rd/apps/map/amm1f.html

West Antarctic ice sheet interferometry

(I. Joughin, JPL; L. Gray, CCRS; R. Bindschadler, GSFC/G)

Interferometric SAR data from 1997 reveal an intricate pattern of tributaries feeding the Siple Coast ice streams and present-day positions of the grounding line around Crary Ice Rise. Comparisons with earlier studies suggest a slowing of Ice Stream B and an increase in the area of grounded ice around the Crary Ice Rise.

Flow rates of the Stancomb-Wills Glacier

(L. Gray, N. Short, CCRS)
Speckle-tracking interferometry is being used to map ice flow of Stancomb-Wills Glacier and its ice tongue.

Glaciologist and Parliamentarian visit

(W.P. Adams, Geog/TrentU)
As a guest of Antarctica New Zealand, which manages New Zealand's affairs in Antarctica, W.P. Adams visited Antarctica in support of strengthening Canada's involvement in Antarctica, particularly through increased co-operation between Canada and New Zealand on polar matters. Recommendations examined included Canada's ratification of the Protocol on Environmental Protection to the Antarctic Treaty, and becoming a full party to the Antarctic Treaty. The Canadian Polar Commission and the Canadian Committee for Antarctic Research encouraged this initiative.

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EXTRA-TERRESTRIAL GLACIOLOGY

Internal layers in an "accublation" ice cap

(D.A. Fisher, NGP)
Assuming the white areas of the North Polar Cap of Mars accumulate water ice and the dark scarp/trough spirals ablate and assuming there is ice motion from one type of zone to the other, the question is: "what do the isochrone layers look like internally and on the surface?" A simple 2-D time-varying isothermal model is used to demonstrate that the layering internally and in the ablation zones is strongly determined by the migrating scarp system and that waviness and discontinuities are to be expected in the internal layering and in the surface expressions of the layers on the ablation scarps.

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Model for "cottage cheese" lineations on North Polar Cap of Mars

(D.A. Fisher, NGP; H. Winebrenner, APL/UWA)
A model for producing the white area linear features is presented that relies on differential sublimation on various slopes, migration and joining of surface depressions, and on ice motion. The model steps through a number of related processes. It starts with an assumed field of round shallow depressions (pot holes) that experience different ablation rates on the S- and N-facing sides and which become elongated and/or migrate. The elongation and migration result in some of the depressions joining along a line at some angle to the pole. The spread of possible angles is initially symmetric on either side of the N pole, but ice motion and further differential ablation/accumulation rotates them preferentially, so that in some regions of the ice cap there is strong bias to lineations making a positive (clockwise CW) angle to the pole, and in others a negative or counter-clockwise angle. Some very large angles can be expected where the velocity field changes direction and has very large value. The large velocities are associated with the Chasme Boreale, and one can speculate how the inferred large velocities are generated by enhanced katabatic wind flow increasing sublimation accumulation.

INTEGRATED CRYOSPHERIC RESEARCH

Climate Change Action Fund

One component of this Fund is Science, Impacts and Adaptation that has funded several projects where glaciers and permafrost are a central or integral part.
http://www.climatechange.gc.ca/english/html/fund/index.html
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National Glaciology Programme

(GSC/NRCan; NHRC/NWRI)
In January of 1999, glaciological expertise and resources at NRCan (Eastern Arctic) and EC (Cordillera) were consolidated into the "National Glaciology Programme" within GSC's Terrain Sciences Division. Cooperation has enabled interdisciplinary research on climate-change detection, water resources and glacier/ice cap remote sensing, and the joint management of the Canadian Glacier Information Centre which houses the Canadian Glacier Inventory and related archives. The NGP delivers glacier-climate data and assessments to international programmes, such as WGMS and IASC.

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Use of the Cryospheric System to Monitor Global Change in Canada (CRYSYS)

(B. Goodison, R. Brown, MSC)
CRYSYS is a Canadian contribution to EOS, hosted and currently funded by Canadian agencies and universities, and led by the Meteorological Service of Canada. Investigations use remote sensing, modelling, field studies and data integration to monitor the state of the cryosphere, and improve understanding of cryospheric processes and variability. Goals are to: (1) monitor and understand regional and larger-scale variations in cryospheric variables; (2) develop and validate local, regional and global climate/cryospheric models, and; (3) to assemble, maintain and analyze key historical, operational and research cryospheric datasets. Components cover sea ice, lake and river ice, snow, permafrost and glaciers/ice caps.

http://www.msc-smc.ec.gc.ca/crysys/

Investigation of the 1998 Arctic summer

(B. Alt, BEA; CRYSYS Investigators)
1998 was likely the warmest year in the instrumental record since the mid-19th century. This investigation considers the variation of the cryosphere in Arctic Canada during 1998, including glaciers, sea ice, snow cover, permafrost and related climatology.

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Climate change in Nunavut

(B. Alt, K. Parlee, BEA; K. Parlee, CDN-NU;
B. Lavender, GSC)
Past, current and projected climate in Nunavut, along with impacts related to glaciers and sea-level rise, human activities, the landscape and its flora and fauna, have been illustrated as a public outreach project.

http://www.nrcan.gc.ca/gsc/education_e.html

Collaborative-Interdisciplinary Cryospheric Experiment (C-ICE)

(D.G. Barber, CEOS)

C-ICE has been established to address many of the uncertainties over global warming in the Arctic environment. It is a multi-year field experiment on sea ice in the central Arctic conducted since 1996, and from 1990–95 as the Seasonal Sea Ice Modelling and Monitoring Site (SIMMS). The main objective is to describe and estimate changes occurring in the marine cryosphere, and develop numerical models of processes operating within this environment using a continuum of scales from the micro to the regional. By coupling remote sensing and numerical process modelling, the observational data will be able to be "scaled-up" to the local and regional scales throughout the annual and interannual time scales of interest. We are beginning to understand the ability of the Arctic sea-ice system to respond to a CO_2-enhanced atmosphere.

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Contributed by Michael N. Demuth

Abbreviations used:

AB	Archaeology Branch (YG)
APL	Atmospheric Processes Laboratory (UWA)
BC	British Columbia
BCH	British Columbia Hydro and Power Authority
BEA	Balanced Environments Associates, Carlsbad Springs, Ont.
BIO	Bedford Institute of Oceanography (DFO)
Biol	Department of Biology/Biological Sciences
BPRC	Byrd Polar Research Center (OHSU)
C-CORE	Centre for Cold Ocean Research and Engineering (MUN)
CCIW	Canadian Centre for Inland Waters (NWRI) Burlington, Ont.
CCRS	Canadian Centre for Remote Sensing (NRCan)
CDN-NU	Canada–Nunavut Geoscience Office
CEN	Centre d'Études Nordiques (ULav)
CEOS	Centre for Earth Observation Science (UMAN)
CHC	Canadian Hydraulic Centre (NRCC), Ottawa
CIN/EP	École Polytechnique/Centre d'Ingénierie Nordique, Montréal, P.Q.
CIS	Canadian Ice Service (MSC)
Civil	Department of Civil Engineering
CRRC	Cold Regions Research Centre (WLU)
CRREL	Cold Regions Research & Engineering Lab., 72 Lyme Road, Hanover, NH 03755, U.S.A.
CSC	Campbell Scientific Corporation
CU	Carleton Univ., Ottawa, Ont.
DFO	Department of Fisheries and Oceans
EAS	Earth and Atmospheric Sciences
EC	Environment Canada
EOS	Department of Earth and Ocean Sciences
ERIGS	Équipe de Recherche en Ingénierie du Givrage des Structures (UQAC)
ES	Department of Earth Sciences
Geog	Department of Geography
Geol	Department of Geology
GSC	Geological Survey of Canada (NRCan)
GSFC/G	NASA Goddard Space Flight Center, Greenbelt, MD 20771, U.S.A.
IASC	International Arctic Science Committee
IIInc.	Icefield Instruments Inc., Whitehorse, Y.T.
IIP	International Ice Patrol, US Coast Guard
IMD	Institute for Marine Dynamics (NRCC), St. John's, Nfld
INRS	Institut National de la Recherche Scientifique-Eau (UQAQ)
IRD	Institut de Recherche pour le Développement (ex ORSTOM), La Paz, Bolivia
JPL	Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, U.S.A.
LGGE	Laboratoire de Glaciologie et Géophysique de l'Environnement, Grenoble, France
LTMEF	Laboratoire de Télédétection et de Modélisation des Environnements Froids (ULav)
McGU	McGill University, Montréal, P.Q.
MSBTC	Ministry Small Business, Tourism and Culture, B.C.
MSC	Meteorological Service of Canada (EC)
MUN	Memorial University of Newfoundland, St. John's, Nfld
NGP	National Glaciology Programme (GSC), Ottawa, Ont.
NHRC	NWRI at National Hydrology Research Centre (EC), Saskatoon, Sask
NIPR	National Institute of Polar Research, Itabashi, Tokyo, Japan
NRCC	National Research Council of Canada
NRCan	Natural Resources Canada, Ottawa, Ont.
NRI	Noetix Research Inc.
NWRI	National Water Research Institute (EC)
OHSU	Ohio State University, Columbus, OH 43210-1002, U.S.A.
RC	Ricker Consulting,Vancouver, B.C.
RR	Renewable Resources (YG)
SFU	Simon Fraser University, Burnaby, B.C.
SPRI	Scott Polar Research Institute, Lensfield Road, Cambridge, England
TAU	Trans-Alta Utilities, Calgary, Alta
TrentU	Trent University, Peterborough, Ont.
UAlb	University of Alberta, Edmonton, Alta
UBC	University of British Columbia, Vancouver, B.C.
UCal	University of Calgary, Calgary, Alta
ULav	Université Laval, Québec, P.Q.
UMAN	University of Manitoba, Winnipeg, Man
UOtt	University of Ottawa, Ottawa, Ont.
UQAC	Université du Québec à Chicoutimi, P.Q.
UQAQ	Université du Québec à Québec, Sainte-Foy, P.Q.
UQATR	Université du Québec à Trois-Rivières, P.Q.
UTorE	University of Toronto, Erindale Campus, Toronto, Ont.
UWA	University of Washington, Seattle, WA 98195-1360, U.S.A.
UWO	University of Western Ontario, London, Ont.
WGMS	World Glacier Monitoring Service, Zürich, Switzerland
WLU	Wilfrid Laurier University, Waterloo, Ont.
WSB/AE	Water Sciences Branch, Alberta Environment
WSC	Water Survey of Canada
YG	Yukon Government

INTERNATIONAL GLACIOLOGICAL SOCIETY

STAFF CHANGES

The end of 2000 saw the departure of two staff from the Society's offices in Cambridge.

Dave Garbett, who had been assisting with the production of the *Journal of Glaciology* and the *Annals of Glaciology*, followed his heart to Holland and is now living in Utrecht and working for an Internet company.

Liz Farmar, who worked part-time setting papers for both publications, resigned because of the pressure of an increased workload in her other job.

It is with great regret we must mention the loss of Sylva Gethin, who died in February after a short illness. Sylva, who was an experienced library cataloguer, had worked part-time for the Society for many years in the Scott Polar Research Institute, verifying and checking references for all papers. Her knowledge of languages was a great asset. Her experience and attention to detail, as well as her personality, will be sorely missed.

We will shortly be attempting to fill these positions.

LORIS SELIGMAN

We are very sad to have to report the unexpected death of Loris Seligman, Gerald Seligman's widow, in January of this year. The Secretary General visited her at her home in Bristol about two years ago, just before she moved to be closer to her family.

Her niece has advised us that she has made a most generous bequest to the Society of £5000.

SNOW STRUCTURES AND SKI FIELDS

The Society's reprint of Gerald Seligman's classic work is now out of print and we would like to arrange for a further reprinting. The recommended technology for short-run reprintings is DocuTech. However, for this we need a good original. Unfortunately, the current reprint does not have illustrations of sufficiently high quality

If anyone has a copy of the original edition, we would ask that they consider offering it to the Society so it can be used as the basis for the next reprinting. We would reimburse the donor and provide a copy of the new reprint.

THE AMERICAN FUND FOR CHARITIES

The International Glaciological Society has become a member of the American Fund for Charities. This organization accepts donations on behalf of its member charities. It is exempt from U.S. federal income tax under Section 501(a) of the Internal Revenue Code, as an organization described in Sections 509(a)(1) and 170(b)(1)(A)(vi). This information will be of interest to any U.S. member who has considered making some provision for the Society in their will, or who is otherwise considering making a donation for which they wish to receive tax relief. Donation forms can be provided on request from the IGS office in Cambridge.

IGS BULLETIN BOARD

Newer IGS members may not be aware that the Byrd Polar Research Center of The Ohio State University generously hosts an electronic bulletin board for the International Glaciological Society

Instructions for subscribing or sending messages to subscribers are as follows:

To send a message to the list send mail to:
igs@geology.ohio-state.edu
To subscribe to this list send mail to:
igs-subscribe@geology.ohio-state.edu
For help information send mail to:
igs-help@geology.ohio-state.edu

JOURNAL OF GLACIOLOGY COVER

Several readers have commented that the Journal cover has not changed during the past year. The suggestion that this might have been a mistake was possibly reinforced by an error on the spine of Number 153 that identified it as 1st Part, the same as Number 152, when it should have been 2nd Part.

Two years ago, the IGS Council was considering how best to respond to members' concern that the time taken to publish an accepted manuscript was too long. One constraint was because with only three issues per year, there was roughly four months between each issue. Council decided that by repackaging the three into four, some improvement in publication time could be achieved. However, with the high value of the pound, all felt this should be done at minimal or no extra cost to subscribers. By retaining the same cover for each volume, and printing a blank at the beginning of the year, it was possible to save most of the additional mailing costs incurred by the extra issue. Members and authors can now expect not only a slightly faster turnaround but, with the number of submissions to the Journal creeping up, also more total pages in each volume.

JOURNAL OF GLACIOLOGY

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

K W Birkeland
Spatial patterns of snow stability throughout a small mountain range

H Björnsson, H Rott, S Gudmundsson, A Fischer, A Siegel and M T Gudmundsson
Glacier–volcano interactions deduced by SAR interferometry

H F J Corr, C S M Doake, A Jenkins and D G Vaughan
Investigations of an "ice-plain" in the mouth of Pine Island Glacier, Antarctica

W Greuell, B Denby, R S W van de Wal and J Oerlemans
Correspondence. Ten years of mass-balance measurements along a transect near Kangerlussuaq, central West Greenland

W Haeberli, A Kääb, D Vonder Mühll and P Teysseire
Prevention of outburst floods from periglacial lakes at Grubengletscher, Valais, Swiss Alps

He Yuanqing, W H Theakstone, Shi Yafeng and Yao Tandong
The isotopic record at an alpine glacier and its implications for local climatic changes and isotopic homogenization processes

C S Hvidberg, K Keller, N Gundestrup and P Jonsson
Ice divide flow at Hans Tausen Iskappe, North Greenland, from surface movement data

Y Iizuka, H Satake, T Shiraiwa and R Naruse
Formation processes of basal ice at Hamna Glacier, Sōya Coast, East Antarctica, inferred by detailed co-isotopic analyses

Kang Shichang, Qin Dahe, P A Mayewski and C P Wake
Correspondence. Recent 18O years oxalate ($C_2O_4^{2-}$) records recovered from the ice core in Mt. Everest: some environmental implications

Li Yingkui, Liu Gengnian and Cui Zhijiu
Morphological variations in cross section morphology along a glacial valley, a case study from Tian Shan, China

P R Porter and T Murray
Mechanical and hydraulic properties of till beneath Bakaninbreen, Svalbard

E Ramírez, B Francou, P Ribstein, M Descloitres, R Guérin, J Mendoza, R Gallaire, B Pouyaud and E Jordan
Small glaciers disappearing in the Tropical Andes. A case study in Bolivia: the Chacaltaya Glacier, 16° S

M Schmeltz, E Rignot and D R MacAyeal
Ephemeral grounding as a signal of ice-shelf change

M J Siegert and S Fujita
Internal ice-sheet radar layer profiles and their relation to reflection mechanisms between Dome C and the Transantarctic Mountains

M Truffer, K A Echelmeyer and W D Harrison
Implication of till deformation on glacier dynamics

C Warren, D Benn, V Winchester and S Harrison
Buoyancy-driven lacustrine calving, Glaciar Nef, Chilean Patagonia

OBITUARY

Akira Higashi (1922–2000)

Akira Higashi was born in Tokyo (Japan) on 20 January 1922. He studied the physical sciences as an undergraduate student at the Department of Physics, Hokkaido University, gaining his B.S. in Physics in 1945. He remained there as a graduate student and his doctoral work on the thermal conductivity of frozen soil was performed under the supervision of Professor Nakaya. He obtained his Ph.D. in 1950.

Higashi became a lecturer in the Department of Physics, Hokkaido University in 1950 and two years later he was appointed an associate professor of Nakaya's laboratory of the Department. After his field work study on snow survey, he went to the Snow, Ice and Permafrost Research Establishment (SIPRE) and worked on experimental research of frost heaving as a contract scientist from 1955 to 1958. He also cooperated there with Dr. A. E. Corte from Argentina on the experimental study of desiccation cracks in soil.

During the latter period at SIPRE, he began experiments on the plastic deformation of polycrystals of ice. In 1960, after his return to Hokkaido University, he organized the Hokkaido University expedition team for the glaciological survey of Mendenhall Glacier, Alaska, and successfully collected good quality ice single crystals from icebergs in Mendenhall Lake. The second expedition was organized in 1964.

Under Higashi's leadership, the group carried out extensive studies on the mechanism of plastic deformation of single crystals of ice. He investigated the existence and motion of dislocations in ice crystals, using X-ray diffraction topography; the so-called Lang method. For his research achievements, he was awarded the Academic Prize of the Japanese Society of Snow and Ice and the Prize of the Yamaji Foundation for the Promotion of Natural Science in 1968.

Higashi was appointed a professor of the Department of Applied Physics in 1964, when it was established as a new department in Hokkaido University. He continued his work on the single crystals of ice and began the experimental investigation of plastic deformation of deep ice cores from Antarctica under high hydrostatic pressures, in conjunction with the problem of the ice sheet flow.

In 1985, Higashi moved from Hokkaido University to the International College of Christianity in Tokyo. He was elected President of the Japanese Society of Snow and Ice in 1987, and made a great effort to modernize the society up to the end of his term in 1992. Higashi was awarded the Seligman Crystal by the International Glaciological Society in 1992, when he retired from the college and moved to Sapporo. Continuing his work, he enjoyed a happy life with his wife, Akiko, in a comfortable house with an attractive garden in a suburban area of Sapporo.

Higashi was an excellent research worker and his activity was truly international. He was also always a kind and considerate teacher. His many students are working actively in the various fields of science and engineering, as professors in universities and leaders of research and development in companies. He had a talent for writing scientific essays and introductory books on science for the general public and students. For example, in 1967 he published "Hyoga" (Glaciers), which described his two expeditions to Alaska and his laboratory work on the plastic deformation of ice.

Just about three months before the 100th anniversary of Professor Nakaya's birth, at the end of winter 1999–2000, an illness suddenly overtook him which eventually led to his death on 23 March 2000.

Shinji Mae

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Fourth International Workshop on the Micromorphology of Glaciogenic Sediments, University of Tübingen, Tübingen, Germany
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14–17 May 2001
* Snow and Ice: Principles, Processes, Management and Use, Ottawa, Ontario, Canada.
J. Pomeroy, Centre for Glaciology, University of Wales, Aberystwyth SY23 3DB, U.K. (Tel [44](1970)622781; Fax [44](1970)622659; john.pomeroy@aber.ac.uk; http://www1.tor.ec.gc.ca/crysys/esc/)

4–8 June 2001
** Fourth International Symposium on Remote Sensing in Glaciology, College Park, Maryland, U.S.A.
Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, UK (www.spri.cam.ac.uk/igs/home.htm)

10–14 June 2001
Workshop on Antarctic Ice Sheet Mass Balance, Washington-Baltimore-Annapolis area, U.S.A.
T.H. Jacka, Australian Antarctic Division, Channel Highway, Kingston, Tasmania 7050, Australia (Tel [61](3)6232-3365; Fax [61](3)6232-3215; jo.jacka@aad.gov.au)

13–18 June 2001
* Millennial-scale Events in the North Atlantic Region during Termination I, University of Ulster, Northern Ireland, UK
J. Knight, School of Environmental Studies, University of Ulster, Coleraine, Co Londonderry BT52 1SA, Northern Ireland, UK (Tel [44](28)7032-3179; Fax [44](28)7032-4911; j.knight@ulst.ac.uk)

18–21 June 2001
Avalanche Control on the Base of Hazard Mapping in Avalanching Areas, Innsbruck, Tyrol, Austria
Gernot Fiebiger, Forsttechnischer Dienst für Wildbach- und Lawinenverbauung, Bergheimerstrasse 57, A-5021 Salzburg, Austria (Tel [43](662)878-152; Fax [43](662)870-215-150; gernot.fiebigerger@wlv.bmlf.gv.at)

12–17 August 2001
16th International Conference on Port and Ocean Engineering under Arctic Conditions (POAC'01), Ottawa, Ontario, Canada
poac@nrc.ca or G.W. Timco, Canadian Hydraulics Centre, National Research Council of Canada, Ottawa, Ont., K1A 0R6, Canada (Tel [1](613)993-6673; Fax [1](613)952-7679; garry.timco@nrc.ca; http://www.nrc.ca/confserv/poac01/)

19–23 August 2001
** International Symposium on Ice Cores and Climate, Kangerlussuag, Greenland
Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, UK (www.spri.cam.ac.uk/igs/home.htm)

20–24 August 2001
3rd International Conference on Cryogenic Soils, Copenhagen, Denmark
B.H. Jakobsen, Institute of Geography, University of Copenhagen, Øster Voldgade 10, DK-1350 Copenhagen K, Denmark (Tel [45]35-32-25-00; Fax [45]35-32-25-01; bhj@geogr.ku.dk; http://www.geogr.ku.dk/cryosols)

20–24 August 2001
Climate Conference 2001, Utrecht, The Netherlands
Land ice and climate; katabatic flows over glaciers and ice sheets
M. van Haersma Buma, Utrecht University, P.O. Box 80125, NL-3508 TC Utrecht, The Netherlands (Tel [31]30-25-33-154; Fax [31]30-25-35-851; m.buma@fbu.uu.nl; http://www.phys.uu.nl/~wwwimau/cc2001.html)

3–7 September 2001
Avalanches and Related Subjects, II International Conference, Kirovsk, Murmansk Region, Russia
Pavel A. Chernouss, Centre of Avalanche Safety "Apatit" JSC, 50th Anniversary of October st., 33 'A', Kirovsk, Murmansk 184250, Russia (Tel [7](815)319-62-30; Fax [7](815)31-12; p.chernous@apatit.com)

8–13 October 2001
2nd International Conference on the Oceanography of the Ross Sea, Ischia, Naples, Italy
Ross Sea 2001, Istituto di Meteorologia e Oceanografia, via De Gasperi 5, I-80133 Naples, Italy (Tel [39](081)-547-5586; Fax [39](081)551-3157; RossSea@nava3.uninav.it; http://antartide.uninav.it

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7–10 February 2002
Winter Cities 2002, Aomori City, Japan
WC2002 Conference Office, 1-22-5 Chuo, Aomori City 030-8555, Japan (Tel [11](17)723-7586; Fax [11](17)723-7585; wc2002@city.aomori.aomori.jp; http://www.city.aomori.aomori.jp/wc2002/)

June 2002
** International Symposium on Fast Glacier Flow, Yakutat, Alaska, U.S.A.
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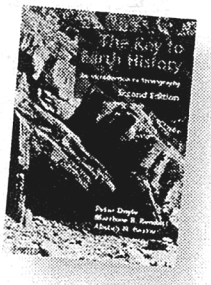

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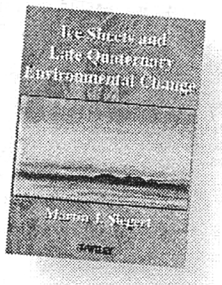

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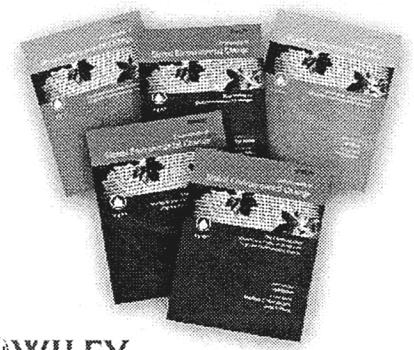

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International Conference on the Physics and Chemistry of Ice, St. John's, Newfoundland, Canada
Stephen J. Jones, National Research Council of Canada, Institute for Marine Dynamics, P.O. Box 12093, Stn. A, St. John's, Newfoundland A1B 3T5, Canada (Tel [1](709)772-5403; Fax [1](709)772-2462; Stephen.Jones@nrc.ca)

19–24 August 2001
First International Conference on Global Warming and the Next Ice Age, Halifax, Nova Scotia, Canada
P. Chylek,Department of Physics, Dalhousie University, Halifax, Nova Scotia B3H 3J5, Canada (Tel [1](902)494-2337; Fax [1](902)494-5191; petr.chylek@dal.ca)

25–30 August 2002 (tentative)
** International Symposium on Modelling Physical and Mechanical Processes in Ice, Chamonix, France
Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, UK (www.spri.cam.ac.uk/igs/home.htm)

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** International Symposium on Snow and Avalanches, Davos, Switzerland
Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, UK (www.spri.cam.ac.uk/igs/home.htm)

23–27 June 2003
8th International Conference on Permafrost, Zürich, Switzerland
Department of Geography, University of Zürich-Irchel, Winterthurerstrasse 190, CH-8057 Zürich, Switzerland (Tel [41](1)635-51-20; Fax [41](1)635-68-48; haeberli@gis.geogr.unizh.ch)

25–30 August 2003
* Seventh International Symposium on Antarctic Glaciology (ISAG-7), Milan, Italy
G. Orombelli, Department of Environmental Sciences, Via Emanueli 15, I-20126 Milano, Italy (Tel [39](2)6447-4403; Fax [39](2)6447-4400; 2a@alpha.disat.unimi.it)

BOOKS RECEIVED

R B Alley. 2000. *The two-mile time machine: ice cores, abrupt climate change, and our future.* Princeton, NJ and Oxford, Princeton University Press.

E R Herren, M Hoelzle and M Maisch, *Eds.* 1999. *The Swiss glaciers, 1993/94 and 1994/95.* Zürich, Swiss Academy of Sciences. Glaciological Commission; Federal Institute of Technology. Laboratory of Hydraulics, Hydrology and Glaciology. (Glaciological Report No. 115/116.)

E R Herren, M Hoelzle and M Maisch, *Eds.* 1999. *The Swiss glaciers, 1995/96 and 1996/97.* Zürich, Swiss Academy of Sciences. Glaciological Commission; Federal Institute of Technology. Laboratory of Hydraulics, Hydrology and Glaciology. (Glaciological Report No. 117/118.)

J F Hiemstra. 2001. "Dirt pictures" reveal the past extent of the grounded Antarctic ice sheet. (Ph.D. thesis, Universiteit van Amsterdam.)

H G Jones, J W Pomeroy, D A Walker and R W Hoham, *Eds.* 2001. *Snow ecology: an interdisciplinary examination of snow-covered ecosystems.* Cambridge, Cambridge University Press.

A J Maltman, B Hubbard and M J Hambrey, *Eds.* 2000. *Deformation of glacial materials.* London, Geological Society. (Special Publication 176.)

M Nakawo, C F Raymond and A Fountain, *Eds.* 2000. *Debris-covered glaciers.* Wallingford, Oxon., IASH Press. (International Association of Hydrological Sciences Publication 264.)

T D Prowse. 2000. *River-ice ecology.* Saskatoon, Sask., Environment Canada. National Water Research Institute; Indian and Northern Affairs Canada.

P Wadhams. 2000. *Ice in the ocean.* Amsterdam, etc., Gordon and Breach Science Publishers.

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