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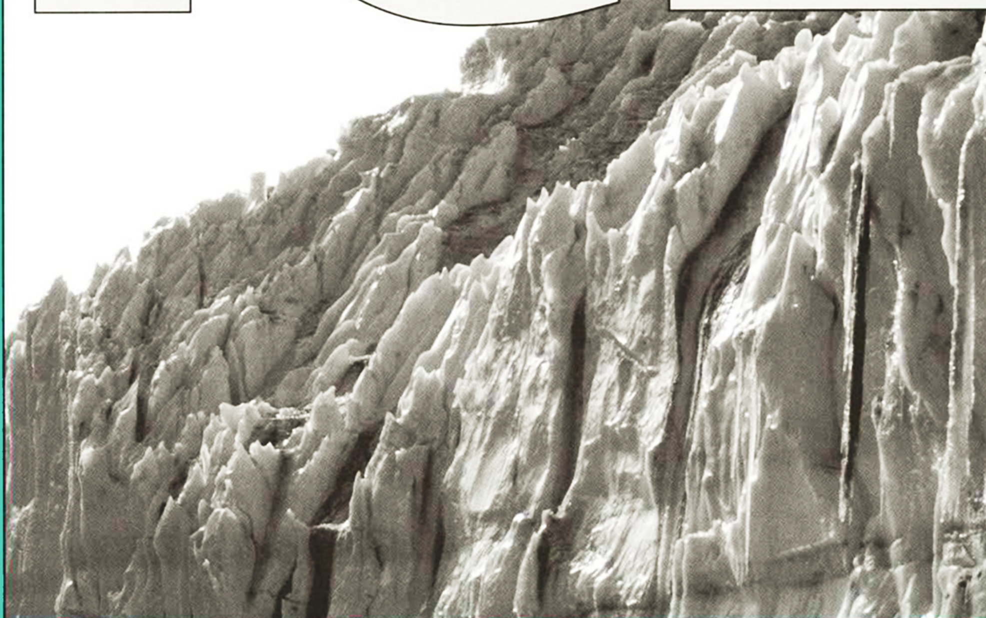

NEWS BULLETIN OF THE INTERNATIONAL GLACIOLOGICAL SOCIETY

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COVER PICTURE: Victoria Upper Glacier, Victoria Valley, Antarctica. (Photograph by Joel Barker)

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 21)

GENERAL

CRYSYS - CRYosphere SYStem in Canada
(B.E. Goodison, N. Neumann, CPEOD)
CRYSYS is an Interdisciplinary Science Investigation (IDS) in the NASA Earth Observing System Program, hosted and funded by Canadian agencies (particularly the Canadian Space Agency) and universities, and led by the Meteorological Service of Canada. It will continue until the end of the 2005/06 fiscal year. In 2003/04 CRYSYS supported 13 university research projects, and three private-sector contracts covering all components of the Canadian cryosphere. Recent significant satellite-related accomplishments include: development of a method for estimating SWE on first-year sea ice; identification and correction of systematic bias in the cross-platform (SMMR and SSM/I) EASE-Grid brightness temperatures, permitting the construction of SWE time series over central North American since 1978; improved estimation of passive-microwave-derived SWE from forested terrain; investigation of the potential of RADARSAT-1 and SSM/I for mapping seasonal ground freeze in the taiga zone; improved understanding of the optimal conditions for wet-snow detection using RADARSAT SAR; documentation of changes in the areal extent of ice caps and the flow characteristics of surge-type glaciers in the Canadian High Arctic; development of improved methods for automated classification of sea-ice information in SAR imagery; estimation of the depth and ice thickness of shallow sub-Arctic lakes using space-borne optical and SAR data; development of a simple retrieval method for land-surface temperature and fraction of surface-water coverage from satellite microwave-brightness temperatures in sub-Arctic areas; and application of ground-penetrating radar for imaging periglacial conditions. Further details can be obtained from the CRYSYS website (www.msc.ec.gc.ca/crysys/). The State of the Canadian Cryosphere (SOCC) website (http://www.socc.ca), established by the CRYSYS project in 1999, has been expanded and updated to include online datasets, educational resource material, and near real-time information on cryospheric conditions in Canada.
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Canadian Cryospheric Information Network
(E.F. LeDrew, P. Yoon, EnvS/UWat; M. Polanski, Noetix)
The Canadian Cryospheric Information Network (CCIN), an on-line portal for all Canadian cryospheric related data and information, was developed to enhance awareness and allow access to Canadian cryospheric information and related data for all members of the science community and the general public. Limited access to such timely, comprehensive, and quality cryospheric data has been an obstacle to improved knowledge and understanding of the cryosphere in Canada. Important datasets reside in various government or university labs, where they remain largely unknown or access-restrictions prevent effective use. Through a data- and information-management infrastructure, the CCIN addresses these problems by providing a conduit for users to access real-time and historical data regarding snow, lake ice, sea ice, glaciers, and permafrost, while supplying educational information directly involving climate variability and change in Canada.

The CCIN can be accessed via the world-wide-web through the SOCC website (http://www.socc.ca), which is a CCIN-based project, or by directly going to the CCIN website at http://www.ccin.ca.
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Linkages between spring 0°C isotherm dates and hydrocryospheric variables over Arctic Canada
(B. Bonsal, T. Prowse, M. Lacroix, NWRI/Sask)
An important feedback process within Arctic environments involves albedo changes associated with transitions from ice/snow-covered surfaces to open conditions during spring and autumn. These transitions are directly linked to surface temperature and, particularly, to the threshold of 0°C. There is a consensus among most GCMs of substantial future warming over polar regions, due in part to positive feedbacks associated with shorter snow- and ice-cover seasons. To obtain better insight into these potential future changes, historical trends and variability in spring 0°C isotherm dates over Arctic Canada are being examined. The isotherms are also linked to selected hydrocryospheric variables derived from several geographically ranging rivers in the Canadian North. These include the last date of backwater effect (i.e. "B"

dates), as well as the timing of the first major pulse of snowmelt recorded in the rivers. From 1950-98, Arctic Canada is associated with a distinct west-to-east gradient in trends of spring 0°C isotherm dates. This includes significantly earlier dates over Western Canada, slightly earlier ones over the central Arctic, and later springs over eastern regions. 0°C isotherm dates show significant relationships to spring pulse and last "B" dates during overlapping periods suggesting similar long-term trends for these hydrocryospheric variables.
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Evaluation of EOS snow-cover and sea-ice products
(A.E. Walker, T.A. Agnew, CPEOD)
New snow-cover and sea-ice products from MODIS and AMSR-E sensors, launched on the Terra and Aqua satellites, are being assessed. MODIS snow-extent products have been evaluated each winter since 2000 for the prairie and boreal-forest regions in Western Canada by comparison with SSM/I SWE maps produced by the MSC. Results indicate good agreement between the two snow-cover products during winter and spring; the agreement is not as good in the fall. Evaluation of the new passive-microwave data stream from the AMSR-E sensor was initiated with an aircraft/field campaign in Saskatchewan in February 2003. Airborne microwave-radiometer data collection and ground sampling of snow-cover characteristics were conducted along a flight-line network covering agricultural and boreal-forest areas. Initial evaluation of the AMSR-E brightness-temperature data shows minor differences in comparison with the SSM/I data stream. MODIS sea-ice daily-average products (MOD29) and AMSR-E sea-ice products are being compared to Canadian sea-ice charts to evaluate these new satellite-derived products. Passive microwaves (SSMI and AMSR-E) are also being used for near real-time monitoring of sea-ice conditions within Canadian waters.
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GLACIERS — GENERAL

Global glaciology
(J.G. Cogley, Geog/TrentU)
A dataset containing annual mass-balance time series is being maintained. The data, obtained by direct or glaciological measurements, come from some 310 small glaciers around the world (http://www.trentu.ca/geography/glaciology.htm). As records lengthen, the evolution of small-glacier mass balance presents an increasingly coherent picture. The world's small glaciers were close to equilibrium in the 1960s and, consistent with the observed trend of global warming, have been losing mass since then at an accelerating rate. This conclusion may be conditioned strongly by a single freak year. For 1998, probably the hottest year of the last millennium, the arithmetic average balance was –981 kg m^{-2} a^{-1}. This is nine standard deviations below the average, –308 kg m^{-2} a^{-1} for the other years of its pentad (1995–99). It is not yet known whether this is an artefact of sampling variation.
When estimating small-glacier mass balance we have about 2500 km² of ice per measured glacier, to be compared with about 40,000 km² of land surface per temperature station for IPCC climatologies. At present this glaciological advantage is more than offset by the shortness and variable length of mass-balance records, but the comparison suggests that with care it should be possible to develop estimates of global average mass balance no less reliable than those for temperature.
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Glaciological cartography
(J.G. Cogley, Geog/TrentU)
The accuracy of elevations on maps, and in digital elevation models derived from maps, is of general concern, but is particularly important in glaciological applications such as the geodetic determination of mass balance and the interpretation of reflectance and backscattering from remotely sensed imagery. A project is underway to improve estimates of uncertainty in map-derived elevations and slopes by comparing independent glacier maps of differing scales. It has been shown that errors are proportional to the contour interval, and that taking the uncertainty to be equal to one half of the contour interval is a reliable rule of thumb. An outstanding problem is the systematic under-representation of steeper slopes on maps of smaller scale.
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GLIMS Canada
(M.J. Sharp, L. Copland, F. Cawkwell, D.O. Burgess, S. Williamson, K. Filbert, C. DeBeer, EAS/UAlb; E. Dowdeswell, BGC)
The University of Alberta hosts the Global Land Ice Measurements from Space (GLIMS) regional centre for Canada. The centre has compiled comprehensive sets of aerial photographs and satellite imagery for the Canadian Arctic islands for 1959–60 and 1999–2000. It is analyzing this imagery to determine the nature and magnitude of glacier changes across this region over a 40 year period, to identify the causes of the changes observed, and to assess their consequences for global sea level.
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Glacier mass balance and monitoring
(M.N. Demuth, R.M. Koerner, NGP)
The recently expanded net is monitored every year. It is being augmented now by remote sensing from aircraft and in the future will use satellite imagery (CryoSat). R.M. Koerner handles the Arctic sites and M.N. Demuth the western sites. All members of the NGP are involved. As part of the CryoSat validation programme, test grids were laid out on the Devon Ice Cap and variables that will affect the signal received measured with a facsimile of the CryoSat radar. The NASA aircraft-borne laser altimeter and depth radar flew a Canadian net in 1995 and again in 2001. The changes in

elevations for this net will be reported shortly. The Eastern Arctic ice masses are beginning to feel the effects of warming, especially on Baffin Island. Mass-balance data from the western net is being used to compute the effects of global warming on western Prairie river flow. R.M. Koerner, J. Zheng and C.M. Zdanowicz are monitoring surface snow for pollutants such as acids, metals and organics (see also http://thrust_2.tripod.com/glaciology/one.html).
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Dynamic ice-flow restrictions on glaciers in Canada
(H. Jiskoot, Geog/ULeth)
Tributary-trunk interactions are being investigated through fieldwork, remote sensing (mainly ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer)), glacier-inventory analysis and modelling. The main objectives are to quantify: (a) the effect of tributary flow on the dynamics, hydrology, thermal regime, substrate characteristics and internal structure of the trunk, (b) the effects of glacier disintegration (detachment of tributaries from their trunks) on glacier recession and depletion of glacier systems, and (c) the potential of tributaries to block outflow (possibly providing new insight into glacier surging).
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GLACIERS — NUNAVUT

Glaciological remote sensing, Canadian High Arctic
(J.G. Cogley, M.A. Ecclestone, Geog/TrentU)
Microwave imagery is being used to estimate mass-balance components, in particular the duration and intensity of melting at regional scales. In the accumulation zone, the summer seasonal brightness deficit is a measure of duration and possibly intensity of melting, but early signs are that it is only weakly correlated with whole-glacier mass balance. A study of diurnal pairs of RADARSAT browse images shows that in the accumulation zone backscatter differences are proportional to the accumulated degree-days between morning and afternoon images. The ablation zone has no seasonal signature in microwave imagery. The current focus of this work is on correcting and removing the topographic influence on the microwave signal.
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Large-scale monitoring of Arctic glacier dynamics
(N. Short, Noetix; L. Gray, CCRS)
Using RADARSAT data and interferometric techniques, a comprehensive picture of glacier dynamics is being created for the Canadian High Arctic. Surface velocities for 13 glaciers have been measured since 2000 and those demonstrating active surge phases have been monitored repeatedly. Mittie and Otto Glaciers, both currently surging, have produced speeds of >800 m a^{-1} while many other glaciers show speeds of 150-300 m a^{-1}. The results are helping to establish the characteristics of surging in the High Arctic and to separate climate-induced from cyclical glacier change.
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Monitoring summer melt over ice caps
(L. Wang, M.J. Sharp, EAS/UAlb; S.J. Marshall Geog/UCal)
Inter-annual variability in the mass balance of Canada's High Arctic glaciers is attributable largely to variations in the summer balance so there is considerable interest in being able to monitor the extent and duration of summer melt on ice caps here. Since spring 2001, networks of air temperature sensors have been installed on Prince of Wales Icefield and John Evans Glacier, Ellesmere Island, and more recently on the Devon Ice Cap. The data from these networks will be used to validate satellite-derived mapping of melt extent, duration and intensity. Maps will be produced using a combination of RADARSAT standard-beam-mode SAR imagery, the MODIS Land Surface Temperature (LST) product, and QuickSCAT scatterometer data. If validation is successful, we hope to produce annual melt maps on a routine basis.
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Hydrometeorology of Arctic glaciers, John Evans Glacier, Ellesmere Island
(S. Boon, M.J. Sharp, D. Lewis, EAS/UAlb; P.W. Nienow, R.G. Bingham, GTS/UGlas)
Research at John Evans Glacier (79°40' N, 74°30' W) involves field studies of glacier hydrometeorology to determine Arctic glacier-melt response to climate change. The response to local meteorological conditions has been determined through analysis of six years of meteorological data from three on-ice weather stations. Several conditions that play a significant role in enhancing/suppressing melt have been identified. Winter-wind events result in snow sublimation and redistribution. Summer-snowfall events increase surface albedo and significantly reduce melt amounts. Summer-wind events substantially increase sensible- and latent-heat fluxes and cause significant glacier melt. The surface air temperature lapse rate varies substantially with synoptic conditions and is often much lower than the moist adiabatic lapse rate. Detailed energy-balance studies of a warm-wind event in 2000 suggest that extreme events play a significant role in overall melt and, despite their rare occurrence, can have a significant impact on both glacier drainage-system development, and long-term glacier mass balance. We have examined the role of supraglacial water storage (in both the snowpack and supraglacial ponds/crevasses) in modulating the relationship between melt and runoff production. Sudden drainage of ponded surface waters by hydro-fracture of water-filled crevasses plays a crucial role in the evolution of the subglacial drainage system at the start of the melt season, and in the initiation of subglacial runoff. We are currently using a degree-day model to examine glacier melt and runoff response to climate change.
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Northern ice-shelf cryo-ecosystems

(D.R. Mueller, W.F. Vincent, CEN)

Research focuses on the microbial ecology of ice shelves that fringe the coast of northern Ellesmere Island. We have found diverse microbial communities, composed mainly of algae, lying directly on the ice surface. These communities appear to accumulate over many successive summers when meltwater is available for growth. We are also studying the stability of ice shelves in the region and implications for ice-dependent cryo-ecosystems. One example of this was the loss of an epishelf lake (a body of freshwater, dammed behind an ice shelf that floats over denser seawater) between 2000 and 2002 as a crack formed in the Ward Hunt Ice Shelf. This recent ice-shelf break-up event is the latest in a series of calving causing an estimated 90% reduction in the surface area of the Canadian ice shelves over the past century. (see also www.cen.ulaval.ca /dmueller.html).

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Glacier biogeochemistry

(M.J. Sharp, M. Lafreniere, J. Barker, M. Bhatia, EAS/UAlb; J. Foght, S. Cheng, J. Klassen, Biol/UAlb; R. Turner, Biol/UCal)

Micro-organisms appear to be widely distributed in basal ice, subglacial sediments and subglacial meltwaters. Culture experiments show that many are viable and active under near in-situ conditions. Are these populations simply derived from populations found in soils and sediments that could have been overridden during glacier advances, or are they derived by in-wash from the glacier surface? Alternatively, are subglacial communities unique assemblages of organisms that appear to be well adapted to subglacial conditions (dark, low but stable temperatures, low nutrient and carbon availability)? The molecular technique of Terminal Restriction Fragment Length Polymorphism (T-RFLP) is being used to analyze total community DNA in order to characterize the composition of microbial communities from these different sub-environments. Initial results from John Evans Glacier, Ellesmere Island, suggest that while subglacial communities do include organisms also found on the glacier surface and in extra-glacial sediments, they also include a diverse assemblage of organisms that are unique to the subglacial environment. To establish the prevalence of individuals and the genetic patterns that dominate the bacterial communities in the different settings, amplified rDNA restriction analysis (ARDRA) is being used to compare the 16S rDNA of cultured individuals. Sequence analysis of the cultured organisms reveal that they are similar to those isolated or amplified from other cold environments, including other subglacial systems (e.g., Fox and Franz Josef Glaciers in New Zealand).

Since primary production in subglacial environments is limited by the lack of light, many subglacial communities likely rely on "legacy" carbon as an energy source. Such carbon may be washed in from the glacier surface or derived from overridden soils and vegetation. Subglacial microbial metabolism may alter the characteristics of the source organic carbon (OC), so OC flushed from glaciers by meltwater runoff may have different molecular characteristics than the source OC. The goal of this study is to quantify OC abundance in different glacial settings and sub-environments, and to identify the biogeochemical processes acting on OC in glacier systems. Supraglacial snow, ice and meltwater, subglacial meltwater (where possible), basal ice and basal sediments have been sampled and analyzed for OC abundance. OC molecular characteristics are being investigated using fluorescence spectroscopy. Samples have been collected from glaciers that exhibit different thermal and hydrological regimes, and that exist in environments with obviously different soil and vegetation carbon abundance. These glaciers include John Evans Glacier, Ellesmere Island (79º49' N, 74°00' W), Outre Glacier, British Columbia (56º14' N, 130°01' W), and Victoria Upper Glacier (77º16' S, 161°29' E) in the McMurdo Dry Valleys of Antarctica. OC exists in detectable quantities in all of the glaciers sampled (DOC concentrations range from 0.06 ppm in Outre Glacier subglacial flow to 46.7 ppm in Victoria Upper Glacier ice) and the molecular characteristics of DOC differ between sites and spatially and temporally at each site. Current efforts to identify the specific biogeochemical processes forcing these changes are ongoing.

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Mass balance of White and Baby Glaciers, Axel Heiberg Island

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

Annual mass-balance measurements continue on White and Baby Glaciers. Electronic files are available (www.trentu.ca/geography/glaciology.htm). Preliminary results from a cartographic revision suggest that White Glacier is slightly larger than previously reported, but marginal recession around the lower tongue has reduced total area by 0.7 km2 to 39.8 km2. The impact of this shrinkage on the mass-balance time series is small and is well within previously quoted uncertainties. On both glaciers, the average decadal balance (kg m-2a-1) is less negative during the current incomplete decade than during the 1990s:

Decade	White	Baby
1960-1969	-123±126	-159
1970-1979	- 14±126	+ 11
1980-1989	-111±151	n/a
1990-1999	-257±126	-262
2000-2002	-170±231	-122

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Dynamics and change of Devon Ice Cap

(D.O. Burgess, M.J. Sharp, EAS/UAlb; D.W.F. Mair, GEnv/UAber; J.A. Dowdeswell, T. Benham, SPRI)

The topography, ice-thickness distribution and subglacial bedrock topography of Devon Ice Cap were surveyed by airborne radio-echo sounding in 2000

(SPRI). Changes in ice-cap extent since 1960 were determined by comparing 1959-60 aerial photography with Landsat 7 ETM+ imagery from 1999-2000. The volume-area scaling approach was used to estimate the change in ice-cap volume associated with the observed area changes. The surface-velocity field of the ice cap has been determined using SAR interferometry (from ERS and RADARSAT data), speckle tracking, and differential GPS (global positioning system) measurements (UAlb). The 1960-2000 mass balance of the ice cap has been reconstructed using a combination of shallow ice-coring techniques for the accumulation zone and temperature-index-based mass-balance modelling in the ablation zone (UAber). The contribution of iceberg calving to the mass balance was estimated using a combination of surface-velocity and ice-thickness measurements, and measurements of tidewater-glacier retreat since 1960 (UAlb).
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Calibration/validation of CryoSat radar altimeter: Devon Ice Cap
(M.J. Sharp, D.O. Burgess, EAS/UAlb; D.W.F. Mair, GEnv/UAber; M.N. Demuth, NGP)
The first field campaign was conducted on the Devon Ice Cap in April/May 2004. Work was carried out along a transect from the summit of the ice cap to its southern margin and focused on four sites located in the percolation, wet-snow, superimposed-ice and ablation zones. The program provided direct measurements of the rates of surface elevation change and snow/firn densification, using the "coffee-can" technique, to characterize the near-surface stratigraphy and surface roughness of the ice cap. Three AWSs, 15 air temperature monitoring stations, and a stake grid designed for measurements of mass balance, surface velocity and surface strain rates were also established. The field campaign was synchronized with overflights by an aircraft from the Alfred Wegener Institute carrying a laser altimeter and an airborne version of the CryoSat radar altimeter.
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GLACIERS — WESTERN CANADA

Trapridge Glacier, Yukon
(G.K.C. Clarke, EOSc/UBC)
Field study of the subglacial processes and fast-flow mechanisms of Trapridge Glacier continued in summer 2003. The current focus of this field research is to examine the remarkable sensitivity of englacial and subglacial processes to changes in surface loading of the glacier. There is strong evidence that during the winter season rapid snowfall events and rapid changes in barometric pressure can trigger ice quakes and large changes in englacial strain and subglacial mechanical coupling.
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Response of glacial and nival rivers to climate forcing
(S. Fleming, EOSc/UBC)
A diverse suite of nonparametric statistical and time-series analysis techniques were applied to historical discharge data from five glacier-fed and four snowmelt-fed rivers in the southwestern Canadian sub-Arctic to assess whether, and if so how, glacial and nival rivers respond to climatic forcing at a range of variability time-scales. The results confirm and strongly extend current understanding of the comparative hydroclimatology of glacial and nival rivers; clearly demonstrate the dramatic effects that catchment glacierization can have upon water-resource variability, such as selective teleconnectivity and diametrically opposite climate-change responses; and yield a more integrated framework for conceptualizing and assessing such dynamic watershed processes.
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Alpine glacier extents and retreat rates
(R. Wheate, G. Whyte, Geog/UNBC)
Landsat TM/ETM+ data have been processed for automated detection of glacier extent and accumulation/ablation zones for alpine glaciers and icefields in the western Cordillera of British Columbia. Areas studied to date focus on Mount Robson, the northern Rockies (Muskwa-Kechika), the Salmon and Berendon Glaciers near Stewart, and the Andrei Glacier complex. For the latter, we will be building a terrain database in conjunction with surface measurements by the GSC. Contemporary outlines from Landsat 7 are compared with historic extents from earlier Landsat images, provincial and federal map vectors, and aerial photography, to assess rates of retreat. Historic DEMs have been created from early 20th century topographic maps to recreate perspective models and estimate volume of ice loss. Current provincial DEMs also enable the estimation of equilibrium-line altitude and analysis of glaciers by slope, aspect and watershed.
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Glacier recession, Coast Mountains
(K.E. Ricker)
Periodic observations have been made on the retreat of Wedgemount and Overlord Glaciers.
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Snow and ice loss in Rockies since 1975
(M.N. Demuth, NGP; N. Short, Noetix; V. Pinard Geog/UOtt)
Landsat imagery has been used to delineate snow and ice cover in the catchments of the North and South Saskatchewan Rivers, from the late summers of 1975, 1988 and 1998. Sub-basin results show losses of 10-60 % of snow and ice cover over the 23 year period.
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Spatially distributed glacier surface melt model
(D.S. Munro, Geog/UTorE; M.N. Demuth, NGP; R.D. Moore, Geog/UBC)
The temporal modelling of energy input and melt response on glacier surfaces is being advanced beyond

the scope of the single-point study, e.g., by mapping melt responses to weather variations across entire glacier surfaces, specifically Peyto Glacier, Alberta, and Place Glacier, British Columbia. This is being done using AWS data collected in the terrain off the glaciers, along with the products of Landsat TM image analysis, to drive a spatially distributed model that is validated against AWS data from selected points on the glaciers. Initial success has been achieved at Place Glacier, where the TM images were used to distinguish the principal surface-cover types in the basin, assigning an albedo value to each cover type, and running the model to simulate patterns of snow-cover shrinkage through the summer that compare well to those of the TM records. The modelled meltwater output of the glacier agrees well with stream-gauge measurements. Progress is being made on Peyto Glacier where the questions relevant to spatial modelling focus on TM albedo analysis, spatial resolution and parameterization of the turbulent heat-transfer terms in the model. TM-derived albedo compares well with field data, given AWS data to calibrate a bulk radiation model for image analysis. The melt model used for Place Glacier is being applied to Peyto, using gridcell sizes of 1-250 m, thus addressing the question of model resolution. Regarding parameterization of the turbulent heat exchange over the glacier surface from off-glacier AWS data, it has been found that this compares well with glacier AWS results derived from micrometeorological theory. New recording precipitation gauges in the glacier basins offer the potential to extend the scope of the work, e.g., to model the spatial distributions of the glacier mass balances throughout the year.
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Glacial outburst floods
(G.K.C. Clarke, EOSc/UBC)
Models of subglacial outburst floods are being developed that can be applied to the huge outburst flood of Glacial Lake Agassiz. The rapid release of freshwater water from this proglacial lake is believed to have been the trigger for the 8200 BP abrupt cooling event that is revealed in ice-core records from Summit, Greenland.
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GLACIERS — NON-CANADIAN

Hypsometric characterization of the Greenland ice sheet margin
(H. Jiskoot, Geog/ULeth; S.J Marshall, Geog/UCal)
A subgrid parameterization of the elevation distribution of the Greenland ice sheet marginal zone is being designed through hypsometric terrain characterization to improve the topographic, dynamic and mass-balance characteristics of its peripheral region in numerical models. High resolution DEMs of Greenland were used to obtain ice-surface and bed topography. Hypsometric curves of uniform blocks were reconstructed from these DEMs for the entire ice marginal and peripheral zone of the ice sheet. On the basis of these curves, specific classes of hypsometric functions are extracted to represent the variety in, and homogeneity of, ice surface and proglacial terrain topography, ice-flow dynamics and margin type. This will provide a more accurate portrayal of ice-land distribution and topography of the ice-sheet margin in an existing three-dimensional thermomechanical whole-ice-sheet model. The hypsometric parameterization will be combined with local ablation curves to disclose the mass-balance signal, melt and local response of the ice sheet to climate trends.
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Accumulation on the Greenland ice sheet
(J.G. Cogley, Geog/TrentU)
Accumulation is the most accurately quantified component of the mass balance of the Greenland ice sheet, but until now no formal estimate of its uncertainty has been made. An error model has been developed to address this problem. It accounts for uncertainties due to measurement error, varying duration of measurement records and spatial unevenness of sampling. The result is that Greenland accumulation is estimated as 299 ±23 kg m^{-2} a^{-1}, the uncertainty being quoted as twice the standard error. The estimate is very close to recent estimates. The uncertainty of about 4% is encouraging, but in terms of sea-level equivalent it is ±0.1 mm a^{-1}. Even if the other components of mass balance, ablation and grounding-line discharge, were known with equal accuracy, the Greenland contribution to sea-level change would thus be constrained only to within about ±0.2 mm a^{-1}. This highlights the need for continued improvements in measurement accuracy.
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Monitoring small vertical changes in Antarctic ice sheet elevation
(L. Gray, CCRS)
Interferometric RADARSAT data from the 1997 Antarctic Mapping Mission has been used to solve for three-dimensional surface ice motion in an area of the West Antarctic ice sheet. Areas in the tributaries of ice streams can move both upward and downward at unexpectedly high rates, e.g., the centre of one ~125 km2 area in a tributary of Kamb Ice Stream slumped vertically downwards by ~50 cm sometime between 26 September and 18 October 1997. Other examples of such movement, upward as well as downward, have led to cooperative work with US colleagues to examine airborne and satellite (ICESat GLAS data) lidar altimetry for similar effects. While various interpretations of the data are possible, the suspicion is that the movement of subglacial water pockets is involved.
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Hydrology and dynamics of Vatnajökull, Iceland
(G.E. Flowers, EOSc/UBC; H Björnsson, Á. Geirsdóttir, SI; G.H. Miller, UCO-B)
Numerical models are being applied to datasets of ice-cap hydrology and dynamics from Vatnajökull, southeast Iceland. We are also examining spatial and

temporal drainage patterns, glacier outburst floods and the ice-cap response to climate change over the next 200 years. The models are being employed, in conjunction with new high-resolution paleoclimate records from marine and lacustrine cores, to investigate the Holocene glacial history of Iceland.
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Glacier surveys in the Karakoram Himalaya
(K. Hewitt, Geog & CRRC/WLU)
In surveys of the central Karakoram from 1996–2001, 13 glaciers of intermediate size (10–20 km long) were advancing. Some of the largest (40–70 km long) exhibited 5–10 m of thickening over substantial ablation zone areas; in most of these, termini were not advancing. Along 8 glaciers, thicker, more active ice was causing renewed lateral moraine building, in places overriding moraines that have been ice-free for 50 years or more. 16 disconnected tributaries of large glaciers were advancing. An exceptional number of glacier surges have been reported. Six were confirmed between 1986 and 1996; the most in any decade since the 1830s. Four other rapid advances may have been surges.
These developments seem at odds with most of the world's mountain glaciers which, in recent decades have shown terminus recession and a negative mass balance. Rapidly diminishing ice covers are reported throughout the Greater Himalaya. A similar trend applied generally in the Karakoram from the 1920s through the mid-1990s, and is still observed in the lesser ranges and smaller ice masses. The reported changes apply to glaciers with the highest watersheds and greatest elevation range. Most originate above 7000 m a.s.l. and descend to around 3000 m a.s.l. Some, in the Rakaposhi and Batura Ranges, terminate as low as 2300 m a.s.l., well below any in the Indian and Nepalese Himalaya.
The Greater Karakoram-Hindu Raj have the largest concentration of perennial snow and ice outside high latitudes, or about 18,500 km^2. A relatively few large glaciers make up most of the cover. Glacier nourishment is also distinctive, being intermediate between the summer accumulation glaciers of the Greater Himalaya, and the winter accumulation glaciers of the European Alps to the west. Winter accumulation from westerly air masses is dominant, but a third occurs in summer under the influence of the monsoon. The zone of maximum precipitation is in the accumulation areas 4800–5800 m a.s.l.; much higher than maxima reported for other tropical high mountains.
Climatic changes involving the westerlies and monsoon could modify two other important glacier-response variables, ablation-season conditions and, over the longer term, ice thermal regimes. Summer weather can influence ablation directly through cloud cover and fresh snow, indirectly through influence on dustiness and thinner supraglacial dirt covers. The latter have a large influence on ablation rates. Since most glaciers are polythermal they have the potential to respond to climate change by redistribution of ice by elevation, as well as, or even without, mass-balance change.
It has been argued that glacier behaviour in the Karakoram has differed from other parts of the Northern Hemisphere, especially during the Pleistocene and Little Ice Age. The factor most consistently regarded as distinctive, and influencing the relation to climate, is the heavy supraglacial debris over most lower ablation zones. However, as a climate-response variable it is very conservative; its importance has been exaggerated and its character oversimplified. There is net protection of some of the lowest ice in arid valley-floor environments. However, this represents quite a small part of the glacier cover. A tendency has been to overestimate the thickness of the debris covers and underestimate how dynamic these supraglacial environments can be. A major problem in tracking the climatic relations of these glaciers has been the lack of continuous, spatially adequate, monitoring of high-altitude climate.
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GLACIERS — ICE CORES

Prince of Wales Icefield, Ellesmere Island
(D.A. Fisher, C.M. Zdanowizc, J.C. Bourgeois, J. Zheng, R.M. Koerner, NGP; M.J. Sharp, EAS/UAlb)
This icefield is potentially a very good high-resolution site for coring because it has very high accumulation rates and reasonably low annual temperatures. The immediate objective is to get an absolutely dateable core over several thousand years that contains a good sea-ice proxy time series, especially summer melt layers. Additionally, pollen, and trace metals will be measured.
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A shallow ice-core network for the Canadian Arctic
(M.J. Sharp, E. Doxsey-Whitfield, L. Colgan, EAS/UAlb)
Shallow ice cores are being used to map the 40 year mean accumulation rate across Canadian Arctic ice caps. The 1963 "bomb" layer is used as a reference horizon and is detected in boreholes using in situ 137Cs gamma spectrometry. Detailed density profiles are measured on cores at the time of extraction. Cores from the upper accumulation zones of ice caps are retained for detailed analysis of major ion chemistry and physical stratigraphy. This allows identification of annual layers and the investigation of interannual variability in net accumulation and summer melt (as deduced from the abundance of ice layers in cores). The goal is to construct a net accumulation climatology for these ice caps and to understand the spatial structure of interannual variability in net accumulation.
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Mount Logan, Yukon
(D.A. Fisher, C.M. Zdanowizc, J.C. Bourgeois, R.M. Koerner, NGP; K. Goto-Azuma, NIPR; C.P. Wake, CCRC)
The three cores that were taken at 5400, 4200 and 3000 m a.s.l. by the GSC, NIPR and UNH are being analyzed. The results are just beginning to appear, some being reported at the May 2004 AGU/CGU meeting.

The sites "see" very different sources, with the highest seeing furthest. The upper core spans over 20,000 years and contains clear examples of cross-Pacific dust storms and a very active Holocene climate .
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Interpretation of isotopic signals in high-altitude ice cores
(G. Holdsworth, AINA; H.R Krouse, Phys & Astron/UCal; C. Wake, K. Yalcin, CCRC)
Anomalous isotopic signals that are not directly related to temperature changes at source or site can be explained by an atmospheric model based on the simplified but realistic structure of a cyclone. Vertical profiles of (isotopic) d values of snow from Mount Logan, Yukon, were interpreted as the imprint of atmospheric structure and used to form the basis of the cyclone model. To show that this atmospheric model is not unique to Mount Logan, additional data were obtained. Variations in the "depth" of cyclones will clearly cause variations in the position and thickness of the warm frontal mixed layer which will modulate ice-core-site d values when the sites are located at corresponding altitudes. An attempt is being made to demonstrate the effects of changing mixed-layer thickness by comparing d and snow-accumulation time series at Mount Logan (5340 m a.s.l.) and Eclipse (3016 m a.s.l.) to detect the effects of changing mixed-layer thickness.
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Climate history of Greenland and Antarctic ice sheets
(N. Lhomme, EOSc/UBC and UJF; S.J Marshall, Geog/UCal; C. Ritz, LGGE; F. Parrenin, LEGOS; M. Kageyama, S. Charbit, D. Paillard, CEA-Saclay)
Polar ice sheets contain a rich and complex record of climate history. Three-dimensional numerical models of tracer transport and ice-sheet dynamics have been developed and combined to estimate the fine stratigraphy (age, d18O) of past and present ice sheets. We are attempting to reconstruct the climate history of the Greenland and Antarctic ice sheets by accurately predicting their ice-core records and have estimated the age and isotopic composition of all major ice sheets and their contribution to ocean volume and composition for the present and the Last Glacial Maximum.
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GLACIERS — PHYSICS

Thermomechanics of shear margins
(C. Schoof, EOSc/UBC)
The thermomechanics of shear margins are a key component in understanding how the width and discharge of ice streams evolves in time. Current work focuses on the application of variational methods to the flow of ice streams with Coulomb friction at the bed, and to the problem of temperate-ice formation due to intense strain heating in the transition zones between ice streams and inter-stream ridges.

Water flow at the ice-bed interface
(T.T. Creyts, EOSc/UBC)
Supercooled water flowing at the ice-bed interface has the ability to accrete large amounts of sediment to the sole of the glacier. We are developing models to simulate water flow in these environments numerically via the formalism of the Spring-Hutter equations. Empirical relations for sediment inclusion and frazil-ice formation are also incorporated. Results suggest that small sediment sizes, when available to the flowing water, are rapidly purged from the subglacial network. Larger sediment clast sizes remain trapped by the ice-bed aperture.
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Thermodynamic modelling of ice-melting by effusive subglacial eruptions
(T.-P. Fráppe, EOSc/UBC)
A simple one-dimensional box model is used to quantify heat transfer from a horizontal layer of effusively erupted magma to water and ice in temperate subglacial settings. The research is focused on describing the modes of heat transfer from the quenching magma to the water and evaluating the energy partition between ice and water. The mechanical response of the ice, and of the subglacial drainage system, are ignored and pressure is assumed to be cryostatic. A bound is set on the melt rates and heat fluxes that can be expected from effusive eruptions based on the efficiency of heat transport by the accumulating meltwater.
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Rheology of ice-rock systems and interfaces
(B. Ladanyi, CIN)
Behaviour of both rock glaciers and conventional glaciers is highly affected by the character and temperature of their bottom deforming layer, usually composed of a mixture of ice and rock elements, the latter ranging from silty sand up to large boulders. As with rock-mass mechanics, the large-scale behaviour of such mixtures is difficult to evaluate either by direct in-situ measurements or by sampling. This research extends to frozen slopes, and the frozen debris at the bottom of glaciers and rock glaciers, certain findings and methods borrowed from the fields of rock mechanics and the behaviour of mixtures. The analysis shows how the ice component may be included using these methods, leading to solutions potentially useful for analyzing the stability and motion of frozen slopes under temperature changes.
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Shear strength and creep of ice-filled indented rock joints
(B. Ladanyi, CIN; G. Archambault, UQAC)
In 1977, Ladanyi and Archambault published the results of an experimental study involving direct shear tests with filled, regularly indented joints. They used two types of infilling materials (clay and silty sand), three

types of indentations, varying thickness of infilling, and three different normal pressures. The analytical treatment involved both no breakage and breakage of rock indentations during shear. In 1980, they extended the analysis to completely irregular joint interfaces. Now this analysis has been applied to ice-filled indented rock joints to calculate the relationships among the shape of irregularities, the thickness of ice filling, the temperature and the strain rate. Special attention was paid to the effect of temperature variation on the creep rate of such joints under a given shear stress. This kind of information may be useful for forecasting the sliding behaviour of glaciers and frozen rock slopes under climate-warming scenarios.
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GLACIAL GEOLOGY

Quaternary of the Eastern Townships, Quebec
(J.-M.M. Dubois, CARTEL/Geog & Tél/USher)
The former glacial-lake system formed during deglaciation of watersheds oriented towards the ice sheet, on the south shore of the St Lawrence, is being reconstituted. Hierarchical systems with terrain indices (moraines, beaches, deltas, lake sediments, outlets, etc) are being reconstructed.
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Landscape evolution in the Puget Sound area, U.S.A.
(C. Schoof, EOSc/UBC; F. Ng, MIT; D.B. Booth, B. Hallet, ESS/UWash)
We are trying to quantify the effect of distributed subglacial drainage on landscape evolution in the Puget Sound area. The region is characterized by the widespread occurrence of drumlins, which are believed to have formed under a warm-based ice lobe. The aim is to identify whether sediment transport by a distributed drainage network can account for the formation of these glacial bedforms.
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PERMAFROST

Canadian Permafrost Monitoring Network
(S. Smith, M.M Burgess, F.M. Nixon, GSC)
The GSC, in collaboration with other government departments and institutions, has been developing a national permafrost monitoring network. This contributes to the IPA's Global Terrestrial Network for Permafrost (GTN-P), a network of observatories providing long-term field observations of permafrost thermal state and the active layer, required to characterize and detect changes in permafrost conditions. The GSC network has more than 20 sites in the Mackenzie region and a High Arctic network that includes five boreholes at Alert, Ellesmere Island. Permafrost temperatures are generally measured in the upper 50 m and records vary in length from <10 to >20 years.
Initial analyses indicate that the response of permafrost temperature to recent climate change and variability varies across Canada. Warming of shallow permafrost temperatures has occurred since the mid-1980s in the central and northern Mackenzie region in response to a general warming of air temperature. Warming of permafrost is also observed in the eastern and High Arctic, but this mainly occurred in the late-1990s. These trends in permafrost temperature are consistent with trends in air temperature observed since the 1970s. Local conditions, however, influence the response of the permafrost thermal regime to these changes in air temperature. (see also www.canpfnetwork.com and www.gtnp.org).
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Active-layer monitoring network in the Mackenzie Valley
(F.M. Nixon, C. Duchesne, F. Wright, S. Smith, GSC; L. Kutny, ARI)
During July and August 2003, the 13th annual survey of the active-layer monitoring system in the Mackenzie Valley was completed from Fort Simpson (61°46' N) to the Arctic coast (69°43' N). Sites now number 53, about half in the Mackenzie Delta. Ten have been selected for the Circumpolar Active Layer Monitoring program of the IPA.
Along this 1400 km transect, active-layer thickness varies more as a result of local factors (related to situation) than to regional climate (associated with latitude). Though both air and ground thawing degree-days increase from Arctic through sub-Arctic to boreal environments, active-layer development is similar, except where local factors override regional patterns. The thaw of 1998 was the greatest yet recorded, in keeping with record warm temperatures, while thaw in 1996 north of Norman Wells and in 2000 at many sites was notably less than adjacent years also associated with temperature and season length significantly less than normals. The widespread response to these events builds confidence in the utility of the instrumentation for measuring response in the ground to atmospheric change. In the longer term, measurements from this transect will be used to help model climate-change impact on near-surface permafrost in this fragile environment. (see also http://sts.gsc.nrcan.gc.ca /permafrost/index.html).
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International team-work in permafrost science and engineering
(P.J. Williams, SPRI)
A world-wide group of scientific and engineering specialists involved in current issues concerning permafrost, especially oil and gas extraction, ground contamination and other key geotechnical and scientific issues is being managed from Canada. The main site is found at www.freezingground.org and has many links, in a novel combination of collaborating institutions and individuals, and provides access to many sources of information and services. It is managed independently

of government or other special interest groups and has origins going back many years. Services have been provided recently to several universities, the Russian Academy of Sciences, two major conferences, a journal, several publishers and several industrial concerns.
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SNOW — GENERAL

Canada-wide daily snow-cover maps: derivation and validation
(R. Fernandes, CCRS; R. Brown, CPEOD/Dorval; P. Romanov, NESDIS/NOAA)
Validated daily snow-cover maps of Canada, from 1985 to present, are to be produced in a re-analysis (non-real-time) framework. They will be derived from a combination of satellite observations (both optical and passive microwave) and snow courses. Temporal and spatial patterns of snow cover are important indicators of climate variability and provide information related to fire danger, wildlife habitat, climate-model parameterizations and hydrological behaviour at regional scales. Snow-cover maps from 1998 onwards are based on a blending of operational automated NOAA-NESDIS (4 km resolution daily) and MODIS (500 m resolution) maps (only cloud-free areas). Both products have been validated and agree with snow courses more than 85% (usually >90%) of the time. An annual blended Canada-wide snow-cover map, using MODIS data where available, and NOAA data to fill in cloudy periods, is being produced. A re-analysis of AVHRR data from 1985 to present is being undertaken to produce 1 km resolution daily snow-cover maps of Canada for this period. These maps will be released to the public after validation (see also www.ccrs.nrcan.gc.ca and follow links to the climate-change program).
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Gridded snow-depth and SWE dataset for North America
(R. Brown, CPEOD/Dorval)
A standard optimal interpolation approach has been used to derive a gridded (0.3º lat./long.) snow-depth and SWE dataset over North America for the 1979–97 period. The analysis is based on daily snow-depth observations along with a first-guess field generated by a simplified snow-accumulation, aging and melt model driven by 6 hour values of air temperature and precipitation from the European Centre for Medium-range Weather Forecasting re-analysis (ERA-15). Snow-density estimates from the snowpack model were used to derive SWE estimates. Independent evaluation of the gridded SWE estimates with snow course and SNOTEL data showed good agreement across the mid-latitudes of North America. However, the simple snowpack model was unable to replicate higher snow densities over tundra regions. This would require the inclusion of wind-packing processes in the snow model and the addition of wind speed in the analysis process. The snow-depth climatology from the analysis was shown to be a significant improvement over that by Foster and Davy, particularly over the Western Cordillera (see also www.socc.ca).
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Update of Canadian national snow course database:
(F.J. Eley, CPEOD; R. Brown, CPEOD/Dorval)
MSC published the first digital compilation of Canadian snow course data in 2000. The dataset contained historical (1950-90) SWE and snow-depth measurements from snow surveys taken by more than 20 agencies at weekly, biweekly or monthly frequencies. These data have proven useful in the evaluation of satellite and model-derived estimates of SWE. Work is currently in progress to update the snow-course database through to the end of the 2003/04 snow season, and obtain other data that were not included in the 2000 release. The dataset is scheduled for release in the fall of 2004.
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Development and evaluation of passive microwave SWE retrievals
(A.E. Walker, C. Derksen, CPEOD)
SWE retrieval capabilities from spaceborne passive-microwave brightness temperatures are being developed for major Canadian landscape regions. This has yielded an operational SWE product for the Prairie Provinces with empirical adjustments for the effects of forest cover. Passive-microwave derived SWE maps are produced on a weekly basis and issued to a range of operational users including hydroelectric companies, water-resource management agencies, and weather-forecast offices. Recent evaluation studies have shown that SWE retrievals in open prairie environments are typically within ±15 mm of surface snow surveys. Systematic SWE underestimation, however, is a problem in densely forested areas, with vegetation effects completely masking the passive-microwave signal in some regions. Research is being carried out in collaboration with USher to understand and model the influence of forest canopies on the transmission of microwave energy from the underlying snow-covered surface. Detailed evaluations of passive-microwave SWE retrievals are also being carried out for both the northern boreal forest and tundra environments.
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Merging satellite and in-situ SWE information
(C. Derksen, CPEOD)
Correction coefficients have been developed to standardize brightness temperatures between the SMMR (1978–87) and SSM/I (1987–present) to generate homogenous SWE retrievals through the complete passive-microwave data record over the continental interior of North America. Comparison of these estimates with SWE values estimated from historical gridded snow-depth data showed excellent agreement. This allowed standardized monthly SWE and snow-cover extent anomaly series to be constructed

for the 1915–2002 period from the passive-microwave (1978–2002) and historical data (1915–92). The combined data are currently being analyzed to document the dominant modes of spatial and temporal variability, and to examine linkages to soil moisture and drought conditions (see also www.socc.ca).
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Snow and snow processes in land surface and regional climate models
(M. Mackay, P. Bartlett, CPEOD)
Efforts are being made to improve the representation of snow processes in the Canadian Land Surface Scheme (CLASS) model, the land-surface scheme used in the Canadian GCM and Canadian Regional Climate Model (CRCM). The most recent version of CLASS (version 3), contains a number of improvements based on recent work. These include mixed-precipitation phase, variable snowfall density, and a new snowpack-aging scheme where density varies as a function of depth with an enhanced aging rate for an isothermal snowpack. CLASS 3 also includes a new snow-interception scheme where interception efficiency decreases with the rate of snowfall and the amount of snow on the canopy, and increases with canopy density with a maximum between 3oLAI and 6oLAI depending on snow density. These changes have resulted in marked improvements in simulations of snow depth and density. Regional assessments of snow cover and water balances generated by the CRCM in the Mackenzie River basin, and landscape specific zones (agricultural, coniferous forest, broadleaf forest, open tundra) at mid- to high latitudes have shown that the CRCM provides realistic simulations of regional snow-cover variability, but tends to overestimate maximum SWE values due to insufficient sublimation losses.
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Validation of NOAA weekly snow-cover dataset over Arctic Canada
(L. Wang, M.J. Sharp, EAS/UAlb; R. Brown, CPEOD/Dorval; C. Derksen, CPEOD)
The NOAA weekly snow-cover dataset (1966-) has been widely used to document regional and hemispheric variability in snow-cover extent, but it has received only limited validation, especially for northern high-latitude areas that are most sensitive to anthropogenic climate warming. The NOAA dataset was compared with in-situ observations, and estimates of snow cover derived from AVHRR and SSM/I for the spring melt period over the Canadian Arctic mainland north of the tree line. The NOAA product was consistently late in capturing the onset of snowmelt, and showed delays of up to 4 weeks in melt-onset relative to the other datasets. The likely cause of the apparent delay in melt-onset is confusion of snow and cloud cover in the hard copies of visible imagery used to produce the NOAA product.
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Snow characteristics and snow protection for vines
(J.-M. M. Dubois, CARTEL/Geog & Tél/USher)
Snow characteristics (texture, stratigraphy, water content, etc.), providing the best protection for vines in cold regions, are being examined. Many hybrids need protection during winter, but this practice is expensive. The cheapest protector seems to be natural snow, but there may be a shortage of this at the beginning of winter or during warm periods in January or February when it maybe possible to make artificial snow. We have examined tree holes along the vines but their impact on plant and soil temperature is not obvious. The experiment, near Sherbrooke, southern Québec, used an automatic thermocouple system in the soil, on the soil and on the plant itself.
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Joint winter-runway friction-measurement program
(N.K. Sinha, IAR)
In December 1995, a five-year project was initiated jointly by Transport Canada and NASA to understand and to quantify the factors that influence aircraft braking friction and the contamination drag of various aircraft on winter contaminated runways, in order to estimate landing or take-off distances on runways contaminated with water, slush, snow and ice. The program, now called the Joint Winter Runway Friction Measurement Program (JWRFMP), is still active in 2004. Canadian studies led to the development of a Canadian Runway Friction Index (CRFI) which has become very popular at Canadian and US airports. An International Runway Friction Index (IRFI) has also been developed that is undergoing critical review. Both CRFI and IRFI are based on empirical relationship between indices of friction generated by a number of ground friction measuring equipment and a few aircraft. The scatter is often too large to use as reliable tools for airport operations when the runway conditions are marginal. Long-term solutions require understanding of the complex interaction processes between aircraft tires and the contaminants including the kinetics of environmental conditions and contaminants removal processes. One aspect has been the use of a double-microtoming technique to mini thin-section snow for microstructural analysis of snow bonding, initially developed at the Snow and Avalanche Study Establishment in India, applied to aircraft-compacted snow at the Oslo international airport.
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SNOW — AVALANCHES

Characterization of a typical "avalanche winter"
(P. Haegeli, Geog/UBC)
Current snow-climate classification schemes give only very limited information about related avalanche activity. Analysis of observed avalanche activity across Western Canada with regard to persistent weak layers will give a better picture of the dominant instabilities relevant for forecasting purposes. Key implications have emerged indicating that avalanche winter characteristics can vary significantly between winters of the same snow-climate classification. Additionally, the avalanche-winter characteristics of the transitional snow

climate of the Columbia Mountains, British Columbia, have distinct features and are not simply a mixture of maritime and continental characteristics.
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Forest damage from snow avalanches in timber-harvested terrain
(G. Anderson, Geog/UBC)
Logging in British Columbia is increasingly being conducted in steep, alpine terrain, as less-steep slopes have been extensively logged. This research quantifies and analyzes physical terrain characteristics of logging cutblocks, and the terrain below cutblocks where snow avalanches have run into forest. Approximately 50 examples of forest destruction from avalanches across southern British Columbia are used for the analysis. Forest-penetration distance and forest-damage areas have been analyzed in a run-out analysis framework to evaluate the utility of forest "leave" strips left to protect downslope features.
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Avalanche-risk management in backcountry skiing operations.
(H. Grimsdóttir, Geog/UBC)
Relative risk is associated with different factors such as aspect, elevation, stability ratings and time of the year. A database from a large heli-skiing operator was used for the analyses, which are based on data on skier-triggered avalanches, as well as data on where and when people were skiing. The usage data are essential for defining relative risk. This research represents the first time usage has been taken into account in such risk analyses. A questionnaire and interviews with professional mountain guides was conducted in order to extract knowledge on terrain selection and group management. Avalanche reports were analysed with the same intention.
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Dynamic modelling of avalanche run-out
(C. Borstad, Geog/UBC)
Simple debris and avalanche dynamic models approximate the flow path as a rectangular open channel. In the run-out zone, where frictional effects are assumed to dominate, the channel geometry is the strongest influence on the motion of an avalanche. Current research aims to introduce more complex channel geometries to current avalanche models to better predict avalanche run-out. A Lagrangian finite-difference solution to the St Venant equations is used as a basis for the dynamic analysis. Some field surveys of characteristic run-out zones will be completed in the summer of 2004 to obtain geometric parameters for use in the model.
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Decision support systems for avalanche-risk analysis
(S. Conger, Geog/UBC)
Various decision support systems (DSS) are being analyzed in terms of their ability to enhance risk perception and communication. GVIS or geographic visualization, one of the methodologies employed by such DSS, is being investigated. Initial efforts have reviewed the role of warning ergonomics, signal colours, classic cartographic techniques, and modern educational technologies in avalanche-risk communication.
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Snow-avalanche formation and forecasting
(J.B. Jamieson and others, Civil/Geol/Geophys/UCal)
Current field studies of snow properties and avalanches focus on the following. (1) Nearest neighbour (NN) models for human-triggered avalanches which correctly classify 75-80% of avalanche and non-avalanche days and provide the forecaster with avalanche and terrain characteristics for avalanches that occurred on similar days in the past. In addition to meteorological variables and previous avalanche activity, the NN model uses snowpack properties including slab thickness, slab load and a skier-stability index, which are stepped forward up to 8 days from the last manual snow observations. (2) By distinguishing five characters of fractures in snowpack-stability tests, the correlation of the test results with human-triggered avalanches is improved. (3) High-speed photography shows a slope-normal component to most fractures in weak snowpack layers, indicating a bending wave in the slab during fracture propagation. (4) Arrays of closely spaced stability (rutschblock) tests in avalanche starting zones show that test scores correlate with slope angle, slab thickness, and, for surface-hoar weak layers, crystal size. Since these variables have a physical relation to stability, spatial patterns in stability should reflect process-scale variations in these variables. (5) Cold laboratory and field experiments show growth of faceted crystals within a day in dry snow overlying a layer of wet snow. The freezing time can be estimated from heat-flow theory. The Swiss model SNOWPACK can simulate the freezing time and formation of faceted crystals.
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Fracture toughness of the snow slab
(D. McClung, Geog/UBC)
Research is being conducted on the fundamental problem of slab-avalanche release and related fracture toughness for the snow slab. This is based on field measurements of slab properties. The results illustrate size effects on fracture propagation and that fracture toughness is scale invariant with respect to fundamental scaling parameter for the snow slab over the range of interest for slab-avalanche release. The results are fundamental as a basis for avalanche forecasting. Further, slab-avalanche fracture toughness has a multi-fractal characterization.
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ATMOSPHERIC ICE

Arctic clouds

(U. Lohmann, Phys & AS/DU)

Recent observation and climate modelling highlights the Arctic as a region of particular importance and vulnerability to global climate change. Clouds play an important role in this by interacting with radiative and hydrological fields. Model simulations of Arctic clouds have large discrepancies with observations partly due to an incomplete understanding of the physical processes in clouds and of the ocean-ice-atmosphere system. A mesoscale cloud model and large-scale single-column model (SCM) have been used to simulate clouds observed during the Surface Heat Budget of the Arctic Ocean (SHEBA) and First ISCCP Regional Experiment-Arctic Cloud Experiment (FIRE-ACE) experiments. Results show that anthropogenic aerosols can alter the microphysical properties of Arctic clouds and consequently modify surface precipitation. In contrast to the decrease in riming of snow crystals with cloud droplets found in polluted clouds over the mid-latitude region, the riming rate increases polluted clouds in the Arctic. The amount of precipitation reaching the surface depends crucially on the ice-crystal shape, and can be higher or lower in the polluted vs the clean case. SCM simulations also showed that the parameterizations of cloud cover and mixed-phase clouds have a significant influence on the model reproduction of the observed cloud properties. The results demonstrate the need for future model studies of the clouds in this region (see also www.atm.dal.ca/~lohmann/papers/papers.html).

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Marine-icing study

(R.E. Gagnon, IOT; G.W. Timco, I. Kubat, CHC; T.W. Forest, Mech/UAlb; E. Lozowski, EAS/UAlb)

This multi-year project involves the development of tools that will allow the offshore petroleum industry to predict, and thereby mitigate, the marine-icing operational hazard to vessels and structures. The project focuses on the creation of a user-friendly quality marine-icing database and enhancements to software (RIGICE) for predicting and simulating marine icing on rigs operating in the winter offshore environment. To be useful the database needs reliable field data. To help address this need a Marine Icing Monitoring System has been assembled and deployed on a marine Atlantic ferry. The stand-alone system takes high-resolution photographs of areas prone to icing at 10 minute intervals during the full winter season. The two-camera system is controlled by satellite phone that also enables thumbnail images to be downloaded. The full-resolution visual data are retrieved from the system's hard drive at the end of the icing season so that icing events that may have occurred can then be analyzed. A second system has been assembled for deployment on a suitable vessel/rig in the near future.

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FLOATING ICE — FRESH-WATER ICE

Lake-ice freeze-up and break-up processes

(A.E. Walker, CPEOD)

Since 1992, SSM/I 85 GHz data have been acquired in near real-time to investigate the spatial and temporal variability in ice formation and break-up over large lakes in Canada, with a focus on Great Slave Lake, Great Bear Lake and the Great Lakes. As a contribution to the Mackenzie GEWEX study, a time series of Great Slave and Great Bear Lake ice freeze-up and break-up has been assembled using historical SSM/I 85 GHz data (1987–present). The time series consists of a series of images for each lake documenting each ice freeze-up and break-up season, providing dates corresponding to complete freeze-over and ice-free conditions for each year and yielding information on the variability in the spatial and temporal aspects of ice formation and decay. Information from this time series contributed to a study of the thermal characteristics and bulk heat exchange of Great Slave Lake. The time series of passive-microwave-derived lake-ice information has recently been extended back to 1978, by combining 37 GHz brightness-temperature datasets from SSM/I and the SMMR sensor, which operated on the Nimbus-7 satellite from 1978–87.

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River-ice hydrology: broad scope

(T. Prowse, Geog/UVic//NWRI/Sask)

Freshwater ice is an integral component of cold-region lakes and rivers and an important modifier of related biological, chemical and physical processes. Although serious concerns have been expressed about the impacts of climate change on ice-covered systems (e.g., the recent IPCC assessment), knowledge of such systems is relatively weak making it difficult to predict the nature of the effects of a changing climate. This project focuses on extreme hydrological events, climatic controls and effects on aquatic systems. The focus of extreme hydrological events is river-ice break-up and associated ice jamming. Such events can produce floods exceeding those possible under similar flow during the open-water period. Although break-up flooding is known to produce significant economic damage and also to be critical to the environmental health of aquatic systems, no broad-scale assessment of its importance has been conducted. This study evalu-ates frequency and magnitude of break-up floods and compares the results to those for the open-water period. This also provides the basis for predicting how the frequency and magnitude of such extreme events will be affected by climate change. Major changes in river and lake ecology, particularly water quality, are also expected to result from climate-induced changes to river-ice cover. Projected ecological changes, however, have been based primarily on guesstimates of changes in the ice cover, not on the results of physically-based models. Modelling is being undertaken to forecast how northern aquatic systems respond to climate change.

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Historical river-ice trends in Canada
(M. Lacroix, T.D. Prowse, B. Bonsal, NWRI/Sask; C.R. Duguay, GI/UAK-F; P. Ménard, CEN; D. Milburn, INAC)
The Canadian Ice Database (CID), an amalgamation of ice conditions from the MSC and the CIS, is being used to determine historical trends of river ice across Canada. This is a valuable tool for studies using fresh-water ice as indicators of climate variability and for predicting the future effects of climate change. The CID contains 63,546 records for 757 sites across Canada from 1822-2001 for rivers, lakes, sea water and deltas. Past studies have shown that in general freeze-up dates are occurring later and that break-up dates are occurring earlier around the Northern Hemisphere. Various 30-year periods were analyzed, and in particular the 1966-95 period, for rivers having a minimum 20 years of record for either freeze-up or break-up dates. In data-sparse areas, e.g., eastern Keewatin, western Hudson Bay, Water Survey of Canada "B" dates were supplemented for missing ice records. These are the dates where ice affects the stage-discharge relationship (i.e. backwater effect). Initial results show spatial variations among major climatic regions and some stronger trends noted in Western Canada associated with break-up as opposed to freeze-up dates.
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Mid-winter warming: an increasing source of hydrological extreme events?
(T. Prowse, B. Bonsal, M. Lacroix, NWRI/Sask; S. Beltaos, NWRI)
Shortening and warming of the winter season is forecast to produce major alterations to the shape and timing of seasonal components of river hydrographs. Recent evidence of these climatic changes already exists in the climatic records for some regions of Canada and elsewhere. Most attention on hydrological effects has focused on changes to the timing and magnitude of the spring hydrograph, often the dominant hydrological event of the year in cold regions. Little attention has been paid, however, to the increased potential for mid-winter runoff and ice-break-up events resulting from increases in the frequency and duration of periods of winter warming. The greatest potential for such change exists along the geographical margins of the cold regions. This research analyzes the frequency and magnitude of mid-winter warming events over the last 100 years in Canada. It also evaluates how such warming has been reflected in the production of hydrological events at a range of river sizes from a number of different hydro-climatic regimes. Estimates of future changes likely to result from climate-warming scenarios are also evaluated.
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Hydro-climatology of the Mackenzie River basin
(L. de Rham, Geog/UVic; T. Prowse, Geog/UVic//NWRI/Sask)
The river-ice break-up regime of the Mackenzie River basin, the geographical focus of a major hydro-climatic study (MAGS), is being examined. The importance of the frequency and magnitude of ice-induced extreme flood events, relative to those for open-water conditions, will be quantified for a suite of stations under varying physical and hydro-climatic regimes. Recurrence-interval analyses of relevant hydrometric records and an equilibrium ice-jam hydraulic model (RIVJAM) will be used: to quantify maximum extremes for a range of discharges; to determine the relationship of extreme events to controlling hydro-climatic conditions (e.g., timing of spring warming and snowmelt runoff); and to examine normal temporal patterns of ice break-up for the Mackenzie catchments and link spatial anomalies in these patterns to major atmospheric teleconnection indices (e.g., ENSO, AO, PDO, PNA).
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Hydrological extremes on Arctic-flowing rivers
(T.D. Prowse, M. Lacroix, NWRI/Sask; S. Beltaos, NWRI)
Break-up maximum instantaneous water levels are being compared to the open-water maximum instantaneous levels for Arctic-flowing rivers across the country under various hydro-climatic zones. The specific objectives are: to obtain records (i.e. charts, annual pages, front sheets, site descriptions, etc.) for stations where extreme water levels can occur at break-up for Arctic-flowing rivers; to analyze the recurrence interval of such extremes and compare them to those extremes produced under open-water conditions; to develop a regional hydro-climatic comparison of the data that can be used to quantify the projected effects of climate change. Preliminary results have been obtained at a select number of sites for which there are exemplary data about ice conditions. In most cases, the recurrence line under ice conditions exceeds that for open water. For comparison, at the 10 year recurrence level, ice-induced break-up floods are on average 2.5 m higher than open-water floods (range 1.0-5.4 m). Other cases show a steady divergence in the recurrence lines, indicating that longer-return-period floods will be even more enhanced under ice conditions. In the other instances, there is almost a steady difference between the two relationships or the two lines appear to converge at the higher levels.
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Ice jams at Rideau Falls, Ottawa, Ontario
(D.B. Hodgins, SNC-Lavalin)
The Rideau River drains an area of about 3900 km² before it discharges into the Ottawa River at Ottawa. For more than 100 years, ice on the Rideau River has been broken and flushed over Rideau Falls prior to natural break-up. This prevents ice-related flooding upstream of the falls but leads to a massive accumulation of ice below the falls. This accumulation, which is 15 m high, 200 m wide and extends 250 m into the Ottawa River, causes damaging floods at an adjacent hydroelectric station. The floods occurred when ice and Rideau River flow were discharging into

the accumulation, but the mechanism of flooding was not known. In 2003, all records and observations were synthesized and it was determined that small ice jams were forming and reforming regularly (but randomly) within the ice mass. Periodically, a 10–20 m wide portion of the accumulation would fail, and form a relief channel. This would jam, cause a backwater and cause flooding on those occasions when the channel formed near the generating station.
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Ice jam at Badger, Newfoundland
(Ch. Guillaud, D. Hodgins, SNC-Lavalin)
In February 2003, an exceptional ice jam occurred on the Exploits River at Badger, Newfoundland. This ice jam was the largest on record in almost one century and caused the water level to rise above the 1:100 year flood level. As a result, the town was severely flooded. The ice jam exhibited two unusual features: (1) the water level rose at an exceptionally fast rate and, (2) the water level remained above bank-full conditions for 50 days. One possible explanation is that a severe ice jam had formed previously just upstream of Badger and released on the morning of the flood. This would have sent a wall of water and accumulated ice, composed of a mix of ice-cover debris and slush ice, rushing past Badger to re-jam in the shallows immediately downstream. The extra pressure created by the sudden jam caused the ice-jam components to interlock solidly and enabled it to resist erosion and shoving for the next 50 days. A second possible explanation is that something has changed in the river regime. Compilation of ice observations at Badger since 1915 shows that the frequency of ice-jam flooding has varied with time. Between 1915 and 1950, four large ice jams exceeded the river-bank level, which is a frequency of 4 jams/35 years; between 1950 and 1975, no ice jam exceeded the river-bank level; and between 1975 and 2003, nine ice jams exceeded the river-bank level, which is a frequency of 9 jams/28 years. Further investigations have been recommended in order to explain: (1) the variation in frequency of the ice jams; (2) the reason for the abnormally fast rate of rise in 2003; and, (3) to revaluate the 1:100-year flooding level.
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FLOATING ICE — SEA ICE

Ice-thickness-redistribution model
(I. Kubat, M. Sayed, CHC; T.G. Carrieres, CIS; S.B. Savage CEAM/McGU)
A new ice-thickness-distribution formulation has been developed as part of the Canadian Ice Service operational forecasting model. The approach is based on considering the ice cover to consist of level and ridged parts. The model accounts for the evolution of the concentration and thickness of each part in response to mechanical deformation. Idealized deformation scenarios have been used to examine the performance of the model.
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Passive-microwave sea-ice algorithms
(T.A. Agnew, CPEOD)
We have evaluated the NASA Team algorithm sea-ice concentration estimates from 1979-96 using Canadian regional weekly and hemispheric United States weekly sea-ice charts. The NASA Team algorithm was found to underestimate total ice-covered area when compared with Canadian regional ice charts by 20.4–33.5% during ice melt in the summer and 7.6–43.5% during ice growth in the late fall. The wide range in performance occurs because some Canadian regions, such as the western Canadian Arctic, are only partly in the marginal sea-ice zone, while the Hudson Bay and the East Coast regions are entirely in the marginal sea-ice zone, being completely ice-free in summer. Compared with the U.S. National Ice Center hemispheric chart series, average underestimation is 18.6% in summer; at other times of the year the differences are <7.8%. The magnitudes of the underestimation during ice melt and ice-growth periods, using the Canadian regional charts, are higher than previously published evaluations. These results suggest caution in using the passive-microwave ice-concentration data in the marginal-ice zone where ice-melt and ice-growth conditions are a major component of the sea-ice regime.
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Canadian Arctic Shelf exchange study, Beaufort Sea
(D.G. Barber, CEOS)
Snow and sea-ice dynamic and thermodynamic processes of the Beaufort Shelf, Amundsen Gulf polynya and Canada Basin pack ice have been examined relative to their controls on carbon fluxes on and off the continental shelf. In-situ measurements of thermophysical properties are being made daily between September 2003 and August 2004. Gas, mass and energy fluxes are linked to the various mixes of sea-ice type and thermodynamic state and through this linked to satellite remote sensing in the microwave, thermal IR and visible portions of the electromagnetic spectrum. Preliminary results show that this region of the Arctic is experiencing rapid reductions in sea-ice areal extent and that the Cape Bathurst polynya has moved eastwards, due either to increased upwelling of warm water at the shelf break or increased enthalpy in the water column due to summer warming (see also www.umanitoba.ca/ceos).
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Ice loads on caisson structures, Beaufort Sea
(G.W. Timco, M.E. Johnston, CHC)
A comprehensive overview has been made of the characteristics, instrumentation and measured ice loads on the caisson structures that were used for exploratory drilling in the Beaufort Sea in the 1970s and 1980s (Tarsiut Caisson, the Single-Steel Drilling Caisson, the Caisson-Retained Island, and the Mobile Arctic Caisson Molikpaq). An analysis of over 170 loading events has shown that there is a general increase in the line load (global load per unit width of the structure) with increasing ice thickness. Empirical equations are

presented to predict the global load in terms of the ice thickness and structure width for different ice-failure modes. The most significant result of the analysis shows that the maximum global pressure (line load per unit ice thickness) measured for all types of ice loading events never exceeded 2 MN m^{-2}, with the vast majority less than 1.5 MN m^{-2}.
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Ridged sea ice
(T. Amundrud, EOSc/UBC)
The processes that create and maintain ridged sea ice are being investigated in research supervised by G. Ingram (UBC) and H. Melling (DFO). Ice-draft profiles from the Beaufort Sea are compared with numerical models of ice-draft evolution to examine geometrical constraints on the formation and ablation of ridged ice. During formation, ice-ridge production is found to be constrained by level ice availability, while during melt, the internal flow of warm oceanic water through the porous keel is an important contributor to ridged-ice ablation rates.
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Maximum pile-up height for ice
(A. Barker, G.W. Timco, CHC)
Ice often piles-up along shorelines, and in some cases can cause extensive damage. Reported pile-up heights vary over a very wide range. The question of the maximum pile-up height, and the factors that affect the maximum height, have been investigated by compiling information on reported pile-up heights for a wide range of conditions and geographical locations. The data show that ice can pile-up to a height of over 15 m. Further, there is a trend of increasing pile-up height with increasing ice thickness, with an apparent limit of the pile-up height for different ice thickness. A Particle-in-Cell (PIC) numerical model is used to investigate the factors that affect the pile-up height. The results of this model show that there are three essential factors for a large pile-up height: sufficient driving force, a large fetch area of ice available for feeding the pile-up, and sufficient time for the pile-up to occur. Other factors, such as the shoreline slope, have a less significant impact on the size of the pile-up.
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Effect of structure shape on broken-ice zone around offshore structures
(A. Barker, G.W. Timco, CHC)
The implicit PIC numerical model developed at CHC has been used to investigate the extent of the zone of broken ice around offshore structures during interaction with moving ice. The numerical model simulated level-ice interaction with five offshore structure shapes: a circle, a square, an octagon, a multi-leg platform and a conical structure. Ice properties were held constant for comparisons between structure shapes. Simulation data are compared with available field and laboratory documentation. Comparisons of the extent of the rubble zone were made between the structure shapes. The results were examined in terms of their implications regarding safe evacuation of personnel from offshore platforms in ice-covered waters.
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Discrete-element modelling of ice-related problems
(M. Lau with A.S. Re, W. Raman-Nair, A. Derradji, F.M. Williams, IOT; B. Veitch, A. Patterson, J.C. Liu, OERC; L. Rothenburg, K. Lawrence, Civil/UWat; A.C. Palmer, P. Lee, Eng/UCam; D. Spencer, OCC)
IOT has been using a commercial code, DECICE, to study a wide variety of ice-related problems. The program uses discrete elements in an explicit time-domain solver. The versatility of DECICE in modelling ice-related problems has been demonstrated in a number of recent studies, which included level- and pack-ice loads on fixed and moored structures, rubble loads on conical structures, jamming of floes at bridge piers, modelling of rubble properties, and ridge-keel resistance during ice scouring. The results compared favourable to model tests and analytical models. A multi-year project has recently been established to: (a) consolidate the existing works on DECICE, (b) assess and demonstrate its existing capacity via a selection of additional analyses, (c) perform the necessary upgrades, and (d) assist in its eventual re-marketing. The ice problems presently studied include: (a) ship manoeuvring in level and pack ice, (b) dynamic behaviour of Kulluk in level and pack ice, (c) seabed scouring by ridge keels, (d) life-boat launching and manoeuvring performance in a wave/ice environment, and (e) iceberg towing. Each study involves a small team of collaborators who provide expertise to the particular problem under study.
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Engineering ice-load models
(C. Daley, OERC)
Ice-load models for structural design require two components: the total force, often determined by collision mechanics, and based on ice and structure geometry and ice-indentation behaviour, the latter modelled by a "process" pressure-area relationship; and the local pattern of pressure, including the pressure peaks, modelled by the "spatial" pressure-area relationship. Recent work has developed analytical solutions for a number of collision cases (ice-structure collision geometry). Some of these have been employed directly in the new Unified Requirements for Polar Ships (developed by IACS). A second avenue of study has been to examine the nature of the "process" pressure-area relationship and the link with the "spatial" pressure-area relationship. Re-examination of data measured on the USCGC Polar Sea has indicated some surprising relationships. The two processes appear to be quite strongly linked, and, more surprisingly, the "process" values appear to rise with increasing area, in contradiction to most previous reports. This results in significant changes to predicted loads, e.g., in the case of iceberg-collision loads.
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Ice forces on conical structures
(M. Lau with F.M. Williams, IOT; MUN collaborators: J.F. Tong; L. Rothenburg, K. Lawrence, Civil/UWat)
IOT has accumulated a large database of model cone tests and developed numerical and analytical models to assess the performance of conical structures in ice over the years. Recently, many field measurements of ice loads on the Confederation Bridge piers, Northumberland Strait, were collected. These provide an excellent basis for full/model-scale correlation, and model development and verification. This is a multi-year project to: (a) consolidate existing experimental data in the area of conical structures in ice (continuous, pack and ridge ice), and (b) experimentally, numerically and analytically model the dynamic response of moored cones in ice. The data are being compiled and the consolidation will be finished this year. The first phase of the moored-cone tests was completed and the experimental result compared well with other studies. A comprehensive model test program is planned for this fall, and the results will be compared with the results from a concurrent numerical study. A mathematical model will then be developed to predict the dynamic response of moored cones in level and pack ice.
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Numerical simulation of ice interaction with a wide cylindrical pier
(A. Barker, M. Sayed, G.W. Timco, CHC)
A depth-averaged, hybrid Lagrangian–Eulerian model for ice interaction has been described, and used to evaluate ice loads on a 10 m wide, cylindrical pier. Results previously calculated, using a discrete-element model and from analytical formulas commonly used to estimate ice forces, were compared with the full-scale data. The comparisons are used to verify the results of these different types of approaches for calculating ice loads. There was good agreement between field observations from similar structures and the hybrid model's calculated values. The results obtained using the discrete-element model also compared favourably to full-scale data. In contrast, forces estimated from analytical formulas were much higher than those from the field measurements.
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Local structural response to ice loads
(C. Daley, A. Hussein, M. Pavic, S. Mallard, N. Kozarski, OERC; G. Hermanski, IOT)
Ice loads are very intense locally and the natural variability of ice means that structures designed for ice may well experience overload conditions. Consequently, ice-worthy structural design has moved towards consideration of plastic response and plastic reserve. A program of structural research is examining ship frames and small grillages subject to ice loads. Full-scale structural components are being tested in the structures laboratory at MUN. Finite-element models and analytical formulations are being used to corroborate the experimental work. Guidelines will be developed for the most ice-worthy structural designs.
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Catalogue of local ice pressures
(R.M.W. Frederking, CHC)
A comprehensive compilation and review of measured full-scale local ice pressures on offshore structures and ships is being conducted. Data sources include the 1994 Polar transit of the CCGS Louis S. St Laurent, the 1982–86 trials of the USCGC Polar Sea, 1991 and 1996 polar voyages of the Oden, the 1985/86 deployment of the Molikpaq, plus light piers in the St. Lawrence River. The data are being organized into a database relating local pressures to areas of loading, nature of interaction and ice conditions. Output of the project is information on local design pressure as a function of area for various ice types, conditions and loading behaviour.
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CSA S471-04
(R.M.W. Frederking, CHC)
The Canadian Standards Association has recently published a revised edition of its standard for offshore structures (S471-04 General requirements, design criteria, the environment, and loads). The Annex to the standard on ice loading has been significantly upgraded to provide better guidance on structure design for local and global ice loads. Numerous members of the Canadian ice-engineering community contributed.
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Ice loading on Danish wind turbines: dynamic model tests
(A. Barker, G.W. Timco, CHC; H. Gravesen, Carl Bro; P. Vølund, SEAS)
An extensive model test program has been carried out to investigate the key ice-load issues on offshore wind turbines in Danish waters. Tests were performed using a compliant structure that had scaled structural characteristics. The test program investigated seven configurations of model structures and dynamic characteristics. Both first- and second-mode vibrations issues were investigated. 41 ice sheets were used giving information on 144 different test set-ups. The parameters that were changed in the tests include the structural model, water level on the structure, ice speed, ice thickness, structure stiffness and the natural frequency of the structure. Measurements were made of forces, accelerations and displacement of the model during the interaction with ice. Four different ice-failure modes were identified: flexure, crushing, mixed mode and lock-in. The results gave information on the anticipated ice loads and the likelihood of ice-induced vibrations for both the first-mode and second-mode vibration frequencies. They also provided guidance on the optimum angle and cone-size for a protective ice collar for the wind turbines.
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Bergy-Bit Impact Study
(R.E. Gagnon IOT; M.E. Johnston, R.M.W. Frederking, G. Timco, CHC; C-CORE; R. Ritch, Avron Ritch; R. Brown, R.P. Browne Marine Consultants Ltd; CCG)
Small icebergs and house-sized pieces of glacial ice (bergy bits) pose a hazard to ocean-going vessels on the

Grand Banks of Newfoundland in weather conditions and sea states that reduce visibility. This is particularly true for tankers transporting oil from production sites here. The Bergy-Bit Impact Study is a major project that has been ongoing for several years and aims to provide simulations of the bergy-bit–ship interaction using a fully validated numerical model. A bergy-bit impact field study was successfully completed where the CCGS Terry Fox was instrumented to measure forces and pressures arising from bergy-bit impacts. Three types of instrument were used: an internally strain-gauged portion of the hull, a new external impact panel and a device (called MOTAN) for measuring whole ship motions. A Beowulf computer cluster has been assembled and commissioned that will conduct the numerical simulations. Data from the field tests, in addition to extensive previous in-house experimental data (reported in ICE, Number 125) will be used to validate the numerical model. Recently, novel ice-crushing experiments, that enable a detailed view of the crushing process from the side using high-speed video, have been performed. These data are useful for the ice-mechanics component of the numerical model. Another aspect of the project, not specifically related to the numerical simulations but of more general application, is the development a probabilistic pressure-area relationship for impact with glacial ice based on analysis of MOTAN data and all other available data on glacial and multi-year ice. This approach provides the only feasible means of representing the pressure-area data collected from more than 10 years of ship trials.
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Ship collisions with icebergs
(B.T. Hill, IOT)
An electronic database of approximately 650 events of ship collisions with icebergs in the Northern Hemisphere over the past 200 years has been compiled. The database is searchable by a number of different fields including vessel name, vessel type, geographical location, damage severity and iceberg size. Information includes, when known, such details as vessel characteristics, ship speed, weather and sea conditions, damage descriptions, fatalities, etc., as well as, when possible, images of the vessel, photographs of the damage, and charts showing the location of the collision in relation to the known ice conditions at the time of the accident. The database is available at http://iot-ito.nrc-cnrc.gc.ca/research_dbs.html where historical ice conditions for the east coast of Newfoundland, and the Gulf of St Lawrence and Scotian Shelf can also be found.
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Iceberg deterioration processes
(B. Liang, B. Veitch, C. Daley, OERC)
Iceberg shapes are of significant engineering interest. Shape is a key component of any motion, management, or load model involving icebergs. The deterioration processes that control the evolving shape of icebergs have been examined. Numerical, analytical and experimental studies of ice-block deterioration have been conducted as well as field studies of iceberg-deterioration events. Several processes deteriorate icebergs, including wave erosion and associated calving, natural and forced convective melting, solar-radiation melting, and fragmentation due to thermal and motion-induced stresses and reorientation (rolling). Some of these processes have been successfully modelled, while others present a significant numerical challenge, particularly in the area of finding a suitable geometric paradigm that can practicably reflect the shape-changing processes (e.g., automatic mesh regeneration or NURB modification).
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Determination of iceberg draft, mass and cross-sectional area
(A. Barker, M. Sayed, CHC; T.G. Carrieres, CIS)
A new operational iceberg-forecasting model deals with iceberg drift, deterioration, and calving. One of its main features is the use of detailed environmental conditions. In particular, the vertical distribution of the water current is used to calculate water-drag forces. An accurate description of keel geometry is needed in order to take advantage of the detailed water-current information so analyses have been done to determine the geometry of iceberg keels and sails. Available iceberg data were used to create empirical equations which describe keel cross-sectional areas at different depth intervals from a given waterline length. The equations also determine sail area, draft, and mass as functions of waterline length.
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MOTAN
(M.E. Johnston, R.M.W. Frederking, G.W. Timco, M. Miles, CHC)
An inertial measurement system called MOTAN has been developed to determine the accelerations and ice-induced global loads on ships. The system consists of two parts: an instrument for measuring whole-ship motions, and software for processing those motions to obtain global ice-impact loads. The system has been deployed on four different icebreakers with good success.
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Modeling and simulations of navigation in ice
(A. Derradji-Aouat, IOT; CeMS; C-CORE)
The objective of this project is to extend the capabilities of the Canadian Marine Simulator (CMS) of the CeMS to include modelling and simulations in ice-infested waters. Modeling is defined as the development of the necessary numerical, mathematical and empirical equations needed for the simulations. Simulations, however, are defined as the implementation of the modelling equations into the CMS and investigation of the human response to training in virtual environments. It is a multi-million dollar project involving several partners/collaborators. It includes three main components: (a) navigation in ice; (b) towing of icebergs/iceberg management; and (c) life-boat launching and safe offshore operations in harsh

environments. IOT is involved in all, but it is taking the lead role in the navigation-in-ice component. The project requires the latest and emerging technologies and mathematical models in ice engineering, state-of-the-art computers and software for the simulator, and a dedicated team to revolutionize how ice-engineering problems are studied in the future. Ultimately, the simulator will be used for training and education and as a virtual laboratory.
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ITTC procedure for experimental uncertainty analysis in ice testing
(A. Derradji-Aouat, IOT with NMRI, HUT, HSVA, Dalian University, China; University of Tokyo, Japan)
A procedure for Experimental Uncertainty Analysis (EUA) in ice-tank testing is being produced for the 24th International Towing Tank Conference (ITTC) Ice Specialist Committee for possible adoption by ice tanks worldwide. EUA is an analytical process for estimating the level of uncertainty (or the level of confidence) in the results of a given experimental program. Through this process, laboratories will be able to quantify the agreement (the closeness or the difference) between experimental results and actual "true" values. Until the late-1980s, only a marginal practice of experimental uncertainty analysis was reported by various marine-test facilities. During the 1990s, the ITTC and the International Ship and Offshore Structure Congress recommended and supported the application of uncertainty analysis in both experimental and computational (numerical) fields. This project included various model experiments of ships in ice (resistance and manoeuvring experiments). The data obtained from these tests are used to develop a methodology for calculating experimental uncertainties in ice tanks.
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Ice-scour processes: buoyant-ice model
(A. Barker, G.W. Timco, CHC)
A laboratory program was carried out to measure the loads and seabed response due to a buoyant ice-block scouring sand and gravel, representative of the Grand Banks seabed, offshore of eastern Newfoundland. The results complement previous experimental work carried out at the CHC, which used a rigidly affixed ice block to scour sediment material. The present study used the same sediment to create a model seabed; however, in this test series, the model was towed along an ice tank, free to move throughout the water column. Six tests were carried out. Fresh-water ice, built up into a large block with an overall dimension of 0.76×0.76×0.71 m, was used to scour the seabed at depths up to 0.2 m. The scouring loads, displacement, angular movements and resulting trenches were measured.
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Ice-scour processes: rigid-ice indentor
(A. Barker, G.W. Timco, CHC)
A laboratory study has been carried out to measure the loads and seabed response due to an ice block scouring a seabed. Fourteen tests (35 configurations) were performed with a variety of seabed types that are representative of the oil-discovery areas within the Jeanne d'Arc Basin area of the northeastern Grand Banks. The tests showed that the scour profiles were generally very uniform along each section of the test channels. The ice did not fail in shear, but general erosion was observed. Scour depths measured post test were smallest for scouring through a gravel seabed. Regression analysis yielded the following empirical relationships for the loads:

$P = -1.8v + 10.3h + 2.3B - 0.8$ for the gravel bed ($r^2 = 0.93$)

$P = 8.5v + 46.3h + 28.5B - 7.6$ for the sand bed ($r^2 = 0.90$)

$P = 53.4v + 45.8h + 13.5B - 11.3$ for the sand/gravel bed ($r^2 = 0.96$)

$P = 13.2v + 33.4h + 11.6B - 0.6S - 2.4$ for all seabeds ($r^2 = 0.74$)

where v is velocity (m^{-2}); h is scour depth (m); B is ice block width (m); and S is the seabed type, represented by the D50 value of the seabed material.
garry.timco@nrc-cnrc.gc.ca

Friction coefficient of a large ice block on a sand/gravel beach
(A. Barker, G.W. Timco, CHC)
The amount of ice ride-up on beaches and shorelines is a function of the slope of the beach, the driving force, the size of the ice blocks, and the friction between the ice and the beach. Predicting the amount of ride-up is difficult, primarily because little is known about the friction coefficient of large ice blocks on sand/gravel beaches. To investigate this, a test program was performed to measure the friction of a large block of ice sliding on a sand/gravel beach. Four different friction coefficients were measured, corresponding to the four modes of movement of the block on the beach: static, bulldozing, transition and sliding. The friction coefficient decreased as the movement mode changed from static to sliding. The statistical analysis of the friction coefficient values showed that the mean value generally decreased with an increase in velocity. The static friction values were approximately the same for each test. The implications of the results on the ride-up processes of ice on these types of shorelines were also examined.
garry.timco@nrc-cnrc.gc.ca

EXTRATERRESTRIAL

Mars Phoenix Lander Mission
(D.A. Fisher, NGP)
D. Fisher is providing advice on stable isotopes of water, ice rheology and glaciology for the Mars Phoenix Lander Mission. This mission is due for launch in 2007 to a site about 70° N latitude and will study Martian permafrost, soil chemistry and stable isotopes. Its mass spectrometer and chemical laboratory are capable of several life-detecting measurements.
fisher@nrcan.gc.ca

Contributed by C. Simon L. Ommanney
simon.ommanney@sympatico.ca

ABBREVIATIONS

AINA	Arctic Inst. of North America, Calgary, Alta T2N 1N4
AMSR	Advanced Microwave Scanning Radiometer
AO	Arctic Oscillation
ARI	Aurora Research Inst. (IRC/GNWT)
AS	Atmospheric Sciences
Astron	Astronomy
AVHRR	Advanced Very High Resolution Radiometer
Avron Ritch	Avron Ritch Consulting Ltd, 20 4th Avenue East, Vancouver, BC V5T 1E8
AWS	automatic weather station
BGC	Bristol Glaciology Centre, School of Geographical Sciences (UBris)
Biol	Biology/Biological Sciences
CARTEL	Centre d'applications et de recherches en télédétection (USher)
CCG	Canadian Coast Guard, (DFO), 200 Kent Street, Ottawa, Ont K1A 0E6
C-CORE	Centre for Cold Ocean Research and Engineering (MUN)
CCRC	Climate Change Research Center, Inst. for Study of Earth, Oceans and Space (UNH)
CCRS	Canada Centre for Remote Sensing (NRCan), Ottawa, Ont K1A 0Y7
CEA Saclay	CEA Saclay, Orme des Merisiers, F-91191 Gif-sur-Yvette Cedex, France
CEAM	Civil Engineering and Applied Mechanics
CeMS	Center for Marine Simulation, Fisheries and Marine Inst. (MUN), A1C 5R3
CEN	Centre d'Études nordiques (ULav)
CEOS	Centre for Earth Observation Science (UMAN)
CHC	Canadian Hydraulics Centre (NRCC), Ottawa, Ont K1A 0R6
CIN	Centre d'Ingenierie Nordique, École Polytechnique, Montréal, Qué H3C 3A7
CIS	Canadian Ice Service (MSC), Ottawa, Ont K1A 0H3
Civil	Civil Engineering
CPEOD	Climate Processes and Earth Observation Division (MSC/EC), Downsview, Ont M3H 5T4
CRRC	Cold Regions Research Centre (WLU)
DEM	digital elevation model
DFO	Dept of Fisheries and Oceans
DU	Dalhousie Univ., Halifax, NS B3H 4J1
EAS	Earth and Atmospheric Sciences
ERS	European Remote-sensing Satellite
EASE	Equal Area SSM/I
EC	Environment Canada
Eng	Engineering
ENSO	El Niño-Southern Oscillation
EnvS	Environmental Sciences
EOS	Earth Observing System
EOSc	Earth and Ocean Sciences
ESS	Earth and Space Sciences
ETM	Enhanced Thematic Mapper
GCM	General Circulation Model or Global Climate Model
GEnv	Geography and Environment
Geog	Geography
Geol/Geophys	Geology and Geophysics
GEWEX	Global Energy and Water Cycle Experiment

GI/UAK-F	Geophysical Inst., Univ. Alaska Fairbanks, P.O. Box 757320, Fairbanks, AK 99775, USA
GLAS	Geoscience Laser Altimeter System
GNWT	Government of the Northwest Territories
GSC	Geological Survey of Canada (NRCan)
GTS	Dept of Geography and Topographic Science
HSVA	Hamburgische Schiffbau-Versuchsanstalt GmbH, Bramfelder Strasse 164, D-22305 Hamburg, Germany
HUT	Helsinki Univ. Technology, P.O. Box 5300, FIN-02015 HUT Espoo, Finland
IACS	Inter. Assoc. of Classification Societies
IAR	Inst. for Aerospace Research (NRCC), Ottawa, Ont K1A 0R6
INAC	Indian & Northern Affairs Canada, Ottawa, Ont K1A 0H4
IOT	Inst. for Ocean Technology (NRCC), St. John's, Nfld A1B 3T5
IPA	Inter. Permafrost Assoc.
IPCC	Intergovernmental Panel on Climate Change
IRC	Inuvik Research Centre (GNWT), NWT X0E 0T0
LEGOS	Laboratoire d'Études en Géophysique et Océanographie Spatiale, 18 avenue Edouard Belin, F-31055 Toulouse Cedex 4, France
LGGE	Laboratoire de Glaciologie et Géophysique de l'Environnement, F-38402 Saint-Martin-d'Hères Cedex, France
MAGS	Mackenzie GEWEX Study
McGU	McGill Univ., Montréal, Qué H3A 2T5
Mech	Mechanical Engineering
MIT	Massachusetts Inst. of Technology, Cambridge, MA 02139-4307, USA
MODIS	Moderate-Resolution Imaging Spectrometer
MSC	Meteorological Service of Canada (EC), 4905 Dufferin Street, Downsview, Ont M3H 5T4
MUN	Memorial Univ. Newfoundland, St. John's, Nfld A1B 3X5
NASA	U.S. National Aeronautics and Space Administration
NESDIS	U.S. National Environmental Satellite, Data, and Information Service
NGP	National Glaciology Programme (GSC), Ottawa, Ont K1A 0E4
NIPR	National Inst. of Polar Research, Itabashi, Tokyo 173-8515, Japan
NMRI	National Maritime Research Inst., 6-38-1, Shinkawa, Mitaka-shi, Tokyo 181-0004, Japan
NOAA	U.S. National Oceanic and Atmospheric Administration
Noetix	Noetix Research Inc. 403-265 Carling Avenue, Ottawa, Ont K1S 2E1
NRCan	Natural Resources Canada
NRCC	National Research Council of Canada
NWRI	National Water Research Inst. (EC), 867 Lakeshore Road, P.O. Box 5050, Burlington, Ont L7R 4A6
NWRI/Sask	National Water Research Inst. (EC), 11 Innovation Boulevard, Saskatoon, Sask 7N 3H5
OCC	Oceanic Consulting Corp., St. John's, Nfld A1B 2X5
OERC	Ocean Engineering Research Centre (MUN)
PDO	Pacific Decadal Oscillation
Phys	Physics
PNA	Pacific North American Oscillation
SAR	synthetic aperture radar
SEAS	SEAS Distribution Amba, Slagterivej 25, DK-4690 Haslev, Denmark
SI	Science Institute, UIce
SMMR	Scanning Multichannel Microwave Radiometer
SNC-Lavalin	SNC-Lavalin, Energy Division, Montréal, Qué
SNOTEL	SNOw TELemtry automated system
SPRI	Scott Polar Research Inst., Cambridge CB2 1ER, UK
SSM/I	Special Sensor Microwave/Imager
SWE	snow water equivalent
Tél	Télédétection
TM	Thematic Mapper
TrentU	Trent Univ., Peterborough, Ont K9J 7B8
UAber	Univ. of Aberdeen, Elphinstone Road, Aberdeen AB24 3UF, Scotland, UK
UAK-F	Univ. Alaska Fairbanks, Fairbanks, AK 99775-7320, USA
UAlb	Univ. of Alberta, Edmonton, Alta T6G 2E3
UBC	Univ. British Columbia, Vancouver, BC V6T 1Z4
UBris	Univ. Bristol, Bristol BS8 1SS, UK
UCal	Univ. Calgary, Calgary, Alta T2N 1N4
UCam	Univ. Cambridge, Cambridge CB2 3EN, UK
UCO-B	Univ. Colorado, Boulder, CO 80309, USA
UGlas	Univ. Glasgow, Glasgow G12 8QQ, Scotland, UK
UIce	Univ. Iceland, Dunhaga 5, IS-107 Reykjavík, Iceland
UJF	Univ. Joseph Fourier, B.P. 53, Grenoble Cedex 9, F-38041, France
ULav	Univ. Laval, Québec, Qué G1K 7P4
ULeth	Univ. Lethbridge, Lethbridge, Alta T1K 3M4
UMAN	Univ. Manitoba, Winnipeg, Man R3T 2N2
UNBC	Univ. Northern British Columbia, Prince George, BC, V2N 4Z9
UNH	Univ. New Hampshire, Durham, NH 03824-3525, USA
UOtt	Univ. Ottawa, Ottawa, Ont K1N 6N5
UQAC	Univ. du Québec à Chicoutimi, Qué G7H 2B1
USher	Univ. de Sherbrooke, Sherbrooke, Qué J1K 2R1
UTorE	Univ. Toronto, Erindale Campus, Toronto, Ont L5L 1C6
UVic	Univ. Victoria, Victoria, BC V8W 2Y2
UWash	Univ. Washington, Seattle, WA, 98195, USA
UWat	Univ. Waterloo, Waterloo, Ont N2L 3G1
WLU	Wilfrid Laurier Univ., Waterloo, Ont N2L 3C5

INTERNATIONAL GLACIOLOGICAL SOCIETY

IGS STAFF CHANGES

Last June the IGS hired Ali Woollatt as a typesetter/programmer/TeXpert. Ali came to us from Cambridge University Press, where she had been the resident TeX/LaTeX expert. She has written several class files for books and journals in LaTeX for CUP.

She is a graduate from Loughborough University with an honours degree in Engineering Science and Technology.

Ali has been attacking the backlog of papers that needed typesetting and she has also been working on implementing some of the more complex features of our typesetting programme, 3B2, which we have not been using to its full potential.

Her e-mail is ali@igsoc.org and if you have any questions regarding anything in TeX or LaTeX feel free to contact her.

JOURNAL AND *ANNALS* BACK ISSUES ON THE WEB

At its meeting in Portland in July 2003, Council agreed to have quite a few back issues of the *Journal of Glaciology* and *Annals of Glaciology* put on the web through our regular web publisher Ingenta. These are *Journal* issues 151 onwards and *Annals* volume 28 onwards. These were the issues that could easily be converted to web format. To go further back would involve considerably more effort and cost. How the Society proceeds depends on how this addition is received by the IGS membership.

Ingenta will be launching its new website near the end of September. The new paths will be:

for the *Journal*

`http://www.ingentaconnect.com/journals/browse/igsoc/jog`

and for the *Annals*

`http://www.ingentaconnect.com/journals/browse/igsoc/agl`

IGS members have free access to the *Journal*. All you, as a member, need to do is to register with Ingenta, then activate your personal subscription to the *Journal*. Ingenta will automatically query the IGS office to confirm your membership and subsequently notify you. You will then have free access to all the *Journal* issues available on the web as long as you are a member of the IGS.

It is also possible to purchase individual articles through the website. The price is US$ 35 plus tax per article.

Free access to electronic versions of the individual volumes of the *Annals* is available to everyone who attended the relevant symposium or has subsequently purchased a printed copy. Similarly, all you have to do is to register with Ingenta and activate your personal subscription to the *Annals* volume in question. Remember, you only have to register with Ingenta once. They will then query the IGS office to confirm that you attended the meeting or have subsequently purchased a volume.

JOURNAL OF GLACIOLOGY

Papers accepted for publication between1 January 2004 and 30 June 2004. Some of these papers have already been published.

Perry Bartelt and Othmar Buser
The principle of minimum entropy production and snow structure

Carl Egede Bøggild, Ole B. Olesen, Andreas P. Ahlstrom and Peer Jorgensen
Instruments and Methods: Automatic glacier mass balance observations using pressure sensors

Adam K. Bucki, Keith A. Echelmeyer and Scott MacInnes
The thickness and internal structure of Fireweed Rock Glacier, Alaska as determined by geophysical methods

Leif H. Cox and Rod S. March
Comparison of geodetic and glaciological mass balance techniques, Gulkana Glacier, Alaska

J. Freitag, F. Wilhelms and S. Kipfstuhl
Microstructure dependent densification of polar firn derived from X-ray microtomography

Neil F. Glasser, Stephen J. Coulson, Ian. D. Hodkinson and Nigel R. Webb
Photographic evidence of the return period of a Svalbard surge-type glacier: a tributary of Pedersenbreen, Kongsfjord

Mats A. Granskog, Kristiina Virkkunen, David N. Thomas, Jens Ehn, Harri Kola and Tonu Martma
Chemical properties of brackish water ice in the Bothnian Bay, the Baltic Sea

Wilfried Haeberli, Regula Frauenfelder, Andreas Kääb and Stephan Wagner
Characteristics and potential climatic significance of miniature ice caps (crest- and cornice-type low-altitude ice archives)

W. D. Harrison, M. Truffer, K. A. Echelmeyer, D. A Pomraning, K. A. Abnett and R. H. Ruhkick
Instruments and Methods: Probing the till beneath Black Rapids Glacier, Alaska

Robert L. Hawley, Edwin D. Waddington, Gregg W. Lamorey and Kendrick C. Taylor
Vertical-strain measurements in firn at Siple Dome, Antarctica

Lesley Hill, Edward Lozowski and Russell D. Sampson
Experiments on ice spikes and a simple growth model

C.M. Hofstede, R.S.W. Van de Wal, K. Kaspers, M. R. Van den Broeke, L. Karlof, J.-G. Winther, E. Isaksson, G. Lappegard, R. Mulvaney, H. Oerter and F. Wilhelms
Firn accumulation records for the past 1000 years on the basis of dielectric profiling of six cores from Dronning Maud Land, Antarctica

Bryn Hubbard, Neil Glasser, Michael Hambrey and James Etiene
A sedimentological and isotopic study of the origin of supraglacial debris bands: Kongsfjorden, Svalbard

Ian R. Joughin, Slawek Tulaczyk, Douglas R. MacAyeal and Hermann Engelhardt
Melting and freezing beneath the Ross Ice Streams, Antarctica

Max Konig, Jan-Gunnar Winther, Jack Kohler and Florian Konig
Two methods for firn area and mass balance monitoring of svalbard glaciers with synthetic aperture radar (SAR) satellite images.

B. Legresy, A Potzsch, I. Tabacco, F. Remy and R. Dietrich
Influence of tides and tidal current on the Mertz Glacier, Antarctica

K. G. Libbrecht and K. Lui
An investigation of laboratory-grown "ice spikes"

A. Mahoney, H. Eicken, L. Shapiro and T. C. Grenfell
Ice motion and driving forces during a spring ice shove on the Alaskan Chukchi Coast

Joachim Mathiesen, Jesper Ferkinghoff-Borg, Mogens H. Jensen, Mogens Levinsen, Poul Olesen, Dorthe Dahl-Jensen and Anders Svensson
Dynamics of crystal formation in the Greenland NorthGRIP ice core

Kenichi Matsuoka, Ryoji Saito and Renji Naruse
A novel backpackable ice-penetrating radar system

Kenichi Matsuoka, Seiho Uratsuka, Shuji Fujita and Fumihiko Nishio
Ice-flow-induced scattering zone within the Antarctic ice sheet revealed by high-frequency airborne radar

D. Scott Munro
Revisiting bulk heat transfer on the Peyto Glacier in light of the OG parameterization

Julian B. Murton, Richard I. Waller, Jane K. Hart, Colin A. Whiteman, Wayne H. Pollard and Ian D. Clark
Stratigraphy and glaciotectonic structures of permafrost deformed beneath the northwest margin of the Laurentitde ice sheet, Tuktoyaktuk Coastlands, Canada

Antoine Pralong and Martin Funk
A level set method for modeling the evolution of glacier geometry

Christian Schoof
On the mechanics of ice stream shear margins

Hou Shugui, Jean Jouzel, Jérôme Chappellaz, Qin Dahe, Valérie Masson-Delmotte, Ulrich Shin Sugiyama and G. Hilmar Gudmundsson
Short-term variations in glacier flow controlled by subglacial water pressure and Lauteraargletscher, Bernese Alps, Switzerland

Monica Sund and Trond Eiken
Dynamics and surge of a polythermal glacier: Hessbreen, Svalbard

K.C. Taylor, R.B. Alley, D.A. Meese, M.K. Spencer, E.J. Brook, N.W. Dunbar, R. Finkel, A.J. Gow, A.V. Kurbatov, G.W. Lamorey, P.A. Mayewski, E. Meyerson, K. Nishiizumi and G.A. Zielinski
Dating the Siple Dome, Antarctica ice core by manual and computer interpretation of annual layering

Tina Tin, Ralph Timmermann and Martin O. Jeffries
Field and numerical study of the evolution of sea ice thickness in the Ross Sea 1998/1999

David G. Vaughan, P.S. Anderson, J.C. King, G.W. Mann, S.D. Mobbs and R. S. Ladkin
Imaging of firn isochrones across an Antarctic Ice Rise and implications for patterns of snow accumulation rate

Andreas Vieli, Jacek Jania, Heinz Blatter and Martin Funk
Short-term velocity variations on Hansbreen, a tidewater glacier in SpitsbergenJerome Weiss
Subcritical crack propagation as a mechanism of crevasse formation and iceberg calving

Xiaolan Wu and K.C. Jezek
Antarctic ice sheet balance velocities from merged point and vector data

Yongfu Xu and Yanjun Du
A fractal model for ice fragmentation

CORRECTIONS AND ERRATA

Unfortunately, on occasion, mistakes creep into our publications. Usually we try and publish corrections in subsequent issues in the case of the *Journal*, but in the case of the *Annals* it is more difficult. Hence we are going to publish all corrections in ICE in the future and whenever possible in the *Journal* also.

In Journal vol. 49, issue 166 the affiliation of the authors was printed incorrectly. The article is Rempel and Wettlaufer, *Isotopic diffusion in polycrystalline ice* on page 397. The correct association should have been:

Alan W. Rempel, Department of Geology and Geophysics, Yale University, New Haven, Connecticut 06520.

Present address: Division of Engineering and Applied Science, Harvard University, 29 Oxford St., Cambridge, Massachusetts, 02138

and

John S. Wettlaufer, Departments of Geology and Geophysics and Physics, Yale University, New Haven, Connecticut 06520

Another mistake occurred in Journal vol. 49, but this time in issue 167. The first name of one of the authors was mistakenly reported as Paul when it should have been Patricia. The article in question is Th. Thorsteinsson and others, *Bed topography and lubrication inferred from surface measurements on fast-flowing ice streams* on page 481.The list of authors should have been as follows:

Throstur Thorsteinsson, Charles F. Raymond, G. Hilmar Gudmundsson, Robert A. Bindschadler, Patricia Vornberger and Ian Joughin

GLACIOLOGICAL DIARY

** IGS sponsored * IGS co-sponsored

2004

5–7 October 2004
18th International Forum For Research Into Ice Shelf Processes (Frisp), AWI's Biological Institute, Adrian Jenkins, a.jenkins@bas.ac.uk
Web:http://www.awi-bremerhaven.de/Workshops/FRISP-04

6–8 October 2004
Workshop On "Mountain Glaciers And Society: Perception, Science, Impacts And Policy"
Wengen, Switzerland, Javier G. Corripio, Javier.Corripio@ethz.ch
Web:www.unifr.ch/geoscience/geographie/EVENTS/Wengen/04/Wengen2004.html

15–16 October 2004
North West Glaciology Meeting, Seattle, USA
Professor Edwin D. Waddington, Dept of Earth and Space Sciences, Box 351310, University of Washington, Seattle WA 98195-1310 USA
Email: edw@ess.washington.edu
Web:http://www.ess.washington.edu/Surface/Glaciology/nwg_04.html

16–17 November 2004
Workshop on EOS Snow and Ice Products. Goddard Space Flight Center in Greenbelt, Maryland, Dorothy Hall at NASA/GSFC Dorothy.K.Hall@nasa.gov, Marilyn Kaminski at NSIDC marilynk@nsidc.org.

2005

24–25 February 2005
9th Alpine Glaciological Meeting, Milano, Italy
Claudio Smiraglia, claudio.smiraglia@unimi.it and Guglielmina Diolaiuti guglielmina.diolaiuti@unimi.it
Web: http://users.unimi.it/glaciol/

3–9 April 2005
VIIth IAHS Scientific Assembly, Foz do Iguaçu, Brazil
1) Symposium on Contribution from Glaciers and Snow Cover to Runoff from Mountains in Different Climates
2) Workshop on Andean Glaciology
see http://www.cig.ensmp.fr/~iahs/

11–15 April 2005

Cryosphere - The "Frozen" Frontier of Climate Science: Theory, Observations, and Practical Applications
China Meteorological Administration, Beijing, China
see http://clic.npolar.no/meetings/first/

2–11 August 2005

IAMAS General Assembly. Beijing, China
Web: http://www.iamas.org/

Workshop on Glacier Mass Balance and its Coupling to Atmospheric Circulation
Principal Convener: Prof. Peter Jansson, University of Stockholm, Sweden; Secretary of ICSI. E-mail: peter.jansson@natgeo.su.se

Workshop on Mountain Snow and Ice Cover
Principal Convener: Paul Foehn, Swiss Federal Institute for Snow and Avalanche Research SLF, e-mail: foehn@slf.ch

Workshop on Modeling Forest Snow Processes
Principal Convener: Richard Essery, Centre for Glaciology, Institute of Geography and Earth Sciences, University of Wales, Aberystwyth
e-mail: rie@aber.ac.uk

23–27 August 2005

* Conference on Glacial Sedimentary Processes and Products, Aberystwyth, UK
Centre for Glaciology, Institute of Geography and Earth Sciences, University of Wales, Aberystwyth SY23 3DB, UK
Email: Michael Hambrey mjh@aber.ac.uk, Neil Glasser nfg@aber.ac.uk, Bryn Hubbard byh@aber.ac.uk

1–10 September 2005

The 11th International Conference and Field Trip on Landslides (CFL), Norway
Email: icfl05@ivt.ntnu.no
Web: www.ivt.ntnu.no/ICFL05

5–9 September 2005

** International Symposium on High-elevation Glaciers and Climate Records, Lanzhou, People's Republic of China
Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, UK
Web: http://www.igsoc.org/symposia/

10–14 October 2005

Third International Conference on the Oceanography of the Ross Sea, Antarctica, Venice, Italy
Jane Frankenfield Zanin, CNR-ISMAR (Istituto di Scienze Marine), San Polo 1364, 30125 Venezia, Italy
Email: jane.frankenfield@ve.ismar.cnr.it

5–9 December 2005

** International Symposium on Sea Ice, New Zealand
Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, UK
Web: http://www.igsoc.org/symposia/

BOOKS RECEIVED

J. L. Bamber and A J Payne *eds.* 2004. *Mass balance of the Cryosphere: Observations and modelling of contemporary and future changes.* Cambridge University Press. xvi+644 pp. (ISBN 0-521-80895-2 (hardback), £ 85 (US$ 130))

D. N. Thomas. 2004. *Frozen Oceans: the floating world of pack ice.* Natural History Museum, London. 224 pp. (ISBN 0-565-09188-3)

Sveinn Pálsson. 2004. *Icelandic Ice Mountains: on the basis of a journey to the most prominent of them in 1792 –1794.* An annotated and illustrated English translation. R.S. Williams Jr. and O. Sigurðsson, editors. The Icelandic Literary Society, Reykjavík. xxxvi + 183pp. (ISBN 9979-66-146-1)

W. Dansgaard, 2004. *Frozen Annals: Greenland ice sheet research.* Aage V. Jensens Foundations, Denmark. 122 pp. (ISBN 87-990078-0-0)

NOTES FROM THE PRODUCTION TEAM

To further help us in speeding up production we will be publishing, here in ICE, a few guidelines on how to present your papers. Below is the first of these.

PRESENTATION OF ACCEPTED PAPERS

The final version of your papers can be submitted to us in several ways: on CD by mail; by e-mail to journal@igsoc.org, annals@igsoc.org; or via the IGS ftp site (igsoc@igsoc.org will supply you with details on request).

Please include text, references, figure captions and tables in one file, not several separate files, with tables and figure captions at the end of the file. Our copy editing is always done in Word, so ideally your file should be in Word; or TeX or Latex, which we convert to Word for editing. We'd be very grateful if you did NOT use hypertext in your paper as it sends our copy-editing template into meltdown! We have to re-key equations, which can be very time-consuming, if they are embedded in the text or submitted as illustrations, so it would be very helpful if you could submit equations in MathType or equation editor, if using Word, or in TeX.

The name of the submitted file should include the number originally assigned to the original paper, e.g. `04J234_main.doc` or `42A345_main.tex.`

Figures should be in individual and separate files and can be sent as eps, pdf, ps, tif or psd files. The names of the files should reflect the number originally assigned to the paper and the number of the figure, e.g. <paper_number>_fig1, <paper_number>_fig2 etc.

Thank you for your help!
Christine Butler
Production Manager

NEW MEMBERS

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