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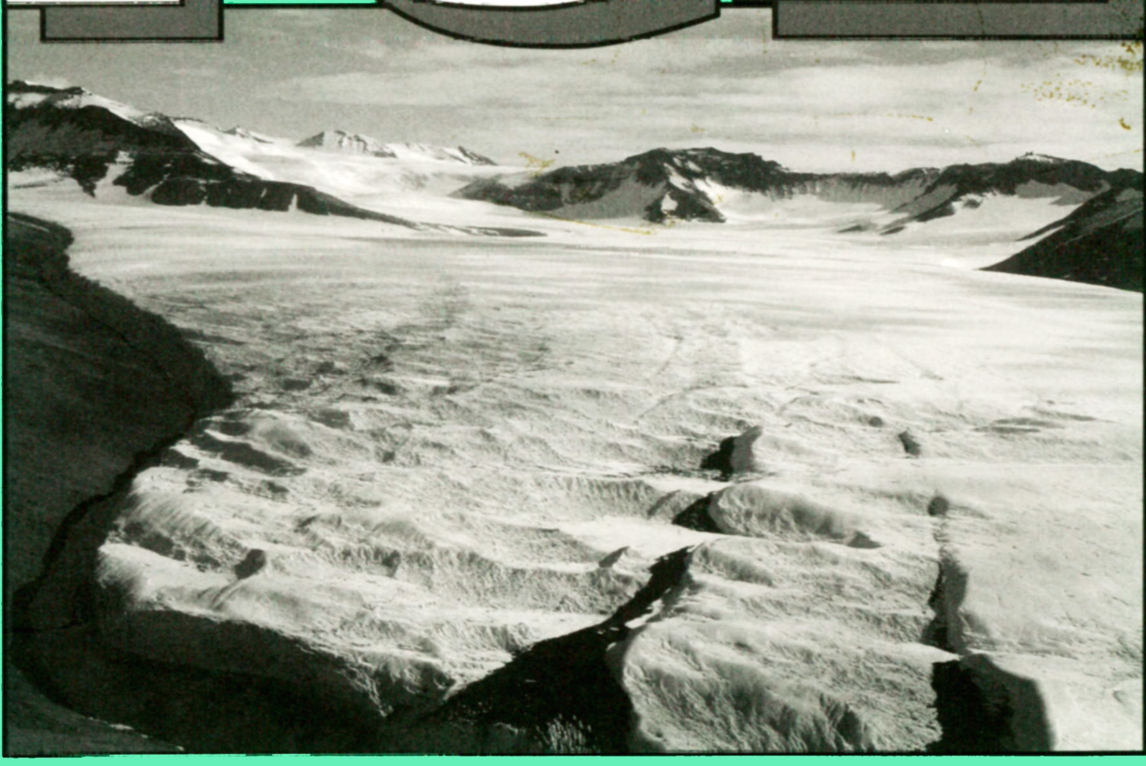

NEWS BULLETIN OF THE INTERNATIONAL GLACIOLOGICAL SOCIETY

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CONTENTS

COVER PICTURE: Victoria Lower Glacier, Dry Valleys, Antarctica, 16 January 1998. (Photograph by Konrad Steffen)

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

NEW ZEALAND

(For abbreviations used see page 22)

GLACIAL GEOLOGY

McMurdo Sound area, Antarctica

(P. Augustinus, Geol/UAuck)
Research in Antarctica in summer 1999/2000 involved high-resolution ground-penetrating-radar imaging of raised beaches in the McMurdo Sound area. The objective was to evaluate the depth, stratigraphy and evolution of the beaches rapidly in a non-destructive manner, as well as to identify and select targets for later shallow drilling of the frozen sediments. We now have a database of GPR images from fossil beaches from most of the southern Ross Sea beaches.

Rennick Glacier area, Antarctica

(P. Augustinus, Geol/UAuck; D. Fabel, R. Brown ES/UMel; D. Fink, ANSTO)
The 2000/2001 Antarctic field season involved mapping of glacial geology and selection of material from the lower Rennick Glacier area of northern Victoria Land, to develop a ^{10}Be and ^{26}Al exposure-age-based chronology of late-Pleistocene glacial advances. Similar work was undertaken in 2000 on late-Pleistocene glacial sequences in western Tasmania and the northern Southern Alps of New Zealand to identify not only the timing of the latest phases of ice expansion on a hemisphere-wide basis, but to test for hemispheric synchroneity of the causative events. This work will continue in the Rennick Glacier area during the 2001/2 season.

Allan Hills, south Victoria Land, Antarctica

(P.J. Barrett, ES/VUW)
The Allan Hills, a nunatak 1800–2300 m a.s.l. behind the Transantarctic Mountains, covers about 100 km^2. In the centre, it contains seven patches of compact glacial till covering about 2 km^2. These deposits have been studied by field parties from the University of Bern (surface age dating, C. Schlüchter), the University of Amsterdam (subglacial deformation and micromorphology, J. van der Meer) and VUW (glacial geology). The deposits record the last time when wet-based East Antarctic ice flowed over this low point in the Transantarctic Mountains. Striae and other direction indicators show that regional flow was from east to west, and record a late-stage topographically controlled flow from south to north. The deposits cannot be dated directly, but surface age dates from the region >10 Ma suggest that they are at least as old and likely much older.

Cape Roberts project

(P.J. Barrett, ES/VUW; Cape Roberts Science Team)
The project developed in 1993 from earlier drilling on fast ice in McMurdo Sound, Antarctica. The aim is to investigate the early climate and tectonic history of the East Antarctic ice sheet and the West Antarctic rift system 34–17 million years ago by drilling off Cape Roberts (77.0°S, 163.7°E). We have drilled through the western margin of the Victoria Land Basin, a sedimentary succession 1500 m thick, dating from 34 to 17 Ma, and 100 m into the underlying basement, Beacon sandstone of Devonian age (~350 Ma).

The Cape Roberts Project is a cooperative venture between Australia, Britain, Germany, Italy, The Netherlands, New Zealand and the U.S.A. The key is a 55 tonne drilling system, set up 13–16 km offshore in early October on fast sea ice. Water depths were 153–295 m and core recovery for the 1680 m drilled was 95%.

The cores provide a nearshore marine sedimentary record, continuous and detailed for some intervals but with a number of significant time breaks due to erosion or non-deposition. The strata show that:

- The Ross Sea coast had a cool temperate climate with a low woodland vegetation (Nothofagidites, podocarps and palms) from 34–24 Ma when mountain glaciers and probably inland ice sheets were releasing icebergs to the Ross Sea;
- the period 24 to 17 Ma was cooler, with a low-growing sparse tundra on adjacent mountains, and periods of more extensive grounded ice offshore;
- the Transantarctic Mountains had achieved most of their present height by 34 Ma, whereas most subsidence in the adjacent Victoria Land basin took place 34 to 17 Ma ago. The cores provide the first measure of the frequency of the growth and collapse cycles of the Antarctic ice sheet in the distant past (100,000 years or less around 24 million years ago).

Detailed results from individual drill holes have been published in Terra Antartica. More information can also be found at http://www.geo.vuw.ac.nz/croberts/.

Southern Alps, Aoraki Sheet (1:250,000)

(S. Cox, D. Barrell, IGNS)
Visitors to New Zealand's Southern Alps glaciers will soon have access to a modern interpretation of the geology of the area. The old Mt Cook 1:250,000 map sheet of 1967 is being revised, with much of the area being revisited. The new map and bulletin is scheduled for publication in 2004.

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Aggradation of Waiho River, South Westland

(M.J. McSaveney, IGNS; T. Davies, LU)
The Waiho River at the bridge beside Franz Josef Glacier Village has aggraded persistently since the 1930s and buried the site of the original swing bridge

across the Waiho Gorge. Past studies blamed advances of the Franz Josef Glacier, but the escalating flood-hazard problem is a direct result of earthworks built to confine the active channel to a small sector of the river's otherwise active alluvial fan. Without the confining banks, the river bed would never have risen to the level now achieved, where it threatens parts of the village on the upthrown side of the Alpine Fault.

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River sediment yields from cosmogenic ^{10}Be

(M.J. McSaveney, IGNS)

Many rivers draining the Southern Alps are unrated for river flow or sediment discharge, but it would be very useful to have reliable estimates of their sediment yields. Work with in-situ-produced ^{10}Be shows that measured basin mean annual denudation rate is highly correlated with the apparent mean surface-exposure age of quartz pebbles at the basin outlet as determined from ^{10}Be over the range 30–30,000 tonnes km^{-2} a^{-1}. At the highest denudation rates, however, ^{10}Be seems not to be the cosmogenic isotope of preference, because of its relatively low production rate.

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CLIMATE STUDIES

Climate and landscape history from shallow drilling of Antarctic ground ice

(W.W. Dickinson, ES/VUW)

A climate record from Antarctic ground ice and soils will be recovered using a new portable drill. The cores potentially will hold detailed climate information dating to 15 Myr ago. The cored material will also provide stratigraphic information for ground-penetrating radar studies and outcrop maps of glacial sediments.

The origin of ground ice at high elevations (<1000 m) throughout the Dry Valleys of Antarctica is unclear because there is no obvious contemporary source of water. The possibilities are: (1) the water only came with the original deposition of the sediments; (2) additional water was introduced after deposition during an undocumented warm period in Antarctic history, or; (3) additional water has condensed from atmospheric vapour and diffused into the ground over millions of years.

Holocene climate record, Dry Valleys

(N.A.N. Bertler, P.J. Barrett, W.W. Dickinson, J. Shulmeister, A. Pyne, ARC/VUW; P.A. Mayewski, K.J. Kreutz, IQCS/UME; M. Twickler, CCRC-EOS/UNH)

We are obtaining a Holocene climate record of the Dry Valleys area, Antarctica, from ice cores from the Victoria Lower Glacier (VLG) system. The dynamic climate system of Victoria Valley is created by the interacting influences of the Dry Valleys, the East Antarctic ice sheet and the Ross Sea. The sensitive balance and strong contrasts in this system mean even subtle shifts in the regional annual temperature, sea-ice extent, snow cover, etc, significantly alter the local weather pattern. The Victoria Valley provides an ideal opportunity to study rapid, high-frequency climatic variations.

The VLG is a small, independent glacial system (max. thickness 350 m), with a dome at 750 m a.s.l., at the mouth of the dry Victoria Valley. The dome is under the immediate influence of the Dry Valleys summer quasi-stable high-pressure cell, the East Antarctic katabatics and the Ross Sea moisture flux. Shallow (30 m) firn cores have been recovered from the VLG and vicinity and have been analysed for physical properties, dust content, major ion composition and isotopic ratios. The results display the dynamics of the Victoria Valley during the last 200 years, and confirm the value of a long paleoclimate record. A 240 m ice core from the VLG is expected to provide a continuous dataset of 10,000 years climate history of the Dry Valleys area, and will be recovered during the 2001/2002 season.

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Third Assessment Report of the Intergovernmental Panel on Climate Change

(B.B. Fitzharris, Geog/UOtago)

Blair Fitzharris has been a Coordinating Lead Author for the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), assessing the impact of climate change on the polar regions. The results will appear as Chapter 16 of the IPCC report due to be published in mid-2001.

B. Fitzharris and G. Clare (Geog/UOtago) and T. Chinn, J. Salinger and J. Renwick (NIWA) have continued their research on variations in end-of-summer snowlines of glaciers of the Southern Alps and the associated hemispheric-scale climatic controls.

Climate monitoring, Scott Base

(A. Harper, NIWA)

Daily climate observations have been made at Scott Base since March 1957; one of the longest continuous records in Antarctica. The parameters measured are wind speed and direction, air temperature, barometric pressure, and global, direct and diffuse solar radiation. The instrumentation and method has remained the same throughout, ensuring a good homogeneous record.

In December 1996, an electronic weather station (EWS) was installed beside the existing manual instruments. The EWS logs 10 min and hourly mean data for all parameters, maximum wind gust (3 s) and temperature data each hour as well as 1 min means for temperature and pressure to enable good data compatibility with the historical and current manual readings. All data are archived on the National Climate Database managed by NIWA.

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Climate change and natural hazards, Ruapehu Volcano, New Zealand

(J.R. Keys, Department of Conservation, Turangi)

Extreme climatic events over the last few decades have resulted in occasional slush avalanches with implica-- tions for ski-area management. Both increased and decreased frequency of snow avalanches has occurred in different seasons. "Extreme" warm temperatures, heavy precipitation and thick or thin seasonal snow depths have occurred in response to Southern Oscillation extremes and large sulphur-rich ash plumes from SE Asia volcanoes. Mean daily air temperatures in winter have changed little since the 1950s, but may be starting to warm more significantly now although any increases are so far still less in winter than in other seasons. Precipitation has changed on decadal scales, becoming wetter in late winter/early spring, and the number of both heavy rain days and rain events has increased. Hazards not usually encountered on Ruapehu, including slush avalanches in winter or spring and mass movement from an area of unstable hydrothermally altered rock, now have higher occurrence probabilities. Increased vigilance is needed to mitigate risks.

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Inter-regional atmospheric dust transport: evidence of contemporary processes from the Southern Alps, New Zealand and Victoria Land, Antarctica

(H.A. McGowan, S.K. Marx, B.F. Ayling, ES/VUW)
This research should throw new light on the nature of inter-regional atmospheric transport of particulate — specifically mineral dust. There is particular interest in the frequency and magnitude of long-range dust trans-port from principal dust sources in the Southern Hemisphere such as Australia. Evidence of this dust transport is believed to be preserved in the perennial snowfields and glaciers of the Southern Alps, New Zealand, where precipitation scavenging of atmospheric particulate occurs during westerly airflow.

Identification of aeolian dusts retrieved from snow and ice pits/cores and their probable source areas is made on the basis of grain-size, shape, colour and mineralogy, while biogenic material contained within the samples such as diatoms, phytoliths and pollens provide further evidence of the source area. Recently, samples of aeolian dust collected from Fox Glacier were identified as having originated from the arid grasslands of western Queensland, Australia. The mean grain-size of these samples was 17–20 μm, and they contain a high abundance of charcoal. Atmospheric transport of grains of this size from their source to Fox Glacier is believed to be associated with the passage of troughs and cold fronts over western Queensland. Such weather systems are required to produce the necessary vertical velocities in the airstream to suspend dust grains of this size for several days, thereby enabling their long range (2500–3000 km) atmospheric transport. Consequently, this study is also providing information on regional synoptic-scale circulation patterns (e.g. mid-latitude depressions and anticyclones).

In December 2000, sampling was extended to the Baldwin and Victoria Glaciers, Antarctica, as part of a palaeoclimate study. Dust samples, collected from snow-pits excavated to approximately 4.5 m, are currently undergoing laboratory analysis to determine their source and transport histories. Results will contribute further to our knowledge of atmospheric dust transport in the Southern Hemisphere and its role in biogeochemical cycles and regional climate systems.

SEA ICE

Light propagation in sea-ice

(P.E. Bond, Phys/UOtago)
Beam-spread measurements were performed on first-year sea ice and laboratory grown NaCl ice to determine the influence of the ice structure on the propagation of light at optical wavelengths. Subsequent Monte Carlo modelling of the beam-spread profiles revealed the assumption of optically flat air–ice interfaces to be inappropriate for modelling ice whose surfaces were smooth to the touch. The effects of an air-filled, vertical, spreading crack in the ice were found to be insignificant to the horizontal propagation of light. Considerable attenuation of light was observed for cracks containing snow and refrozen slush. A preferential direction for the propagation of light in the horizontal plane was found in the first-year ice at Cape Evans, McMurdo Sound, Antarctica. This direction coincided with the basal plane of the aligned ice platelets observed at depths >0.2 m.

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Sea-ice studies using NMR techniques

(P.T. Callaghan and colleagues, IFS/MAU)
Since 1994, a team from MAU has been using a Nuclear Magnetic Resonance (NMR) apparatus specially constructed for use in Antarctica to measure brine content and brine mobility in sea ice. The method relies on the use of pulsed magnetic field gradients in precise analogy to well-established laboratory procedures. One version of the apparatus uses ice-core samples which were subsequently analysed on site. A later version uses a probe head inserted into the ice sheet, thus minimizing any sample perturbation. The diffusive motion of water molecules in brine inclusions has been found to be strongly anisotropic, and, over short length scales, to exhibit a rapidity greatly in excess of that expected for thermal equilibrium Brownian behaviour, an effect attributed to convective transport. These studies were carried out in McMurdo Sound, near Inaccessible Island, in October 1995 and October 1997.

In October 1999, an improved apparatus was taken to the same site. It further reduces ice-sheet perturbation by reducing the diameter of the magnetic field gradient coils. These measurements of Antarctic sea-ice brine diffusivity are consistent with previous studies.

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Modelling and measurement of ocean-wave propagation in the MIZ and in fast ice

(C. Fox, Math/UAuck; M. Meylan, MAU/Albany Campus; T.J. Haskell, IRL)
Models are being developed for ocean-wave propagation, scattering, and damping in pack ice, with validation using measurements of wave dispersion in the Antarctic MIZ. Semi-empirical propagation and scattering models are being developed based on the linear Boltzman equation. Measurements to date have been made by instrumenting floes to determine the (directional) relationship between wave period and wave

length. An associated program is to determine ocean-wave propagation and scattering in fast-ice covers. The same team is conducting field work in McMurdo Sound, focusing on measurement of the maximum length scale over which the period/wavelength relationship can be derived by modelling the ice sheet as having homogeneous mechanical properties.

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Analytic methods for calculating wave/ice interaction

(C. Fox, H. Chung, Math/UAuck)

Mathematical methods are being developed for calculating the motion of floating ice when subject to ocean-wave forcing. The project focuses on relatively idealized geometries such as forcing at a straight ice edge, propagation across straight cracks and straight transitions in ice thickness, etc. The main techniques used are the boundary-integral method and the Wiener-Hopf method, both leading to easily computed solutions, expressed as sums over the natural modes, for all the geometries described above. Current research is into expressing the crucial step in the Wiener-Hopf method (an application of Liouville's theorem) in the context of the boundary-integral method with the aim of substantially reducing the numerical effort required to solve in more general geometries. As by products, that work has led to a simple form for the Green's function for forcing of a floating ice sheet, and a scaling law for the flexural motion of ice sheets.

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Wave-induced break-up of sea ice

(T.J. Haskell, IRL; P.J. Langhorne, V.A. Squire, M.A. Gribble, Phys/UOtago; C. Fox, Math/UAuck)

It is well known that an incoming ocean swell produces a strain field in a landfast ice sheet. The attenuation and spectral content of this strain field can be calculated and has been measured. The response of sea ice to this type of cyclic forcing has also been measured and the number of cycles to failure for sea ice loaded at constant amplitude estimated. The response of the landfast ice sheet or vast floe to a measured ice-coupled wave field of variable amplitude is considered. The Palmgren–Miner cumulative damage law is used, with stress–lifetime curves taken from field experiments in McMurdo Sound, Antarctica, to predict the lifetime of the sea-ice sheet as a function of significant wave height and sea-ice brine fraction. Calculations have been performed to account for the swell entering a landfast sea-ice sheet at an arbitrary angle. The influence of *c*-axis alignment and the presence of pre-existing cracks are also considered.

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Properties of refrozen cracks in sea ice

(T.J. Haskell, IRD; P.J. Langhorne, Phys/UOtago)

Refrozen cracks are a feature of most landfast sea-ice sheets. The refreezing of a liquid-filled crack involves heat flow in two-dimensions, upwards to the ice–air interface and laterally to the sides of the crack. We would expect this pattern of freezing to affect the trapping of brine within the ice. Temperature measurements have quantified the rate of refreezing in arti-ficially formed cracks in the sea-ice sheet of McMurdo Sound, Antarctica. Salinity profiles show that the refrozen material is generally more saline down the mid-plane of the crack, while crystal *c* axes are aligned parallel to the long axis of the crack. The presence of cracks also affects the flexural strength of the ice sheet, this strength increasing with refreezing time, and decreasing with crack width. Natural cracks will be examined in the 2001 field season, and compared with results of the artificially formed cracks.

Platelet ice of McMurdo Sound, Antarctica

(I. Smith, P.J. Langhorne, Phys/UOtago; T.J. Haskell, IRL)

Measurements of temperature and salinity were made beneath the land-fast sea ice of McMurdo Sound, Antarctica in 1999 and 2000 in areas with and without platelet ice. The water 15 cm beneath the platelet ice was found to be approximately 0.01 K supercooled. No discernible supercooling was found at the site with no platelet ice. Time-lapse video imaging at one site showed a platelet crystal attached to the sea ice above grew 5 cm longer over a 2 day period. Attempts are being made to develop a theory that can explain growth under such conditions.

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Wave propagation across features in sea ice

(V.A. Squire, T.W. Dixon, Phys/UOtago)

A project to study how cracks and/or abrupt changes of thickness, or the material properties of sea ice, affect the propagation of ice-coupled waves has recently been completed. A Green's function/integral equation approach has been used to model the following physical phenomena theoretically: a train of waves crossing a single crack in an otherwise perfect sheet of sea ice; a train of waves impinging on a region of either regularly or randomly separated cracks in an ice sheet; an iceberg embedded in sea ice, of different thickness and physical properties, which is subjected to an incoming, ice-coupled wave train. While the first of these problems has been solved numerically before, a closed-form solution has now been found that is much easier to apply. In each case, the reflection and transmission coefficients associated with the interaction can be found, allowing the amount of wave energy passing beyond the feature to be computed. It is reported that single cracks and fields of cracks favour the passage of long waves and inhibit short-wave propagation.

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Using the coherent potential approximation to model wave propagation in ice pack

(T.W. Dixon, V.A. Squire, Phys/UOtago)

To compute the transport properties of a marginal ice zone (MIZ) as a function of floe size and concentration, the MIZ has been modelled as a discrete random medium, i.e. an analogue of a composite material with two different refractive indices. The basic idea is to construct a ficti-tious continuum "effective medium" using conservation of energy principles, thereby incorporating the multiple-scattering behaviour of a real MIZ to first order. This first step of the programme was to construct a transport theory for multiple scattered flexural waves governed by the Euler–Bernoulli thin-plate equation. Augmenting that work, together with the Green's function for harmonic forcing of an ice cover, the effective-medium principle for a two-dimensional MIZ has been devised. Energy transport velocities, dispersion relations and scattering mean free paths for varying floe lengths and concentrations have been computed. As expected, long waves are unaffected by the presence of many ice floes but, as the wavelength and floe size become comparable, a number of interesting features emerge. The velocity of energy transport becomes much faster in the MIZ than the group velocity in open water, but slower than the group velocity in a continuous ice sheet. The velocity curve exhibits a great deal of variation as relative floe size increased. The mean free path curves, which indicate the decay rate of the incident wave due to multiple scattering, also have considerable fine structure for large relative floe sizes. Numerical dispersion relations are multi-valued, a result unseen in field experiments, but not an uncommon property of electromagnetic multiple-scattering wave systems.

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Heat flow in sea ice

(H.J. Trodahl, M.J. McGuinness, VUW)

The research of the VUW group is based on high-resolution measurements of the temperature field in sea ice. The central element is an array of thermistors separated by 100 mm in a vertical string, deployed in McMurdo Sound and measured twice an hour from July through December. The data are analysed to determine the effective thermal conductivity of the complex ice–brine mixture, and its dependence on temperature and structure. The results to date show a thermal conductivity close to the values predicted thirty years ago, but limited by disordered structure near the surface and enhanced by brine channels near the underlying sea water. Horizontal heat flow will be investigated by similar techniques.

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GLACIERS AND ICE SHEETS

Glacier ELA monitoring programme

(T.J. Chinn, NIWA/Dunedin)

A programme to estimate the mass-balance changes of some 49 selected "index" glaciers of New Zealand's Southern Alps has been continued using the end-of-summer snowline elevation (EOSS, which is the same as the annual ELA) as a surrogate for annual mass balance. The data are collected by simple oblique photographs taken from a small fixed-wing aircraft. The observed snowline is visually transferred to a contoured glacier map where the accumulation area is digitized. The ELA is then unambiguously determined from the glacier area–altitude curve.

The programme commenced in 1977 when gathering data for the New Zealand glacier inventory and, in the two decades since that time, the glacier balances have been dominantly positive. However this trend reversed from 1998 to 2000 when strongly negative balances were recorded. Preliminary indications from the 2001 survey, completed in early March, indicate that the past year was one of near zero to positive balance.

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Shear strength of basal ice and substrate in dry-based glaciers, McMurdo Dry Valleys

(S.J. Fitzsimons, P. Sirota, Geog/UOtago; K. McManus, CE/UCan)

Blocks of substrate within the basal ice of several glaciers in the Dry Valleys suggest that at least in some cases dry-based glaciers are capable of deforming and entraining the bed. Direct shear and triaxial tests of basal ice and substrate samples are used to understand how basal ice interacts with the substrate. Direct shear tests in tunnels excavated into glaciers, and in a laboratory, have demonstrated an overlap in the peak strength of different basal-ice facies and the glacier substrate. Further tests using a triaxial stage are underway.

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Basal-ice formation and deformation in dry-based glaciers

(S.J. Fitzsimons, S. Mager, Geog/UOtago; R.D. Lorrain, FUB)

The origin of basal ice of several glaciers in the McMurdo Dry Valleys is being investigated by examining the solute chemistry, gas content and isotopic composition. To date, results suggest that in some locations liquid water has been present as basal ice is formed. Measurements of velocity and strain in tunnels excavated into the glaciers have shown complex patterns of strain near the bed that are not well described by Glen's Law. The complexities include sliding at –18°C, gas-filled cavities, strain concentrations in weak-ice facies and thin shear zones within the basal ice.

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Sedimentary processes at the margins of lake-terminating glaciers, Southern Alps, New Zealand

(S.J. Fitzsimons, K. Roehl, S. Mager, Geog/UOtago)

Many large glaciers that flow from the eastern side of the Southern Alps terminate in marginal lakes that have developed in the last few hundred years. Observations of glaciological and sedimentary processes at modern ice margins are being used to develop depositional models to reconstruct the formation of Late Pleistocene end moraines which contain substantial glaciolacustrine sediment.

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Ross Ice Shelf changes and giant icebergs, Ross Sea, Antarctica

(J.R. Keys, Department of Conservation, Turangi)

The calving of Ross Ice Shelf in March–April 2000 was one of the two largest ice-shelf-calving events documented and produced the largest iceberg yet observed. Iceberg B15 had an area of 11,000 km^2 for two months before it split in two. Shortly after calving, it collided with the eastern Ross Ice Shelf producing further large icebergs B17, B18 and smaller bergs. In September 2000, B15A collided with a peninsula in the western ice front that had been present since at least 1962, producing iceberg C16 and smaller bergs. The total area of calving was about 14,000 km^2, similar to the 1986 calving of the Ronne Ice Shelf. The B15 calving occurred primarily along transverse rifts extending west from the Bay of Whales. These rifts had formed relatively recently (between 1987 and 1992) compared to those controlling the Ronne calving (at least 30 years) and that of iceberg B9 (20 years) from the eastern Ross Ice Shelf in 1987. However, calving and initial fragmentation of B15 and B16 also occurred where ice-shelf thickness changed greatly and at rifts perpendicular to the ice front. The ice front is now about where it was in 1983 (171°E), is still at its northernmost extent (from 174°E to 178°W), and in 175°W is at the latitude it was in both 1911 and 1962. East of 174°W, the entire other half of the ice front is at its southernmost-recorded latitude (to 78°38.5′S at 165°W in January 2001) except for 1911–1935 when the southernmost part of the Bay of Whales was a narrow calving bay called Amunsden Arm (to 78°41′S at 164°W in February 1911). The suite of icebergs formed have moved, often independently, in various directions driven apparently by a complex mix of tidal action, the west-setting and slope boundary currents, northwest-setting surface currents and deeper north- and south-setting currents.

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New dating tool for glacier ice

(U. Morgenstern, IGNS)

Ice cores contain many proxies for climate forcing and climate response, including CO_2 CH_4, dust, and aerosols, as well as indicators of solar irradiance, precipitation rate, temperature and wind strength. Cosmogenic radionuclides can provide accurate dating for the glacier archive. Until now, there has been no appropriate radiometric dating method in the time range 100–1000 years, an important period for assessing human influences on climate. The cosmogenic radionuclide ^{32}Si (half-life about 140 years) provides time information in this range. Measurement is extremely difficult, and only accelerator mass spectrometry (AMS) is suitable for analysing ice-core samples. Recently, we succeeded in measuring natural ^{32}Si by AMS. This new dating method will help reveal climate records over the past millennium from mid- to low-latitude glacier ice, to gain a comprehensive picture of the Earth's climate.

Understanding glacier flow

(U. Morgenstern, IGNS)

Franz Josef Glacier, Southern Alps, New Zealand, is particularly sensitive to changes in climate. Considering New Zealand's isolated position in the South Pacific, understanding the fluctuations of this glacier is important. Various radionuclide methods (^{32}Si, ^{3}H) are being used on Franz Josef and Tasman Glaciers to understand glacier dynamics and to calibrate glacier-flow models.

Contributed by Patricia J. Langhorne

UNITED KINGDOM

(For abbreviations used see page 22)

ANTARCTIC

Global Interactions of the Antarctic ice sheet (GIANTS) programme (BAS)

The umbrella for ice-sheet research at the British Antarctic Survey is the Global Interactions of the Antarctic Ice Sheet (GIANTS) programme. The GIANTS programme comprises five 5-year core-funded projects and several externally-funded collateral projects:

- DANDY (R.C.A. Hindmarsh) covers numerical modelling of ice sheets with special emphasis on theoretical aspects of ice-sheet modelling and the assimilation of data into ice-sheet models.
- TORUS (A.M. Smith, E.C. King) considers the role of basal conditions in promoting fast-flow in ice sheets and Arctic glaciers.
- RISOC (K.W. Nicholls, A. Jenkins, K. Makinson, A.M. Wood) covers the interaction of ice sheets with oceans.
- LCHAIS (J.L. Smellie) investigates subglacial volcanic eruptions, both as a method of determining glacial conditions at the time of eruption and as an influence on the ice sheet.
- BBAS (D.G. Vaughan, H.F.J. Corr, C. Rolstad) is an integrated balance assessment and investigation of the causes of change in the Pine Island Glacier basin in West Antarctica.

Collateral projects include: investigation of fracture in ice (C. Nath); exploration and investigation of ice-shelf cavities using the autonomous submarine, Autosub; hot-water drilling to the bed of an Antarctic ice stream (A.M. Smith, K.W. Nicholls, K. Makinson); ice and climate interactions (D.G. Vaughan).

Chris Doake is a senior advisor to the GIANTS programme and conducts personal research in ice dynamics through an Individual Merit Promotion.

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Dielectric profiling at Dome C (EPICA)

(E.W. Wolff, P.R.F. Barnes, R. Mulvaney, G.C. Littot, T. McCormack, S.J. Foord, BAS)

BAS is a partner in the European Project for Ice Coring in Antarctica. As part of the deep ice-core drilling at Dome C, BAS has completed a dielectric profile (DEP) at 2 cm resolution of the core drilled to date. This has been used to synchronize the two EPICA Dome C cores and to identify interesting chemical signals. Work has been done on the relationship between electrical signals and chemistry of the ice. In addition to the DEP, BAS is a full partner in the ionic chemistry analysis of the ice, which involves 6 different groups in Europe.

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Photochemistry of snow

(A.E. Jones, E.W. Wolff, BAS)

Experiments have been carried out in collaboration with AWI which show beyond doubt that NO_x is produced from Antarctic snowpacks in sufficient quantity to affect the atmospheric boundary layer. We have coordinated a modelling exercise to quantify the production, and to see the different chemical effects that this activity in the sunlit firn layer may have, both for ice cores and the atmosphere.

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Scanning electron microscopy of polar ice

(P.R.F. Barnes, E.W. Wolff, BAS; H.M. Mader, UBris)

A SEM with X-ray chemical microanalysis has been used to examine ice from glacial and Holocene periods from Greenland and Antarctic cores. Morphological characteristics seen in optical microscopy have been observed (e.g. bubbles and clathrates). In addition, dust particles have been examined for their chemistry and their effects on grain boundaries. Soluble impurities at grain boundaries have also been studied.

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Trace gases in firn-air (FIRETRACC)

(R. Mulvaney, BAS; W.W. Sturges, UEA)

As part of the EU funded project Firn Record of Trace Gases relevant to Atmospheric Chemical Change, BAS collected samples of firn air from a range of depths from the surface down to pore close-off at 75 m in Dronning Maud Land, and collaborated with its European partners to collect a parallel sequence from Dome C. Analysis at UEA of a suite of chlorofluorocarbons has shown the atmospheric growth in these species over the past 40 years. Analyses of other gases were made at the Max Plank Institute for Chemistry, Mainz, LGGE and at the University of Bern.

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Ice-core research, Dronning Maud Land

(R. Mulvaney, N. Holman, B. Knight, G.C. Littot, S.J. Foord, BAS)

A 120 m deep ice core from Dronning Maud Land (DML), a UK contribution to EPICA, has given a 1200 year record of climate and changes in aerosol chemistry. Clear volcanic horizons visible in both the chemistry and the dielectric profiles tie the chronology to other cores collected in this region, including Berkner Island to the west of DML, and across the continent to Dome C. A 450 km long ground-penetrating radar survey, tied in with a series of 20 m ice cores, is being analysed for evidence of the spatial pattern of accumulation.

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Bedrock drilling project of Berkner Island

(R. Mulvaney, BAS)

Together with colleagues from LGGE, AWI, and other partners, BAS plans to drill to bedrock, at 950 m depth, on Berkner Island. The ice core will incorporate the climate history of this region from the Last Glacial Maximum (LGM) to present. Of particular interest will be the phasing of the termination of the glacial period compared to other Antarctic and Arctic ice-core records. Additionally, the core should reveal if Berkner Island was overrun by the West Antarctic ice sheet during the LGM, and, if so, when it emerged as an independent ice sheet. Equipment, including an AWS supplied by IMAU, has been placed at the site in preparation for the drilling.

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Neogene (pre-Quaternary) history of the Antarctic ice sheet

(M.J. Hambrey, CG)

Collaborative work on uplifted glaciomarine sediments with B. McKelvey and J. Whitehead (Australia) has determined the strongly fluctuating nature of the Lambert Glacier in pre-Quaternary time, reflecting substantial changes in ice-sheet thickness. Analogous work has also been undertaken on the controversial Sirius Group deposits of the Shackleton Glacier area (Transantarctic Mts.) with P.N. Webb, D.M. Harwood and L.A. Krissek (U.S.A.), and the evidence suggests much warmer glaciers existed when those sediments were formed.

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Ice-shelf fracture mechanics

(P.R. Sammonds, M. Rist, Geol/UCL; C.S.M. Doake, BAS; H. Oerter, AWI)

We have applied experimental and theoretical fracture mechanics to the Filchner–Ronne Ice Shelf to investigate (1) depth of crevasse penetration, (2) spatial distribution of top crevasses and (3) height and location of bottom crevasses. In a collaborative AWI/BAS project since 1994, we have conducted a research programme that integrates laboratory experiments on ice-shelf core gathered by AWI, theoretical fracture mechanics, satellite remote sensing and computer numerical modelling of ice-shelf dynamics. This approach has allowed us to model crevassing successfully. We intend to model the dynamics of the ice-shelf disintegration process.

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Investigation of widespread enhanced flow in the interior of the Antarctic ice sheet

(J.L. Bamber, M.J. Siegert, BGC; D.G. Vaughan, BAS)

The complex flow processes that occur in the interior of Antarctica are being measured and quantified. This will be done by investigating the flow regime in the region of Bailey Ice Stream and Slessor Glacier. Within this project we intend to (1) identify regions of enhanced flow from ice-flux calculations; (2) perform an airborne radio-echo sounding survey of the Bailey Ice Stream and its tributaries; (3) analyse these radio-echo data and determine the basal ice-sheet conditions and internal structure of the ice sheet; (4) calculate the glaciological conditions required to allow such ice-sheet behaviour by coupling our observations with a numerical simulation of ice-stream flow. We hope to undertake a series of flights in the 2001/02 field season around Bailey Ice Stream and Slessor Glacier using the BAS radio-echo sounding system. These data will provide information about the englacial and basal conditions and their influence on enhanced ice flow.

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Modelling physical and chemical processes in Antarctic subglacial lakes

(M.J. Siegert, P. Bates, M. Tranter, BGC)

The physical and chemical dynamics of Antarctic subglacial lakes are being established from a series of ice-sheet measurements and numerical models. Work has concentrated initially on the largest, and best known, subglacial lake, called Lake Vostok. Datasets for Lake Vostok include airborne radar (for ice thickness and subglacial conditions), ice-core information (for the thickness of refrozen ice above Lake Vostok), ERS-1 altimetry (for the ice-surface elevation) and interferometric SAR (for the ice-surface velocity). Combination of these data reveals the rates of subglacial melting and freezing over the lake. These measurements form boundary conditions for thermo-fluid dynamics models of water circulation and chemistry within the lake cavity. By adjusting the ice-sheet conditions (such as during glacial–interglacial cycles), the model results indicate how the lake has responded to past environmental change. Our work is fundamental to (1) determining the habitat of the lake's biota (2) future exploration of subglacial lakes and (3) the planned exploration of Europa, the Jovian Moon, where a Lake Vostok analogy is expected.

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Internal radar layering and past rates of ice accumulation in Antarctica

(M.J. Siegert, BGC; R.C.A. Hindmarsh, BAS)

Ice-sheet layering, measured from radio-echo sounding (RES) data, has been traced continuously across five ice divides in East Antarctica. Numerical ice-flow models are used to replicate the internal layering by adjustments to the accumulation rate at these sites. The model results indicate temporal variations in ice accumulation over the two last glacial–interglacial cycles at five ice-divide sites. The next steps will be to (1) trace internal layers across the 40% of the ice sheet covered by the SPRI RES database, (2) design a numerical ice-sheet model capable of replicating the 3-D flow of ice in Antarctica, and (3) match model results to internal-layer measurements to establish the full spatial and temporal history of ice accumulation. Such information will be used to construct a time-dependent palaeoclimate for Antarctica for the past 300,000 years.

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GLACIER FLUCTUATIONS AND MASS BALANCE

Surface albedo, Haut Glacier d'Arolla, Switzerland

(B.W. Brock, Geog/UDun)

Surface albedo was measured in a surface-parallel plane over a level site on Haut Glacier d'Arolla for an 11 day period in August 1999. The 1 second measurements were averaged over 10 min intervals, and incorporated the final wastage of the winter snowpack, bare ice and a fresh snowfall. Two influences on short-term (<1 d) albedo variability were investigated. Cloud cover was the biggest factor, explaining up to 90% of short-term albedo variability. Solar zenith-angle variations (25–75°) explained at most only 13% of albedo variability. Parameterizations were developed to incorporate the influence of cloud cover on the surface albedo in numerical energy-balance melt models.

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Melt modelling of debris-covered ice

(M.H. Thomson, B.W. Brock, M.P. Kirkbride, Geog/UDun)

Studies of heat-energy transfer through debris overlying Sülheimajökull (SJ) in Iceland (fine-grained volcanic ash) and Ghiacciaio del Miage (GM) in Italy (rock debris of various sizes) have been undertaken since 1997. Debris-cover surface temperature, the most important variable for modelling ice-melt rates beneath debris covers, can be estimated accurately on an hourly basis from nearby meteorological data (radiation, temperature and wind speed). Debris thickness is a significant influence on debris-surface temperature at GM, but not at SJ where only four measurement sites were available. A semi-distributed surface energy-balance model of the lower ablation zone of GM, which has a continuous debris cover, has been developed. The model is being used to investigate the impact of the debris cover, through heat insulation, on the mass balance of GM.

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Potential instability of ice-cap outlet glaciers, Ellesmere Island, Canada

(J.A. Dowdeswell, T. Benham, R.P. Bassford, BGC; M.J. Sharp, EAS/UAlb; M.R. Gorman, SPRI)

Ice-mass collapse, and major increases in the rate of iceberg flux, have only been considered of potential significance for drainage basins within the Antarctic ice sheet that are grounded below sea level. Airborne ice-penetrating radar data, from spring 2000, and satellite datasets on the form and flow of the 80,000 km^2 ice caps on Ellesmere Island, suggest that the outlet glaciers draining them have a morphology that makes them particularly sensitive to future climate changes. Many outlet glaciers on Ellesmere Island are 700–1000 m thick and flow through deep bedrock troughs up tens of kilometres in length, whose beds lie below modern sea level. Most have 200–300-m thick marine termini grounded on submarine topographic sills. Some also have floating ice tongues which extend into the adjacent fjord waters. The glaciers lose mass through iceberg production at these marine interfaces. If surface melting increased at low elevations on these outlet glaciers, they could become unstable due to increased buoyancy and, therefore, iceberg production would increase dramatically at their marine margins. Equally, if the thickness and duration of winter sea-ice cover in the adjacent fjords was reduced, iceberg production could also increase. Through either, or a combination, of these mechanisms, glacier-terminus retreat would take place into the progressively deeper water of the bedrock troughs, increasing iceberg production further. Thus a relatively small amount of marginal thinning could result in major retreat of a large number of Ellesmere Island outlet glaciers, with the relatively rapid release of mass to the global ocean.

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Ice-sheet dynamics and the keel depths of large tabular icebergs

(J.A. Dowdeswell, J.L. Bamber, BGC)

The morphology and flux of tabular icebergs is controlled by the dynamics of the parent ice sheet and the nature of interactions between ice margin and adjacent ocean. Satellite radar-altimeter measurements of the ice-surface elevation of the marine margins of the Antarctic ice sheet are inverted to produce ice-thickness values, assuming hydrostatic equilibrium. The volume of icebergs of given thickness produced from the ice sheet is calculated from balance fluxes using ice-surface elevations and net surface mass-balance in ice-sheet drainage basins. Calving flux is highest where fast-flowing ice streams and outlet glaciers are present. Glaciological controls on iceberg keel-depth are ice thickness at the grounding line and distance to the calving margin. Oceanographic influences include the nature and rate of melting/freezing at the floating ice-shelf base. The distribution of sea-floor scours produced by iceberg keels is dependent on the changing form and flow of the glaciers and ice sheets from which icebergs are derived. Sea-floor evidence for icebergs with particularly deep keels has sometimes been interpreted to indicate the presence of extensive ice shelves. However, iceberg scours found at palaeo-water depths in excess of 400–500 m in the geological record are a clear indicator of the former presence of fast-flowing ice-sheet outlet glaciers. Numerical models of iceberg drift and melting also require iceberg-keel thickness data to calculate drag and to specify the depth-range of ocean temperatures needed.

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Mountain glaciers past and present

(I.S. Evans, K.E. Arrell, Geog/UDurh)

As a basis for modelling glacier distribution, present and past glaciers (and glacial cirques) are being related to altitude, aspect and topographic form: the local and regional variation of ELA proxies is analysed. For effective coverage of large areas, the World Glacier Inventory (WGI) is currently being used for Europe: an edited dataset of 5192 glaciers has been produced for the Alps. Most variability in glacier mid-altitude relates to position, followed by aspect and glacier type: glacier size and gradient account for a little more. Glacier numbers and mid-altitudes consistently show northward preference (lower glaciers) in the Alps, due to reduced radiation, with some local deviations related to wind and cloudiness. The main limitations of WGI data for this purpose are variations in the application of glacier classification between countries, and the absence of accumulation-area gradients. For glaciers mapped from air photos in British Columbia, the aspect and gradient of each glacier source are recorded.

Fuller modelling of glaciers in relation to mesoclimate is possible with DEMs. These are being used to provide hypsometry, gradients and topographic context, so that mass balance can be predicted for any stipulated climate and feedbacks can be taken into account.

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GLACIER STRUCTURE AND PROCESSES

Tephrochronological dating of Icelandic glacier fluctuations

(M.P. Kirkbride, Geog/UDun; A.J. Dugmore, Geog/UEdin)

Holocene glacier fluctuations have been reconstructed for 10 glaciers in south, central and north Iceland using tephra layers in aeolian soil to provide bracketing ages on moraine and meltwater deposits. A composite chronology for small, fast-responding mountain glaciers includes four main periods of advance within the later "Little Ice Age" (LIA, post AD 1690), advances immediately before and after the Mediaeval Warm Period (MWP), and three other periods of advance between about 5 kyr BP and the MWP. The LIA chronology has been correlated with atmospheric circulation changes in the North Atlantic sector. The work confirms earlier indications that large ice caps and small mountain glaciers have responded differently to Holocene climatic variability.

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Structural evolution of a polythermal glacier (Midre Lovenbreen), Svalbard

(N.F. Glasser, M.J. Hambrey, CG)

This research concentrates on structural and sedimentological data from Midtre Lovénbreen (NW Spitsbergen), a typical land-based polythermal valley glacier that is being investigated as part of the NERC thematic programme "Arctic Ice and Climatic Variability". Structural mapping on the glacier indicates that the earliest structures to develop are folds with flow-parallel axes and an associated axial-plane foliation of longitudinal orientation. Some folds are associated with supraglacially derived debris that crops out on the glacier surface as medial moraines. Numerous fractures of various orientations (crevasse traces) intersect the foliation. Towards the snout are arcuate up-glacier dipping fractures, some of which are associated with debris of basal origin. These structures are interpreted as thrusts. Many of the glacier structures are relict; the crevasse traces and thrusts reflect processes that occurred in the thicker and more dynamic glacier that existed at its Neoglacial maximum (late 19th/early 20th century). Analysis of sediments in the proglacial area of the glacier supports the interpretation that the thermal structure and dynamic regime of the glacier have changed through time. The glacier was wet-based and sliding on its bed at its Neoglacial maximum. During this advance, a thin deforming layer of diamicton was draped over the existing morphology, whilst erosion of the underlying bedrock appears to have been limited. Radio-echo soundings of the glacier show that at present it is partly frozen to the bed (polythermal). Modification of the bed is inhibited under this thermal regime and, as a result, the supraglacial environment dominates modern sedimentation. We conclude that Midtre Lovénbreen has more than one dynamic mode and that it switches between dynamic modes largely as a result of climatically induced changes in mass balance.

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Direct measurement of basal sliding at a hard-bedded, temperate glacier: Glacier de Tsanfleuron, Switzerland

(B.P. Hubbard, CG)

A "sliding mast" has been used to measure late-summer basal-ice motion directly in a frontal cavity at Glacier de Tsanfleuron. The rigid-sliding mast, which was fixed to bedrock within the cavity, housed 5 multi-turn potentiometers, each of which were linked by a thin cord to an anchor emplaced in the adjacent ice wall. These 5 anchors were 25 mm (anchor 1), 60 mm (anchor 2), 115 mm (anchor 3), 195 mm (anchor 4) and 265 mm (anchor 5) above the ice–bed interface. Potentiometer resistances were recorded by data logger every 10 s and averaged every 120 s throughout the 6-day period of the experiment. These data were converted into distances (sensitivity = 0.003 mm) for each anchor, and into speeds for each 120 s measurement interval. Thus, a 6-day long time series with a sampling interval of 120 s of basal-ice motion was constructed for each of the anchor locations.

Results indicate that basal ice at the margin of Glacier de Tsanfleuron moved at a speed >10 mm d^{-1} throughout the measurement period. A consistent, quasi-linear spatial gradient in this speed was recorded away from the glacier bed, increasing from ~10.6 mm d^{-1} at anchor 1 (25 mm above the bed — *a.b.*) to 11.8 mm d^{-1} at anchor 5 (265 mm a.b.). Extrapolating this trend to the glacier bed indicates that a speed of 10.4 mm d^{-1}, or ~88 % of that recorded at a height of 265 mm a.b., is accommodated at the ice–bed interface. Detailed analysis of the anchor time series indicates that basal-ice motion is highly variable, being characterized by long periods of little or no motion separated by short periods of relatively rapid motion (up to 400 mm d^{-1} over the 120 s measurement period). The reasons for this strongly non-uniform motion (whether methodological or glaciological) are being investigated.

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Glacial-hazard assessment and risk minimization

(J.M. Reynolds, S.D. Richardson, A.P. Heald, RGSL)

RGSL has been awarded a contract under the DFID KaR programme to investigate glacial hazards in the Himalayas and Andes. The project runs to June 2003 and involves field-based and remote-sensing studies in Nepal, Bhutan and Peru. The objectives are to: (1) improve technical procedures for identifying and evaluating potentially dangerous glacial lakes; and (2) develop methods to assess the vulnerability of local communities to floods from glacial lakes and from subsequent landslides. The work is being undertaken in collaboration with host governments so that results from the project can be used to improve disaster preparedness and risk-reduction strategies.

Glaciers and glacial lakes in the Khumbu Himal, Nepal, are being examined, especially focusing on the interaction between supraglacial drainage, glacial structures and processes of lake development and expansion. Preliminary studies have also been undertaken of the geomorphic and geotechnical impacts of a recent lake outburst flood from Sabai Tsho, Hinku valley, Nepal. Approaches of glacier and glacial-lake inventory compilation appropriate for hazard assessment and monitoring are being reviewed using aerial photographs and IRS, SPOT, and Landsat ETM satellite imagery. Procedures developed for the pilot area in Nepal will be applied and tested at critical sites in Bhutan and Peru.

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Radar investigations at Haut Glacier d'Arolla, Switzerland, 1996–99

(L.A. Plewes, B.P. Hubbard, CG)

Radar surveys were carried out at Haut Glacier d'Arolla, a predominantly temperate-based Alpine valley glacier, during 4 summer field seasons (1996–99) to locate and image englacial drainage structures. Two radar systems, system I (SI) a monopulse ice-surface radar, and system II (SII) a Pulse-EKKO IV GPR were used. SI operates at 10, 20 and 50 MHz; SII operates at 50, 100 and 200 MHz. Three types of radar survey were undertaken: (1) constant-offset (CO) reflection profiling, (2) common mid-point (CMP) velocity profiling and (3) repeated sounding at a fixed point at pre-specified time interval (t).

The dataset is one of the most extensive for any temperate valley glacier. A reflection catalogue details descriptive (length, dip angle, depth, phase, location coordinates) and numerical (reflected power) aspects of the reflections. Data have been interpreted by reference to synthetic radar reflections created by geophysical modelling and by reference to non-radar field data, e.g. maps of surface moulin locations and from borehole and dye-tracing studies at this site.

A variety of glacial features have been identified including: (1) deep (60–120 m depth), continuous linear reflections interpreted as the glacier bed (CO surveys); (2) near-surface (0–40 m depth) hyperbolic reflections interpreted as englacial drainage structures (CO surveys), and; (3) constant, linear reflections throughout the depth of the ice mass (t surveys).

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Hydrology and dynamics of polythermal glaciers

(D.M. Rippin, I.C. Willis, N.S. Arnold, UCam; A.J. Hodson, Geog/USheff)

The hydrology and dynamics of Midre Lovénbreen, Svalbard, are being studied using a combination of field-based and photogrammetric methods. Digital elevation models (DEMs) of the glacier surface have been constructed for 1977 and 1995. A DEM of the glacier bed has been produced from radar data collected during the early-mid 1990s by H. Björnsson and J.C. Moore. These DEMs have been used to map subglacial hydraulic potential for various assumptions about steady-state subglacial water pressure, and these have been used to construct, theoretically, the overall structure of the subglacial drainage network and therefore the position of major hydrological pathways under the glacier. Results suggest that the position of the terminus stream is sensitively dependent on subglacial water pressures. Observations over the last decade of the main terminus stream suggest that switches in its position have occurred. Analysis of snow and weather data confirms that its position is influenced by the rate at which water enters the glacier in spring that, in turn, must affect subglacial water pressures.

Analysis of ground-penetrating radar data collected during the 1999 summer suggests that basal reflective properties vary spatially, possibly due to variations in the amount of basally stored water. Measurements of surface-velocity variations in the 1999 summer suggest that spatial variations in glacier dynamics are also controlled by the presence of basal water. Temporal fluctuations in glacier dynamics occur in response to weather-related surface inputs.

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Glacier hydrology and ice dynamics, John Evans Glacier, Ellesmere Island, Canada

(P.W. Nienow, R.G. Bingham, GTS/UGlas; M.J. Sharp, L. Copland, T. Wohlleben, S. Boon, K. Heppenstall, EAS/UAlb)

A detailed ice-motion study of John Evans Glacier, a polythermal High Arctic glacier, is being undertaken to determine the extent to which changes in the subglacial drainage system impact on ice dynamics. Preliminary findings from the integrated field and modelling study demonstrate a clear link between the development of the glacier's drainage system and an associated response in ice dynamics. Large volumes of supraglacially ponded meltwater develop at the start of the melt season and subsequent hydrofracture of crevasses enabled propagation of englacial and consequent subglacial drainage. This drainage event resulted in reduced basal friction causing a short-lived motion event. Dye-tracing and water-chemistry results indicate that the drainage system evolved rapidly during the melt season to become hydraulically efficient. These findings suggest that the structure and evolution of the supraglacial drainage system is fundamental to the development of subglacial drainage and its subsequent impact on ice dynamics. We infer that the scale of Arctic ice masses is critical to the likelihood of the development of subglacial drainage such that medium-to-large ice masses are most likely to exhibit subglacial drainage. This scale issue has significant implications for the potential response of Arctic ice masses to changes in meltwater runoff in response to predicted climate change.

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Multiple phases of superimposed-ice formation on Svalbard glaciers

(J.L. Wadham, BGC; A.M. Nuttall, ULJM)

Three years of meteorological and snowpack-temperature data from Midre Lovénbreen, northwest Spitsbergen indicate two distinct annual phases of rapid snowpack warming and potential superimposed-ice formation. Short periods of positive air temperatures, lasting up to 36 h, occur throughout the winter period. Warm events in early winter, when the snow cover is thin, warm the snowpack on the lower part of the glacier to 0°C in several hours. Spring snowpit observations indicate a layer of high-density clear blue ice overlain by a layer of low-density “snow ice”. The former is interpreted to form by slow freezing of a saturated slush layer at the snowpack base and the latter by rapid and cyclic refreezing of an overlying layer of partially wetted snow. Ice lenses form at higher altitudes. The second period of snowmelt and superimposed ice formation commences in May/June and typically continues for 4 weeks at low altitudes and throughout the summer at high altitudes. Whereas the summer phase of superimposed-ice formation is a glacier-wide process, winter superimposed-ice formation is concentrated on the lower glacier, with ice lenses forming at higher altitudes. These observations at Midre Lovénbreen are typical of Spitsbergen glaciers and reflect the unique climatology of the region. They contrast with those from glaciers in more continental climatic settings, where superimposed-ice formation is confined to a single period during summer. An additional winter period of superimposed-ice formation has significant implications for glacier mass balance, with superimposed ice locally comprising up to 60% of winter balances. Superimposed ice contributes by ~ 20% to the glacier-wide net balance at Midre Lovénbreen. Since projected climatic warming is greatest during the winter months in Arctic regions, superimposed ice is anticipated to become an increasingly important component of the winter balance and potentially the net balance of Spitsbergen glaciers. These processes may also operate in other maritime settings, such as parts of the Antarctic Peninsula and the periphery of the Greenland ice sheet.

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3-D patterns of stress and velocity in glaciers

(I.C. Willis, Geog/UCam; B.P. Hubbard, CG; P.W. Nienow, GTS/UGlas; D. Mair, EAS/UAlb; U.H. Fischer, VAW; A. Hubbard, UCan)

An integrated field-work and modelling strategy is being used to study how basal conditions affect the 3-D distribution of stress and velocity within the ablation area of Haut Glacier d'Arolla, Switzerland. Fieldwork took place between May 1998 and August 1999 when we monitored spatial and temporal variations in basal water pressure (transducers), sediment thickness, texture and strength (penetrometer and ploughmeters), surface motion (terrestrial surveying), internal deformation (tilt cells and inclinometer), sliding (drag spools) and subglacial sediment deformation (tilt cells). There were distinct patterns of surface, internal and basal motion that varied between spring, summer, and fall/winter, which reflect patterns of basal water pressure and sediment characteristics. These, in turn, are influenced by the proximity to subglacial drainage axes. For example, during spring, the glacier surface speeds up from ~2 cm d^{-1} to >10 cm d^{-1} over short periods of a few days. The zone of maximum surface velocity shifts from the centre of the glacier towards the major drainage axes where water-pressure fluctuations are greatest and sediments are relatively thin and coarse grained. The relative importance of basal motion to surface motion increases during these “spring events”, particularly towards the drainage axes and less so away from them. The field data have been used to drive and test a 3-D glacier-flow model. The model is able to reproduce the spring, summer, fall/winter, and annual patterns and magnitudes of movement very accurately. Discrepancies between model calculations and field measurements suggest that glacier ice, particularly at depth, may become softer during spring and summer, especially around subglacial drainage axes.

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An investigation of the dynamics driving the responses of ice caps to climatic forcing

(J.K. Hart, A.J. Payne, D.J. Baldwin, N.S. Eyre, R. Gooday, Geog/USoton; P.R. Sammonds, C. Stafford, Geol/UCL)

The behaviour of a small, relatively assessable ice cap resting on a deformable bed (Langjökull, Iceland), is being studied to investigate the effects of subglacial dynamics on the response of an ice cap to climatic forcing. This includes: ice-cap survey, ice-cap modelling, subglacial in situ instrumentation, geotechnical testing of proglacial and subglacial till.

Field research took place in summer 1999, spring 2000, summer 2000 and spring 2001. Initial research in summer 1999 concentrated on collecting data for the in situ subglacial-process studies (via hot-water drilling, to record subglacial-sediment movement and water pressures), and in addition recovering subglacial- and proglacial-till samples for geotechnical testing by triaxial experiments. This was continued in spring 2000 and summer 2000 with two GPR surveys. Subglacial instrumentation was very successful, three of the ploughmeters inserted in 1999 were still working in summer 2000; in addition, three new tilt cells, one new ploughmeter and three new drag spools (of two different designs) were successfully inserted. These instruments were left logging over the winter and the results will be collected in the spring.

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Basal conditions beneath Svalbard surge-type glaciers

(T. Murray, Geog/ULeeds; A.M. Smith, BAS; G.W. Stuart, ES/ULeeds, J. Woodward, H. Jiskoot, Geog/ULeeds; B. Davison, EBS/ULanc)

Bakaninbreen, southern Svalbard, began a prolonged surge during 1985. In 1986, an internal reflecting horizon on radio-echo sounding data was interpreted to show that the position of the surge front coincided with a transition between areas of warm (unfrozen) and cold (frozen) bed. Ground-penetrating radar lines run in 1998, during early quiescence, were acquired in the region of the present-day surge front. These show the same pattern of thermal structure — down-glacier of the surge front the bed is cold, up-glacier it is warm. Thus, as in early-surge phase, the location of the surge front is now at the transition between warm and cold ice at the glacier bed. We suggest that the propagation of the front was associated with this basal thermal transition. Seismic surveys show that where the surge terminated coincides with discontinuities in basal permafrost beneath the glacier. Termination may have occurred because the bed leaked through these unfrozen regions. Leakage of basal water and sediment up through faults in the glacier ice also occurred during the surge.

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Controls on dynamics of Midre Lovénbreen, Svalbard

(E.C. King, A.M. Smith, BAS; T. Murray, G.W. Stuart, Geog/ULeeds; B. Kulessa, PSU)

Coincident seismic reflection and GPR surveys were undertaken in spring 2000 prior to a hot-water drilling campaign in summer 2000. The physical properties of the bed have been determined from seismic surveys by calculating acoustic impedance from comparison of the energy of the primary and multiple reflections. Interpretation of the acoustic impedance as a three-phase mixture of ice–water–sediment suggests that the glacier rests on a coarse clastic deposit of up to 50% porosity, thought to be over-ridden scree.

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Radar techniques to image glacier water systems and sediment inclusions

(T. Murray, G.W. Stuart, N.H. Gamble, P. Miller, Geog/ULeeds; M. Fry, ES/ULeeds)

Falljökull is a temperate glacier in Iceland. Radargrams on temperate glaciers are dominated by scattering and penetration is relatively limited. At Falljökull, surface GPR has been used to map the glacier water system by following channels down-glacier of moulins. Englacial channels flowing from the base of moulins were low and wide in cross-section, and dropped steeply from the bottom of moulins in a series of near-vertical steps. Surface and borehole GPR have been used to derive velocity models and hence map the distribution of englacial water. This is important because of the very strong effect of water on the mechanical and electrical properties of ice. Cold ice is almost transparent to radar. We have undertaken a study over a large (up to 6 m in diameter) englacial channel at Austre Brøggerbreen, Svalbard. Synthetic radar modelling using ray-tracing was used to aid the interpretation of reflections and multiples. The GPR data were analysed to determine the depth, size, shape and water content of the channel. The channel became shallower in the ice and became increasingly full with distance from the moulin. Analysis of migrated GPR profiles suggested that the channel varied from being elongated horizontally close to the moulin, to being elongated vertically close to the glacier terminus. Corroboration of the interpretations are possible using measurements made by G. Vatne (NTNU) by direct access through a moulin. 3-D data-collection and processing techniques and forward modelling of the radar response of channels and faults will be developed.

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HYDROLOGY AND HYDROCHEMISTRY

Trace-element chemistry of meltwaters draining Alpine glacial catchments

(A. Mitchell, G.H. Brown, R. Fuge, CG)

Dissolved major elements (e.g. Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, $NO3^{-}$, $SO4^{2-}$) are now routinely measured in bulk meltwaters draining Alpine glaciers. These studies have furthered our understanding of chemical weathering processes and the controls on meltwater-quality variations in glacial environments. However, the use of the major-ion chemistry of the bulk meltwaters to define solute provenance and flow routing is somewhat equivocal. To date, minor and trace elements (e.g. Sr, Rb, U, Mn, Zn, Pb, Cr, Co, Cu, Al) have rarely been determined, despite their potential use in solute-provenance studies in glacial environments. This study investigates seasonal and diurnal variations in minor-and trace-element concentrations draining Haut Glacier d'Arolla, Valais, Switzerland, and has generated a unique suite of water-quality data which have been used to fuel geochemical reaction and mass-balance models. Further, long-term (seasonal) variations in bulk-meltwater minor- and trace-element concentrations and fluxes have been used to assess the timing of these environmentally important elements' delivery, from this glacierized headwater catchment, to downstream environments. These data will further our understanding of solute provenance in glacial environments and trace element export from glacierized headwater catchments.

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Spatial and temporal variations of isotope geochemistry, Okstindan, Norway

(W.H. Theakstone, Geog/UMan; S. Gurney, K. White, Geog/URead)

Aerial photographs taken in 1998 are being used to construct a new digital terrain model of the Okstindan area to facilitate the use of satellite imagery (Landsat ETM, EMISAR and JERS-1 data) for monitoring seasonal and long-term snow and ice cover in this area.

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Laboratory investigations of the strength, static hydraulic conductivity and dynamic hydraulic conductivity of glacial sediments

(B. Hubbard, A. Maltman, CG)

58 static hydraulic conductivity tests, 28 triaxial deformation tests and 25 dynamic hydraulic conductivity tests (in which hydraulic conductivity is measured simultaneously with deformation) have been undertaken on 7 samples of glacial sediments recovered from the margins of Haut Glacier d'Arolla, Switzerland, and from Traeth y Mwnt, mid Wales. Testing reveals that hydraulic conductivity is inversely related to effective pressure, particularly at effective pressures below ~100 kPa. Over the full range of effective pressures used (50–900 kPa), this relationship is best described by a negative power law above a base hydraulic conductivity value, termed K_0. The value of K_0 varies between samples by over 3 orders of magnitude, from 10^{-8} m s^{-1} to 10^{-11} m s^{-1}. These values vary directly, but weakly, with the square of the effective grain-size of the samples tested.

Dynamic testing revealed a commonly repeated pattern of sample failure: axial stress approached its maximum value at critical state, after which the sample deformed in a ductile manner from its initially cylindrical shape to a barrel shape. Most commonly, sample deformation and failure were accompanied by a decrease in hydraulic conductivity, although increases were also recorded. Dynamic testing also resulted in strongly linear relationships between effective pressure and the yield stress at failure. Such relationships are broadly consistent with a Mohr–Coulomb type model, revealing significant inter-sample variability in frictional resistance, and a cohesive term that is statistically indistinguishable from zero.

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Hydraulics of distributed subglacial drainage systems

(I. Cochrane, P.W. Nienow, T. Hoey, GTS/UGlas; B.P. Hubbard, CG)

The hydraulics of distributed subglacial drainage systems are poorly understood, but critically affect subglacial water pressures and thus rates of basal sliding. During summer 1999 and 2000, a network of boreholes of 50–120 m deep was drilled to the glacier bed at Haut Glacier d'Arolla, Switzerland. A series of down-borehole and moulin dye-tracer tests were undertaken to determine the hydraulic structure and connectivity of the distributed drainage system and the interaction between distributed and channelized systems. Dispersion of the dye cloud at the glacier bed was monitored using a mobile down-borehole fluorometer and a further fluorometer detected dye emergence at the glacier snout. Results demonstrate a high degree of hydraulic connectivity within the distributed drainage system and a complex diurnal variability in flow direction as a result of variations in basal water pressure. Analysis of the data will determine variations in the hydraulic conductivity of the distributed drainage system over both seasonal and diurnal time-scales. Variations in this conductivity are likely the result of preferential evacuation of fines close to the major subglacial channels.

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Provenance of suspended sediment in subglacial drainage systems

(D. Swift, P. Nienow, T. Hoey, GTS/UGlas)

The mechanisms by which the products of glacial erosion are evacuated from the subglacial environment by glacial drainage systems are poorly understood. Fieldwork at Haut Glacier d'Arolla in 1998 and 1999 investigated both the mobility of suspended sediment and the efficiency of sediment evacuation within the channelized and distributed drainage systems. Techniques employed included turbidity and particle-size records from both proglacial and down-borehole sampling locations, as well as radionuclide (^{137}Cs, ^{210}Pb), stable-isotope mineralogy (ä^{18}O) and optically stimulated luminescence-tracing techniques. Results demonstrate major changes in the efficiency of sediment evacuation as the drainage system evolves during the course of the melt-season. The system showed no sign of sediment exhaustion on a seasonal basis and increasing efficiency of evacuation is believed to be critically linked to the enhanced amplitude of the diurnal cycle.

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Sulphide oxidation under partially anoxic conditions at the bed of the Haut Glacier d'Arolla, Switzerland

(S.H. Bottrell, ES/ULeeds; M. Tranter, BGC)

Oxygen-isotope data for bulk glacial meltwaters draining the Haut Glacier d'Arolla, and for the sulphate contained within them, have been analysed. Sulphate in early ablation-season (May) meltwaters is relatively ^{18}O depleted, whereas later in the season sulphate becomes more ^{18}O-enriched. The sulphate derived from subglacial chemical weathering in May is so depleted in ^{18}O that it must have formed, at least partially, in an anoxic environment. Under these conditions, Fe^{3+} can act as an oxidizing agent and oxygen atoms incorporated into sulphate are derived from ^{18}O-depleted water molecules (whereas O_2 is strongly ^{18}O-enriched). These data therefore confirm the hypothesis that the glacier bed is seasonally anoxic and that Fe^{3+} acts as a significant oxidizing agent under these conditions.

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Geochemical weathering at the bed of Haut Glacier d'Arolla, Switzerland - a new model

(M. Tranter, H.R. Lamb, BGC; M.J. Sharp, EAS/UAlb; G.H. Brown, B.P. Hubbard, CG; I.C. Willis, Geog/UCam)

Waters were sampled from 17 boreholes at Haut Glacier d'Arolla during the 1993 and 1994 ablation seasons. Three types of concentrated subglacial water were identified, based on the relative ratios of Ca^{2+}, HCO_3^- and SO_4^{2-} to Si. Type A waters are the most solute rich and have the lowest relative proportion of Si. They are believed to form in hydrologically inefficient areas of a distributed drainage system. Most solute is obtained from coupled sulphide oxidation and carbonate dissolution (SO–CD). It is possible that there is a subglacial source of O_2, perhaps from gas bubbles released during regelation, since the high SO_4^{2-} levels found (up to 1200 $\mu eq\ L^{-1}$) are greater than could be achieved if sulphides are oxidized by oxygen in saturated water at 0°C. A more likely alternative is that sulphide is oxidized by Fe^{3+} in anoxic environments. If this is the case, exchange reactions involving Fe(III) and Fe(II) from silicates are possible. These have the potential to generate relatively high concentrations of HCO_3^- with respect to SO_4^{2-}. Formation of secondary weathering products, such as clays, may explain the low Si concentrations of type A waters. Type B waters were the most frequently sampled subglacial water. They are believed to be representative of waters flowing in more efficient parts of a distributed drainage system. Residence time and reaction kinetics help determine the solute composition of these waters. The initial water–rock reaction is carbonate and silicate hydrolysis, and there is exchange of divalent cations from solution for monovalent cations held on surface exchange sites. Hydrolysis is followed by SO–CD. SO_4^{2-} concentrations are usually < 400 $\mu eq\ L^{-1}$, although some are in the range of 530–580 $\mu eq\ L^{-1}$, which suggests that elements of the distributed drainage system become anoxic. Type C waters were the most dilute, yet they were very turbid. Their chemical composition is characterized by low SO_4^{2-}:HCO_3^- ratios and high pH. Type C waters were usually artefacts of the borehole chemical-weathering environment. True type C waters are believed to flow through sulphide-poor basal debris, particularly in the channel marginal zone. The composition of bulk runoff was most similar to diluted type B waters at high discharge, and was similar to a mixture of type B and C waters at lower discharge.

These observations suggest that some supraglacial meltwaters input to the bed are stored temporarily in the channel marginal zone during rising discharge and are released during declining flow.

Little of the subglacial chemical weathering we infer is associated with the sequestration of atmospheric CO_2. The progression of reactions is from carbonate and silicate hydrolysis, through sulphide oxidation by first oxygen and then Fe(III), which drives further carbonate and silicate weathering. A crude estimate of the ratio of carbonate to silicate weathering following carbonate hydrolysis is 5:1. We speculate that microbial oxidation of organic carbon may also occur. Both sulphide oxidation and microbial oxidation of organic carbon are likely to drive the bed towards sub-oxic conditions. Hence, we believe that subglacial chemical weathering does not sequester significant quantities of atmospheric CO_2 and that one of the key controls on the rate and magnitude of solute acquisition is microbial activity, which catalyses the reduction of Fe(III) and the oxidation of FeS_2.

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Enhancement of glacial solute fluxes in the proglacial zone of a polythermal glacier

(J.L. Wadham, R.J. Cooper, M.Tranter, BGC; R. Hodgkins, ULonRH)

Annual proglacial solute fluxes and chemical weathering rates have been monitored over two melt seasons (1999–2000) at a polythermal high Arctic glacier. Bulk-meltwater samples were collected from gauging stations at the eastern and western margins of the glacier terminus and at "the outlet", 2.5 km downstream where meltwaters discharge into the fjord. Runoff at these gauging stations was monitored continuously throughout the sampling periods. These data have been used to calculate solute fluxes at either end of the proglacial reach. The difference in these fluxes gives the proglacial solute flux. Fluxes of non-snowpack HCO_3^-, SO_4^{2-}, Ca^{2+} and Mg^{2+} increased by 21–38 % between the glacier terminus and outlet in 1999, indicating that meltwaters are able to access, and chemically weather, carbonates and sulphides in the proglacial zone. No increase in fluxes of non-snowpack derived Na^+, K^+ and Si signifies that proglacial chemical weathering of silicates is minimal. Enhanced solute fluxes in the proglacial zone are mainly due to the chemical weathering of active-layer sediments. Active layer pore waters are highly mineralized and have a SO_4^{2-}–Ca^{2+}–Mg^{2+}–HCO_3^- composition. They drain into the main proglacial channel via a number of small tributary streams and by diffuse porewater advection. The PCO_2 of these ground waters is above atmospheric pressure. This implies that solute acquisition in the active layer involves no drawdown of CO_2.
A component of the proglacial flux of non-snowpack HCO_3^- and Ca^{2+} is acquired from bulk meltwater suspended sediment. The annual proglacial chemical weathering rate in 1999 is calculated to be 2,800 meqΣ^+ m^{-2}. This exceeds the chemical-weathering rate for the glaciated part of the catchment (1200 meqΣ^+ m^{-2}) by a factor of 2.3. Hence, the proglacial zone at Finsterwalderbreen is an area of high geochemical reactivity. This has implications for chemical weathering rates in other areas where glacier-retreat rates are high and the bedrock contains reactive minerals.

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ICE PROPERTIES

Laboratory modelling of ice rheology

(D.H.B. Irving, B.R. Rea, ES/UWC; B.P. Hubbard, CG; J. McKinley, CE/UWC)

Centrifuge modelling of ice deformation under realistic stress conditions (~100 kPa shear stress) has been carried out in a 2 m beam centrifuge. This method has the advantage of applying a linear (as opposed to uniform) stress gradient through a sample (1×0.5×0.25 m). A number of tests have been completed on bubble-rich and bubble-poor clean-ice samples, and bubble-rich, sediment-rich artificial-ice samples. Shear strains of 1–2% have been developed in tests of 10–20 h in duration, although to date, transient effects have not been completely removed from observed deformation. Thin-section and further image analysis of test data remains to be completed.

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Ice-core investigations at Glacier de Tsanfleuron, Switzerland

(B.P. Hubbard, CG; J.-L. Tison, FUB; B. Spiro, IGL/NERC)

Five ice cores have been retrieved from a transect close to the terminus of Glacier de Tsanfleuron. The cores extend from the ice surface to the glacier bed, and are 3.5–44.8 m long. Stratigraphic logging based on bubble size and density reveals the presence of a highly metamorphosed basal ice layer, about 10 m thick, from which all traces of bubble-rich ice have been removed. This bubble-poor ice, which corresponds closely with clear-facies ice observed in cavities beneath numerous temperate-based glaciers, contrasts with the overlying bubble-rich or bubble-foliated englacial ice and the underlying debris-rich and bubble-free dispersed-facies basal ice.

Down-core patterns in major-ion composition, stable-isotope composition, and total gas content and composition are generally consistent with formation of clear-facies ice by deformation-related metamorphism of bubbly, englacial ice. In addition, isotopic data suggest that storage of downward percolating meltwaters occurs close to the upper surface of the clear-facies ice layer, perhaps reflecting a local variation in ice permeability across the transition from englacial to clear-facies ice. Enrichment in crustally derived ionic species is noted in the lowermost decimetres of the debris-free, clear-facies ice that immediately overlies debris-rich dispersed-facies basal ice. This ionic enrichment in debris-free ice is interpreted in terms of active intergranular meltwater flow within some decimetres of the glacier bed.

Ice crystallographic measurements have now been made on a total of eight flow-parallel cores retrieved from the glacier, indicating the presence of four crystallographic units. Unit 1, composed of homogeneous, fine-grained ice with a uniform fabric, is located within ~20 m of the ice surface in the accumulation area of the glacier. Crystal growth within this unit occurs in the absence of significant stresses, and its rate is closely described by an Arrhenius-type relationship. Unit 2 ice, characterized by the local development of coarser crystals, forms after some decades of Arrhenius growth, marking the initial influence of processes of dynamic recrystallization. Unit 3 ice, characterized by an abrupt increase in minimum crystal size, occurs at a depth of ~33 m throughout the glacier. In the accumulation area, this increase coincides with the first evidence of systematic fabric enhancement, interpreted in terms of dynamic recrystallization. Unit 4 ice, characterized by large, interlocking grains with a multi-modal, girdle fabric, develops within ~10 m of the glacier bed. Here, the measured minimum crystal size is consistent with a steady-state balance between Arrhenius processes of grain growth and strain-related processes of grain-size reduction. These changes are interpreted in terms of the effects of intense, continuous deformation in this basal zone.

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Flow of anisotropic ice

(P.R. Sammonds, S. Boon, N. Hughes, Geol/UCL)

We have designed and built a true triaxial cell for ice creep deformation that incorporates seismic tomographic imaging to allow the development of the ice fabric to be monitored. The apparatus, funded by the Paul Instrument Fund (administered by the Royal Society), will be used for testing deep ice core with the aim of developing an anisotropic flow law for ice. The apparatus is housed in a new cold-room complex at UCL, consisting of five interconnected cold rooms with independent temperature control.

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ICE–OCEAN–ATMOSPHERE INTERACTIONS

Carbon cycling and burial in a glacially influenced ocean

(J. Taylor, M. Tranter, BGC; G. Munhoven, ULiège)

We have collated published records of carbon storage (weight % calcium carbonate and organic carbon) in polar North Atlantic sediments, in order to assess the role that the glacial history of the Greenland and Fennoscandia may have had on carbon cycling in this oceanographically important region. The proportion of carbonate in sediment varies between 0 and ~50%, while that of organic carbon varies between 0 to ~2.0%. The spatial variation of the concentration and accumulation of both constituents is markedly different. Bulk accumulation shows a strong relationship with both depth and distance offshore and the location of major glacial outlets on neighbouring land masses. Therefore, ice-sheet dynamics and erosion influenced carbon (especially organic carbon) storage strongly during the Late Weichselian via their impact on sedimentation rates and constituents. By contrast, water-mass characteristics are important in determining the pattern of carbon storage during the Holocene. Carbonate fluxes to the polar North Atlantic sediment column fall by approximately 50% during glacials to $\sim 1.1\times10^{13}$ kg kyr^{-1}, but organic carbon storage is maintained at or greater than interglacial levels ($\sim 4.6\times10^{11}$ kg kyr^{-1}). This represents a 200% change in the rain ratio of inorganic to organic carbon. When combined with reduced deep-water ventilation, this could lead to enhanced CO_2 storage in deep waters of the polar North Atlantic, since there will be respiration of organic carbon and enhanced dissolution of carbonate, both in the water column and from the sediment surface. The release of CO_2 stored in this way could influence atmospheric CO_2 levels by several ppm over repeated, short time intervals.

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Modelled glacial and non-glacial HCO_3^-, Si and Ge fluxes since the LGM

(I.W. Jones, M. Tranter, BGC; G. Mundhoven, ULiège; P. Huybrechts, FUB; M.J. Sharp, EAS/UAlb)

The runoff and riverine fluxes of HCO_3^-, Si and Ge that arise from chemical erosion in non-glaciated terrain have been modelled for six times during the LGM and the present day. The fluxes that arise from the great ice sheets have also been modelled. Terrestrial HCO_3^- fluxes decreased during deglaciation, largely because of the reduction in the area of the continental shelves as sea level rose. The HCO_3^- fluxes, and the inferred consumption of atmospheric CO_2, were used as inputs to a carbon-cycle model that estimates their impact on atmospheric CO_2 concentrations ($^{atms}CO_2$). A maximum perturbation of $^{atms}CO_2$ by ~5.5 ppm is calculated. The impact of solutes from glaciated terrain is small in comparison to those from non-glaciated terrain. Little variation in terrestrial Si and Ge fluxes is calculated (<10%). However, the global average riverine Ge:Si ratio can be sensibly perturbed if the glacial Ge:Si ratio is high. Hence, variations in terrestrial chemical erosion appear to have only a reduced impact on $^{atms}CO_2$, and only little influence on the global Si and Ge cycle and marine Ge:Si ratios during deglaciation.

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MODELLING & REMOTE SENSING

Self-similarity in glacier-surface characteristics

(N.S. Arnold, W.G. Rees, SPRI)

The surface characteristics of ice sheets and glaciers are one of the primary controls on mass balance at both long and short time-scales. To date, however, many mass- or energy-balance models have relied on simple parameterizations including factors such as elevation, cumulative melt amounts, and depth of snow cover in the case of albedo, and generally spatially uniform, empirically derived values for roughness. Such relationships have generally exhibited large scatter, which has generally been attributed to the difficulties in measuring these variables, or to other, usually unspecified, controls. This research aims to improve on the relationships used to parameterize surface characteristics, by evaluating both the temporal and, more particularly, the spatial scales of variation in these parameters, and their possible controls. The methodology involved spatially-intensive surveys using both direct measurements and remotely sensed images of glacier surface characteristics including albedo, roughness, snow depth, density and water content. These data have been analysed to determine any topographic controls by comparison with digital elevation models, and to determine any self-similarity (or fractal characteristics) within the spatial variation. These results will be incorporated into the distributed-surface energy-balance model developed in Cambridge, and the better understanding of spatial and temporal variations in these characteristics should improve estimates of snowmelt and ice-melt in distributed, catchment-scale hydrological studies, as well as at larger scales.

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Cold regions hydrological modelling

(J.W. Pomeroy, CG; L. Kuchment, A. Gelfan, V. Demidov, RAS; R. Granger, T. Brown, N. Hedstrom, NHRC; D.M. Gray, B. Toth, CE/USask)

This investigation develops physically-based models for circumpolar runoff generation using an intercontinental transfer of cold-regions hydrological experience and archived hydrometeorological observations. The models include sophisticated representations of the processes of snow-cover formation, snowmelt, infiltration to frozen and unfrozen soils, vertical soil-moisture transfer, soil freezing and thawing, evapotranspiration, and flow of water as overland, subsurface, ground and channel flow. The hierarchy of model scales will permit application to a wide range of water problems in the circumpolar regions, from the freshwater discharge of large rivers entering the Arctic Ocean to climate and land-use change assessment.

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Greenland ice sheet dynamics: rapid response to climate change

(J.L. Bamber BGC; A.J. Payne, Geog/USoton)

This project examines the influence of rapid (ice-stream) flow on the stability and dynamics of the Greenland ice sheet (GrIS) by incorporating an ice-stream model into an ice-sheet model and calibrating and validating the coupled model with a range of observational datasets (derived from remote-sensing measurements). These data include radio-echo sounding measurements providing ice thickness and internal flow characteristics and surface velocities from SAR interferometry. We aim to improve the modelling of the GrIS in the crucial area of ice-stream dynamics and make a major advance in the development of model boundary conditions for the GrIS. To this end a new, 1 km resolution surface digital elevation model for Greenland and 5 km resolution ice-thickness and bedrock-elevation grids have been published and are available from NSIDC. Using these datasets, the fully coupled and validated model is being used to examine the sensitivity of the ice sheet to a series of climate-change scenarios.

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Impact of cloud cover on radiation budget of the Greenland ice sheet

(F.G.L. Cawkwell, BGC)

Cloud identification over snow and ice from satellite remote sensing has proved to be a difficult process to automate due to similarities in their visible and thermal properties. We have used stereo-matching of the nadir and forward views of the Along Track Scanning Radiometer (ATSR) onboard the ERS-1 and 2 satellites to identify clouds. Validation of the cloud top heights using radiosonde data indicates 73% of the stereo-matched heights are within 500 m of the radiosonde-predicted cloud tops, and when classifying the clouds as low, middle or high, almost 100% agreement between the two is achieved.

Energy-balance models, driven by radiation and turbulent heat fluxes, have been applied widely to predicting the response of the Greenland ice sheet to climate change, but a lack of knowledge of the temporal and spatial distribution of cloud cover has resulted in large uncertainties in both shortwave and longwave radiation fluxes. We use the properties of the stereo-matched clouds to produce a cloud climatology for the polar regions, and other cloud microphysical properties such as optical depth, for more detailed cloud classification. These data will be input into a radiative-transfer model to determine the impact of measured cloud properties on short- and longwave radiation fluxes. The same techniques will be used to derive a cloud climatology for Antarctica.

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Importance of initial conditions, feedback mechanisms and multiple solutions for an ice-sheet model

(S. Bradford, BGC)

A newly developed, zeroth order, 2-D, thermomechanically coupled flowline model is being used to investigate the importance of initial conditions, boundary conditions and climate history on the final solution of the model. A flowline for part of the Greenland ice sheet was chosen for a region with relatively uniform flow characteristics. Different initial ice thickness, temperature profiles and climate histories were prescribed and the model run to steady-state. The thickness profile was compared with the measured, contemporary dataset. Stepwise changes in the accumulation and surface temperature were applied to the steady-state solution to examine the effect that feedback mechanisms and ice-sheet history have upon thickness and temperature profiles.

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Ice-coverage fluctuations, southern Iceland

(R.G. Bingham, GTS/UGlas; N.R.J. Hulton, A.J. Dugmore, Geog/UEdin)

A three-dimensional, time-dependent numerical model for polar ice-sheets was used heuristically to investigate changing patterns of ice dynamics in southern Iceland in response to climatic forcing. Ice development over southern Iceland was forced using a linear relationship between mass balance and altitude based on empirical observations from Sólheimajökull, a southern outlet of Mýrdalsjökull. The model uses a 1 km-grid DEM of derived from ETOPO-5 with subglacial topography incorporated for Mýrdalsjökull. A continentality factor both accounts for raised ELAs inland and slackens the mass-balance/altitude gradient driving the model towards the interior of Iceland. With this calibration, the present-day ice distribution can be reconstructed. Sensitivity analysis demonstrated that ice extent was most dependent on changes in ELA.

An ELA lowering of 500 m, consistent with a ~5°C temperature depression over southern Iceland at the LGM, enables ice to cover the whole land surface and inundate any hypothetical refugia. This conclusion contrasts with previous assertions that coastal sectors of southern Iceland acted as refugia during the LGM.

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Late Quaternary glaciations, Eurasian Arctic

(M.J. Siegert, R. De'Ath, J.A. Dowdeswell, BGC; G. Bigg, SES/UEA)

Numerical ice-sheet modelling has been used to establish the timing and size of ice sheets in the Eurasian Arctic over the last glacial–interglacial cycle. Ice-sheet model results are compatible with a number of recently acquired glaci-geological datasets such as LGM terminal moraines, deglacial isostatic uplift patterns and bathymetric trough-mouth sedimentary fans. Evidence of ice-free conditions across the Taymyr Peninsula at the LGM, showing that the eastern limit of the last ice sheet was to the west of this region, is also compatible with our reconstruction, provided an East Antarctic style polar desert across the Russian High Arctic is used as a model input. The model results show the time-dependent evolution of the ice sheet, and the palaeoclimate necessary for its development.

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Form and flow of the Academy of Sciences ice cap, Severnaya Zemlya, Russia

(J.A. Dowdeswell, R.P. Bassford, BGC; A.P. Shepherd, CPOM/UCL; M.R. Gorman, SPRI; A.F. Glazovsky, Yu.Ya. Macheret, RAS; H. Miller, AWI; L. Savatugin, AARI; V. Vasilenko, Tashkent)

The 5555 km^2 Academy of Sciences ice cap is the largest in the Russian Arctic. 100 MHz airborne radar, digital Landsat imagery and satellite synthetic-aperture-radar interferometry were used to investigate its form and flow. The ice cap was covered by a 10 km spaced grid of radar flight-lines, and the central part by a grid at 5 km intervals; a total of 1657 km of radar data. Digital terrain models of ice-surface elevation, ice-thickness and bed-elevation datasets were produced (cell size 500 m). Total ice-cap volume is 2184 km^3 (about 5.5 mm sea-level equivalent). Maximum ice thickness is 819 m. About 50% of the ice-cap bed is below sea level. SAR interferometric fringes and phase-unwrapped velocities for the whole ice cap indicate slow flow in the interior and much of the margin, punctuated by four fast-flowing features with lateral shear zones and a maximum velocity of 140 m a^{-1}. Tabular icebergs up to about 1.7 km long are produced. Total iceberg flux from the ice cap is about 0.65 km^3 a^{-1}, and probably represents between 35 and 40% of the overall mass loss, with the remainder coming from surface melting. Driving stresses are generally lowest (<40 kPa) close to the ice-cap divides and in several of the ice streams. Ice-stream motion is likely to include a significant basal component and may involve deformable marine sediments.

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Dynamics of glacier surging using SAR interferometry and off-set tracking, Svalbard

(A.J. Luckman, T. Strozzi, Geog/UWalesS; T. Murray, H. Jiskoot, Geog/ULeeds)

This is a collaboration project between Leeds and Swansea for analysis of velocity and DEMs derived for surge-type glaciers in Svalbard from ERS-SAR data, together with SAR backscatter data. During a surge, ice velocity may exceed that measured using interferometry and, for these areas and times, satellite-radar offset-tracking procedures are used to monitor flow. Data on the complete surge of Monacobreen (1991–97) enable us to derive the 3-D distribution and temporal evolution of velocity patterns, as well as their controls. An accurate portrayal of the velocity structures in surge-type glaciers will be produced enabling elucidation of controls on flow instabilities.

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Ice dynamics during a surge of Sortebræ, East Greenland

(H. Jiskoot, H.D. Pritchard, T. Murray, Geog/ULeeds; A.J. Luckman, T. Strozzi, Geog/UWalesS)

Sortebræ underwent a major surge during 1992–95. A variety of remote-sensing data and techniques have been used to study it. The tidewater terminus advanced more than 5 km in one year and maximum annual ice displacements of 29 m d^{-1} and advance rates of 18 m d^{-1} were measured. Calculations of volume displacement, calving rates and changes in surface profile were made using multi-model photogrammetric analysis. Thinning was up to 219 m in the reservoir zone and thickening up to 74 m in the receiving zone. Topographic evolution has been studied in 3-D using interferometry and GIS. Ice displacements during and after the surge have been mapped using intensity tracking and interferometry. The calving flux of the glacier is estimated as 4–7 km^3 a^{-1}. The surge terminated rapidly and appeared to be caused by a hydrological instability.

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Environmental controls on the global distribution of surge-type glaciers

(K. Hayes, H. Jiskoot, T. Murray, Geog/ULeeds)

Surge-type glaciers are clustered geographically. The environmental and glaciological controls on their distribution are being investigated using statistical modelling techniques. Isolation of these controls provides a valuable insight into the mechanism responsible for the surge process. Recent research suggests that a polythermal regime and fine-grained sediments are conducive to surging in Svalbard. Residual analysis identified previously unrecognized surge-type glaciers and reclassified six glaciers as of normal type. Current investigations are focused on understanding the Icelandic and Yukon surge clusters.

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Volume changes in Svalbard glaciers from remotely sensed data and GIS

(A. Pope, A.J. Luckman, Geog/USwan; T. Murray, Geog/ULeeds)

This project will quantify the volumetric change of glaciers in Svalbard using DEMs derived primarily from automated digital photogrammetry, together with DEMs from long-baseline and differential SAR interferometry and digital map data.

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GLACIMARINE PROCESSES AND SEA ICE

Greenland Sea convection mechanisms and their climatic implications

(P. Wadhams, J.P. Wilkinson, N. Hughes, SPRI)

SPRI is co-ordinating a major new EU Framework 5 project, involving ten partners across Europe and Nordic countries. The objective of CONVECTION is to understand the physics underlying the convection process in the Greenland Sea, particularly in the Odden ice tongue and Nordbukta areas of the Greenland Gyre, and how this process links with climatic factors. Deep-water production in the Greenland Sea has shut off during recent decades, and winter thermohaline convection is now confined to shallow and intermediate depths. This has major implications for European climate: an increasing consensus of modelling studies shows a shutdown of convection associated with reduced heat transport northwards by Atlantic circulation and a resulting cooling of maritime Europe which will dominate the present warming trend.

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Pancake ice in the Weddell Sea

(M. Doble, P. Wadhams, SPRI)

An array of six drifting buoys was deployed into the advancing ice edge of the Weddell Sea, from the R.V. *Polarstern*, during April 2000. The buoys were fully instrumented and included differential GPS positioning, meteorological measurements and vertical wave spectra. Use of the new Orbcomm satellite transmission system gave high data rates and allowed high-frequency variations in the various parameters to be examined. Data from the array, combined with satellite passive microwave and active SAR images, are being used to study absolute and relative motion of the pancake ice, the role of waves in the evolution of the ice cover, implications for ocean–atmosphere heat flux, and the relative contributions of in situ growth and advection to the advance of the winter ice edge.

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Analysis of Arctic ice draft profiles

(P. Wadhams, N.R. Davis, N.E. Hughes, SPRI)

During the past 30 years British submarines have made a number of cruises under sea ice in the Arctic. Measurements of underwater profile of the ice (or draft thickness) collected by upward-looking sonar have been processed from paper-chart rolls into a digital format, and statistical analysis of the ice-draft profiles carried out. Comparison of the 1976, 1987, 1991 and 1996 data shows that there has been a significant decrease in the overall ice thickness since the 1970s. Analysis of data from intervening years is being carried out to determine how the changes are occurring year-to-year rather than between decades. Data are being released to the scientific community through databases at SPRI and NSIDC.

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Sensitivity of long- and medium-range acoustic signals to sea-ice thickness and roughness

(P. Wadhams, A. Kaletzky, SPRI)

Acoustic methods for measuring the average thickness sea ice over medium- and long-range transects are being investigated. Using fast-field acoustic models, however, it was found that there was no reliably measurable sensitivity to ice thickness at the very low frequencies (~20 Hz) at which signals can be sent over ranges of 1000 km and further. With 250 Hz signals and a range of 60 km, there was measurable sensitivity to ice thickness after intensive filtering of the modelled received signal. Unfortunately, the arrival time delays were not monotonic, or even very sensitive, in the region of greatest interest, that of ice thickness of 0.5–3.0 m. Thus, while this acoustic method shows some promise for distinguishing between ice-free and ice-covered areas and for detecting very thick ice, it appears unpromising for our major goal. This lack of sensitivity to sea-ice thickness may, however, be beneficial to ocean acoustic thermometry.

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IceCam: an environmental monitoring system for Ships-Of-Opportunity

(N.E. Hughes, R. Hall, P. Wadhams, SPRI)

IceCam is an integrated visual-monitoring and environmental data-collecting system designed for use on Ships-Of-Opportunity, to provide ground-truth data for satellite sensors. Two prototype units constructed during 1999 were deployed in 2000 on board the R.V. *Jan Mayen* and R.V. *Polarstern* in the Greenland and Weddell Seas respectively. Ice-concentration data derived from IceCam's oblique photographic images were found to correlate well with SSM/I satellite ice-concentration values. During 2001, the IceCam will be supporting fieldwork programmes in the Arctic and Bellingshausen Sea.

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High-latitude continental margin and deep-ocean basin dominated by density-driven down-slope sedimentary processes

(J.A. Dowdeswell, C. O'Cofaigh, J. Taylor, BGC; N.H. Kenyon, SOC; A. Rossell-Mele, UDurh; M. Wilken, J. Mienert, UTrom)

High-latitude continental margins adjacent to modern and Quaternary ice sheets are often dominated by the cyclical delivery of glacier-derived sediments reflected, for example, in the growth of large submarine fans made up of glacigenic debris flows. However, despite the proximity of the Greenland ice sheet, and the strong southward-flowing East Greenland Current, recent marine geophysical investigations from the RRS *James Clark Ross* show instead that the 3500 m deep and almost 250,000 km^2 Greenland basin is dominated by well-developed networks of submarine channels that extend over 400 km from the upper continental slope to the deepest parts of the basin. Extensive side-scan sonar, swath-bathymetric and acoustic-stratigraphic data demonstrate that the channels are up to 80 m deep, 2 km wide, and have braided, anastomosing and sinuous reaches related to changes in gradient of the continental slope. Between the channels, widespread fields of sediment waves are observed, indicating that down-slope flow and sediment-transfer processes are pervasive through the basin. Dense cold and saline water, produced along the 500-km length of the East Greenland continental shelf and adjacent slope by salt rejection during the formation of sea ice, cascades down the continental slope to produce the channels and sediment waves we observe in the Greenland basin. The East Greenland shelf has remained largely free of glacier ice over recent full-glacial periods, because the northeastern sector of the Greenland ice sheet is an area of very low precipitation, and is therefore relatively insensitive to climate cooling. This allows sea-ice production to continue on the shelf even during cold periods, as well as extending eastwards across the basin. Changes in the nature and rate of sedimentation within the Greenland basin should, therefore, provide important clues to the rate of deep-water production in the basin, which is of wider significance to the thermohaline circulation of the North Atlantic and the heat and momentum transfers associated with it.

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Initiation of fast-flowing ice streams during a glacial cycle inferred from glacimarine sedimentation

(J.A. Dowdeswell, BGC; A. Elverhøi, UOslo)

Fast-flowing ice streams drain huge basins within modern ice sheets and are a mechanism for rapid iceberg production and mass loss. Some ice streams are known to be unstable, and to switch between fast flow and stagnation. Numerical ice-sheet models and geophysical observations of large-scale streamlined glacial landforms and large glacier-derived sedimentary fans along high-latitude continental margins indicate the presence of ice streams in Quaternary ice sheets. High-resolution dated sedimentary records from an inter-fan area on the Svalbard continental margin yield evidence on the timing of initiation of fast glacier flow during a glacial cycle of ice-sheet growth and decay. Sedimentation rates and iceberg-rafted debris influx show that debris delivery to the Svalbard margin was relatively high during the period of Late Weichselian ice-sheet growth from about 30–18 kyr BP. Both parameters fell dramatically in inter-fan areas when full-glacial conditions, with ice at the continental shelf edge, were established at about 18 kyr BP. This shift is interpreted to mark the initiation of a fast-flowing ice stream, the convergence of flow from the surrounding ice sheet into this ice stream, and the consequent slowing of ice flow and sediment delivery to the inter-fan area beyond the ice-stream margins. This provides a constraint on the timing of ice-stream initiation during the cycle of ice-sheet growth and decay.

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SEDIMENTS AND GLACIAL GEOMORPHOLOGY

BRITICE: GIS database of palaeoglaciological evidence of the last British and Irish ice sheets, and reconstruction of their dynamics

(C.D. Clark, Geog/USheff; D.J.A. Evans, Geog/UGla; W. Mitchell, ULuton; S. Marsh, C. Jordan, BGS).

Reported evidence of moraines, eskers, drumlins, meltwater channels, glacial lakes, nunatak trimlines, drift limits, etc. are being extracted from published literature, geological survey reports and unpublished data, and input to a GIS. Half of Britain is complete (Feb, 2001) with data assembled as ARC/INFO coverages. New mapping of subglacial bedforms and moraine systems has been conducted from high-resolution DEMs and Landsat TM data. The aim is to produce Britain's first "glacial map" and to use these data to build a glacial-geological inversion model of the behaviour of the ice sheets. Of key interest are ice-divide locations, ice-sheet elevation, and how dynamic these may have been in constraining the overall pattern of retreat. The glacial map will be made available in printed form and as GIS coverages, and it is hoped will contribute to the testing of numerical ice-sheet models, help build regional reconstructions and direct field workers to problematic areas.

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Debris entrainment, glacier structure and deposition in polythermal glaciers, Svalbard

(N.F. Glasser, M.J. Hambrey, CG; T. Murray, Geog/ULeeds)

Work has continued on assessing the role of folding and thrusting in Svalbard valley glaciers in delivering sediment to ice margins. Various landforms, including hummocky moraines and debris trains, are clearly linked to glaciotectonic processes. The Svalbard glaciers have proved to be useful analogues for the formation of British late-Pleistocene landforms.

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Reconstructing late Pleistocene glacial environments in west Wales

(M.J. Hambrey, N.F. Glasser, R.J. Whittington, CG).

A combination of borehole investigations and field studies have demonstrated the existence of a large ice-dammed lake in the Cardigan area. This and associated sedimentary facies indicate how the ice moved onshore from the Irish Sea, and demonstrate that the idea of rapid recession of the Irish Sea glacier in a glaciomarine environment is invalid in the area.

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Mineral magnetic investigations of Neoglacial sediments, Svartisen and Okstindan, Norway

(S. Gurney, K. White, Geog/URead)

Sediment magnetic studies of Neoglacial deposits from northern Norwegian glaciers have been undertaken in order to evaluate whether such techniques might be useful in determining glacial retreat rates.

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Holocene fluctuations and sedimentology of Glaciar Soler, Chile

(N.F. Glasser, M.J. Hambrey, CG)

This research will: (1) describe the structural attributes of Glaciar Soler, a temperate outlet glacier on the east side of Hielo Patagónico Norte in Southern Chile; (2) define the dominant debris transport paths through the glacier; (3) describe the geomorphology and sedimentology of its proglacial area; and (4) document Holocene fluctuations of the glacier using radiocarbon dating of wood samples obtained from the proglacial area in January 2000. The glacier is fed by an icefall from the icefield, and by snow and ice avalanches from surrounding mountain slopes. The dominant structures in the glacier are ogives, crevasses and crevasse traces. Thrusts and recumbent folds are developed where the glacier encounters a reverse slope, elevating basal and englacial material to the ice surface. Sedimentary facies in moraine ridges on the glacier forefield include, in relative abundance terms, diamicton, sandy boulder-gravel, gravel and sandy gravel. Proglacial water bodies are currently developing between the receding glacier and its frontal and lateral moraines. The presence of folded sand and laminites in moraine ridges in front of the glacier suggest that during a previous advance, Glaciar Soler overrode a former proglacial lake. Radiocarbon dating of tree remains demonstrates that the glacier overrode this lake bed sometime between AD 904 and AD 1334. In situ tree remains, plastered onto a large boulder in front of the glacier, constrain this advance to the period between AD 1222 and AD 1342. This advance precedes by several hundred years the maximum Little Ice Age extent of other Hielo Patagónico Norte outlet glaciers, suggesting either an early age for the onset of Little Ice Age conditions or a previously unrecognized period of glacier advance.

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Glacial cirque form and distribution

(I.S. Evans, N.J. Cox, Geog/UDurh)

Glacial cirques have been mapped from fieldwork and air photos for England and Wales and several ranges in the southern Coast Mountains of British Columbia. Work continues on the latter and on Scotland. One morphometric result confirms the static allometry of cirques, with width and length increasing more rapidly than depth: another that cirque development is diverse, with weak relationships between development of headwall, of floor and of plan form. Cirque form and distribution are being related to geology and climate.

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Influence of basal-ice characteristics on ice-sheet sedimentation

(P.G. Knight, ES&Geog/UKeele; C.J. Patterson, MCC; A. Jones, ULiv; R.I.Waller, UGren)

The potential for using moraine sediments to reconstruct the characteristics of basal ice is being assessed. Data on recent changes in the position of part of the margin of the ice sheet have been collected, and changes in the morphology of the margin correlated with changes in basal ice, in ice-marginal moraines, and in sediment routing between the ice and the proglacial area. Debris characteristics and deformation structures in basal ice and in ice-marginal moraines were measured and sedimentological characteristics of the basal ice were found to be preserved in the proglacial moraine. The diagnostic high clay and silt content of one particular type of basal ice (the so-called "dispersed facies") was reflected in the sedimentology of moraines that were supplied by parts of the glacier that contained this ice. Sublimation of ice in winter conditions preserved stratigraphic features and tectonic structures from the ice in the sediments that were left behind after ablation (http://www.esci.keele.ac.uk/staff/pgk/).

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Spectral roughness of glaciated bedrock geomorphic surfaces

(B.P. Hubbard, CG; M.J. Siegert, BGC)

A microroughness meter (MRM) was used to measure the high-frequency roughness of a number of geomorphic surfaces in the forefield of Glacier de Tsanfleuron, Switzerland. Resulting spectral-power densities are added to low-frequency spectra, measured by electro-optical distance meter (EDM), to generate composite roughness spectra that include almost 5 orders of magnitude of roughness in the frequency domain. These are used to define two roughness indices: a general index of bed roughness, as the integral of the raw, spectral-power densities; and a sliding-related index of bed roughness, as the integral of the spectral-power densities weighted to account for the optimum dependence of glacier-sliding speed on hummock wavelength. Results indicate that MRM-measured geomorphic components vary in roughness by 3 orders of magnitude, principally depending on the surface microenvironment measured and profile orientation relative to the direction of former ice flow. Both MRM- and EDM-measured roughnesses are lower parallel to the direction of former ice flow than perpendicular to it. Composite roughness spectra consequently indicate that the glacier bed is smoothed in the direction of former ice flow at all horizontal scales from 1 mm to 40 m, typically resulting in an order of magnitude decrease in sliding-related roughness relative to that measured perpendicular to ice flow. Comparison of data from two survey sites located adjacent to, and ~1.2 km from, the current glacier margin indicates that post-glacial subaerial weathering homogenizes bedrock roughness, in particular reducing high-frequency, flow-orthogonal roughness. Accounting for the effect of 28% ice–bedrock separation over one of the profiles reduces net, sliding-dependent roughness by between 27% and 43%, depending on the transition wave number used.

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Subglacial sediment deformation

(P.P. Sammonds, C. Stafford, Geol/UCL; J.K. Hart, A.J. Payne, Geog/USoton)

We are testing the mechanical properties of glacial sediments from Langjökull, Iceland in an integrated laboratory, field and modelling investigation of the response of this small ice cap to climate change. We gathered one subglacial core and considerable proglacial material from the ice cap in 1999 and 2000, some of which was transported back frozen to preserve fabric and porosity. Testing is still at an early stage.

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Glacier–permafrost interaction, Leverett Glacier, southwest Greenland

(R.I. Waller, UGren; Z.P. Robinson, W.G. Adam, UKeele)

This field-based project has examined the genesis and implications of a pronounced suite of arcuate end moraines located just beyond the margin of Leverett Glacier, southwest Greenland. This is a small outlet glacier that terminates in a region of continuous permafrost. Reconnaissance of the proglacial area revealed a superb longitudinal section, eroded through the entire end-moraine complex by the glacier's main drainage channel. This section is composed of a sequence of highly deformed facies of ice and frozen sediment which bears little relation to the surface topography. The glaciotectonized sequence, hosted within a sequence of massive ice and icy sediments, is similar to many exposures of Pleistocene glacially deformed permafrost observed in the western Canadian Arctic.

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SNOW

Snow studies in the Scottish Highlands

(R.D. Gosling, B.W. Brock, A.R. Black, Geog/UDun; M.T. Slater, A.P. Cracknell, EEP/UDun)

Rapid melting of snow in upland catchments can contribute to lowland flooding in Scotland. The influence of topography on upland water-equivalent snow storage and the meteorological conditions leading to rapid snowmelt are being investigated using a digital terrain model and meteorological data from upland stations. These data are combined within the ARC/INFO GIS. An earlier project investigated the capabilities of high-temporal-resolution satellite imagery (AVHRR, MODIS) to map the extent of snow cover in Scotland, where the short daylight hours and high incidence of cloud cover during the winter months are particular problems for retrieving imagery at visible wavelengths. With few exceptions, it has proved possible to update the Scottish snow-cover map on a weekly basis.

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Snow chemistry at Okstindan, Norway

(W.H. Theakstone, Geog/UMan; P. Readman, CERN)

The Okstindan Glacier Project continued in 1996 and 1997, in col1aboration with NILU (Norwegian Institute for Air Research). Daily precipitation samples are collected at Tustervatn (439 m a.s.l.) for chemical analysis, as part of the Norwegian Monitoring Programme for Long-Range Transported Air Pollutants. If precipitation exceeds 2 mm, a second sample is collected for oxygen-isotope analysis. In late winter, samples are collected in a continuous column downwards from the surface of the snowpack covering the glacier Austre Okstindbreen at an altitude of 1470 m. Stratigraphic variations of the chemical composition of the accumulated snow are compared with temporal variations of winter precipi tation at Tustervatn. Dating of strata within the glacier's snow cover permits calculation of accumulation rates during discrete periods of the winter. The influence of particular synoptic situations on chemical loading of the snowpack is examined.

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Representation of snow ablation processes for land surface schemes

(J.W. Pomeroy, S. Hanson, CG; D.M. Gray, B. Toth, CE/USask; R. Granger, N. Hedstrom, NHRC; R Essery, HC; P. Viterbo, ECMWF; K. Shook, AE)
This study aims to improve the understanding of surface processes and sub-grid dynamics that lead to patterns and rates of snow-cover depletion, and propose new techniques that may be used to represent snow ablation in "tiled" land-surface schemes of atmospheric models. Existing GEWEX datasets on snow accumulation and ablation are being synthesized and used to develop and evaluate appropriate parameterizations of the processes. Sub-grid variability is parameterized by considering the small-scale statistical distribution of driving parameters, with small-scale association amongst parameters solved for in the coupled mass and energy balances at the tile (landscape-type) scale.

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Snow hydrology on Alpine and Arctic glaciers

(A .M. Fox, I.C. Willis, N.S. Arnold, UCam)
We are continuing to develop our semi-distributed physically based glacier-hydrology model. The model has been parameterized and tested using extensive datasets from the temperate Haut Glacier d'Arolla, Switzerland, over the last 10 years. It accurately reproduces observed subglacial water pressures, englacial/subglacial velocities, and proglacial stream discharges during late summer when the glacier is largely snow-free, but it is poorer at predicting these variables when large parts of the glacier are still snow-covered. The model is being adapted to incorporate a more accurate representation of vertical liquid-water infiltration, heat conduction and liquid-water refreezing within unsaturated layers, and lateral water movement and storage within saturated layers. Specifically we are adapting the 1-D vertical model SNTHERM (CRREL) and the 3-D ground-water model MODFLOW (USGS) and plan to merge these with our existing code. The final model will be used to calculate spatial and temporal patterns of snowpack water storage and routing across glaciers.

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Nitrogen and carbon cycling in boreal forest: snowmelt and infiltration to frozen soils

(J.W. Pomeroy, G.H. Brown, H.G. Jones, E. Yates, S. Hanson, CG; T.D. Davies, UEA; D.M. Gray, B. Toth, CE/USask; R. Janowicz, WRD/INAC)
Land areas poleward of 50°N provide about 30% of the global terrestrial carbon sink; many of these lands are snow-covered for over one-half of the year. The budget of nitrogen in snow may exert an important control on the productivity of, and uptake by, northern forests in this zone. The snow nitrogen cycle has not been fully addressed in global models and its contribution to global budgets of nitrogen and carbon remains to be elucidated. This work will further our understanding of the contribution of the snow nitrogen cycle to high-latitude nitrogen and carbon cycling by (1) evaluating existing quantitative nitrogen flux/transformation relationships and assembling a process-based, modular, numerical snow nitrogen model for cold forests; (2) measuring the carbon-dioxide flux associated with infiltration of nitrogen-bearing meltwaters to frozen boreal-forest soils; (3) examining the sensitivity of the budget to climate.

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Contributed by Bryn P. Hubbard

ABBREVIATIONS

AARI	Arctic and Antarctic Research Institute, 38 Bering Street, 199397 St Petersburg, Russia
AE	Alberta Environment, Edmonton, Canada
ANSTO	Australian Nuclear Science and Technology Organisation, Sydney, Australia
ARC	Antarctic Research Centre
AWI	Alfred-Wegener-Institut für Polar- und Meeresforschung, D-27515 Bremerhaven, Germany
BAS	British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET
BGC	Bristol Glaciology Centre, School of Geographical Sciences, UBris
BGS	British Geological Survey
CCRC-EOS	Climate Change Research Center, Inst. for Study of Earth, Oceans and Space, UNH
CE	Civil Engineering
CERN	CERN, Geneva, France
CG	Centre for Glaciology, Institute of Geography and Earth Sciences, UWalesA
CIRES	Cooperative Institute for Research in Environmental Sciences, UCO-B
CPOM	Centre for Polar Observation and Modelling, UCL
EAS	Earth and Atmospheric Sciences
ECMWF	European Centre for Medium-range Weather Forecasts
EEP	Electrical Engineering and Physics
EnvS	Environmental Sciences
ES	Earth Sciences
ETH-Z	Eidgenössische Technische Hochschule Zürich
FUB	Univ. Libre de Bruxelles, B-1050 Brussels, Belgium

Geog	Geography
Geol	Geology/Geological Sciences
HC	Hadley Centre for Climate Prediction and Research, Meterological Office, Bracknell RG12 2SY, UK
IFS	Inst. of Fundamental Science
IGL	Isotopes Geosciences Laboratory, Keyworth, UK
IGNS	Inst. of Geological and Nuclear Sciences, New Zealand
IMAU	Institute for Marine and Atmospheric Research, Utrecht Univ., NL-3584 Utrecht CC, The Netherlands
INAC	Indian and Northern Affairs Canada
IQCS	Inst. for Quaternary and Climate Studies
IRL	Industrial Research Ltd, PO Box 31-310, Lower Hutt, New Zealand
LGGE	Laboratoire de Glaciologie et Géophysique de l'Environnement, Grenoble, France
LU	Lincoln Univ., New Zealand
MAU	Massey Univ., Palmerston North, New Zealand
MCC	Macalester College, St Paul, MN 55105, USA
NERC	Natural Environment Research Council
NHRC	NWRI at National Hydrology Research Centre, Saskatoon, S7N3H5, Canada
NIWA	National Inst. of Water and Atmosphere, Wellington, New Zealand
NSIDC	National Snow and Ice Data Center, CIRES
NTNU	Norwegian Univ. of Science and Technology, N-7055 Dragvoll, Norway
NWRI	National Water Research Institute
Phys.	Physics
PSU	ESSC/Geoscience, The Penn State Univ., Univ. Park, PA 16802, USA
RAS	Russian Academy of Sciences, Moscow
RGSL	Reynolds Geo-Sciences Ltd
SOC	Southampton Oceanography Centre, USoton, SO14 3ZH, UK
SPRI	Scott Polar Research Inst., Cambridge CB2 1ER, UK
UAlb	Univ. of Alberta, Edmonton, Alta, T6G 2E3, Canada
UAuck	Univ. of Auckland, Private Bag, Auckland, New Zealand
UCL	Univ. College London, WC1E 6BT, UK
UCO-B	Univ. of Colorado, Boulder, CO 80309, USA
UCam	Univ. of Cambridge, CB2 3EN, UK
UCan	Univ. of Canterbury, Private Bag 4800, Christchurch, New Zealand
UDun	Univ. of Dundee, DD1 4HN, UK
UDurh	Univ. of Durham, DH1 3LE, UK
UEA	Univ. of East Anglia, Norwich NR4 7TJ, UK
UEdin	Univ. of Edinburgh
UGlas	Univ. of Glasgow, Glasgow G12 8QQ, UK
UGren	Univ. of Greenwich.
UKeele	Keele Univ., Staffs ST5 5BG, UK
ULJM	Liverpool John Moores Univ., L3 3AF, UK
ULanc	Lancaster Univ., LA1 4YQ, UK
ULeeds	Univ. of Leeds, Leeds, LS2 9JT, UK
ULiège	Univ. de Liège, B-4000 Liège, Belgium
ULiv	Univ. of Liverpool, L69 3RX, UK
ULonRH	Univ. of London, Royal Holloway, TW20 0EX, UK
ULuton	Univ. of Luton, LU1 3JU, UK
UMan	Univ. of Manchester, M13 9PL, UK
UME	Univ. of Maine, Orono, ME 04469, U.S.A.
UMel	Univ. of Melbourne, Victoria 3010, Australia
UNH	Univ. New Hampshire, Durham, NH 03824-3525, U.S.A.
UOslo	Univ. of Oslo, P.O. Box 1042, Blindern, N-0316 Oslo, Norway
UOtago	Univ. of Otago, PO Box 56, Dunedin, New Zealand
URead	Univ. of Reading, RG6 6AL, UK
USask	Univ. of Saskatchewan, Saskatoon, Sask., S7N 0W0, Canada
USheff	Univ. of Sheffield, S10 2TN, UK
USoton	Univ of Southampton, SO17 1BJ, UK
UTrom	Univ. of Tromsø, N-9037 Tromsø, Norway
UwalesA	Univ. of Wales, Aberystwyth, Ceredigion, Dyfed SY23 3DB, UK
UwalesC	Univ of Wales, Cardiff, CF1 3YE, UK
UwalesS	Univ. of Wales, Swansea, SA2 8PP, UK
VAW	Laboratory of Hydraulics, Hydrology and Glaciology, ETH-Z, CH-8092 Zürich, Switzerland
VUW	Victoria Univ. of Wellington, Wellington, New Zealand
WRD	Water Resources Division, INAC, Whitehorse, YT Y1A 2B5, Canada

INTERNATIONAL GLACIOLOGICAL SOCIETY

ANNUAL GENERAL MEETING 2001

MINUTES OF THE ANNUAL GENERAL MEETING OF THE INTERNATIONAL GLACIOLOGICAL SOCIETY

7 June 2001 at the University of Maryland, College Park, Maryland, U.S.A.

The President, Dr Robert A. Bindschadler, was in the Chair.

48 members from 15 countries were present.

1. The Minutes of the last Annual General Meeting, published in the ICE, 2000, No. 123, p. 10–12, were approved on a motion by J.-G. Winther, seconded by R. Asher and signed by the President.

2. The President gave the following report for 2000–2001:

It has been a very busy year and a great deal has been accomplished. I have chosen to begin my report by acknowledging those in our Society that work full-time for the Society and without whom I would be left with very little good news to report. The complement of full-time employees in our home office in Cambridge is dangerously small yet, through their hard work and dedication an astounding amount gets done. I visited our home office last March in the midst of our annual audit and found the office humming with activity. Our Society is extremely fortunate to have Simon Ommanney as our Secretary-General and Linda Gorman as his Administrative Assistant. Also in Cambridge are Ken Moxham, our copy editor, and Joan Keating, who processes your manuscripts. Simon sets a standard of work ethic that should inspire and would probably exhaust most of us. Working weekends has become part of his routine to keep from being buried under the e-mail, other correspondence, and the full breadth of journal publication tasks he shoulders day in and day out. So before I list the Society's accomplishments, I want to be sure you know where the credit is due. Simon, on behalf of the Society I want to thank you, Linda and your editors for all you have done for us this past year.

Most of the accomplishments are in the all-important area of publications. For a relatively small professional society, we continue to be extremely prolific, despite relying on so much volunteer labour. Since my report to you last year in Fairbanks, the Society has completed its first year of a four-issue volume of the *Journal of Glaciology*, with the publication of issues 153, 154 and 155 of Volume 46. Council had voted to retain the same cover for all issues of one volume with the expectation that the savings in printing costs would offset the cost of the additional mailing. I'm happy to report this strategy appears to be successful, allowing us to shorten the time a paper sits awaiting publication. The only disadvantage seems to be that many members, upon seeing a familiar cover on subsequent issues assumed they had received the same issue in error. If this happens to you, please check the issue number or, better yet, the contents.

Volume 46 contained 716 pages, a significant increase over the 598 pages published in the previous volume. The first issue for 2001 (Volume 47) is now with the printer. All papers for the second issue of this volume have been edited and we expect it will be in your hands by the end of the summer.

The business of accepting papers falls under the purview of our Chief Editors, Will Harrison and Matthew Sturm, and their indispensable assistant, Monica Court. They continue to do a tremendous job, managing and running the editorial office in Alaska. We all benefit greatly from their hard work. The Society has just concluded an agreement with the University of Alaska to provide some limited support for the editorial office over the next three years. The office of the Chief Editors is continually reviewing procedures and the ability of the Editorial Board to deal effectively with the papers you are submitting. We are most grateful to the editors who serve on the board. This year Dorthe Dahl-Jensen, Roger Hooke and Neal Iverson will be stepping down as editors and I would like to thank them on your behalf for the contributions they have made. I am delighted to say that the following editors — Jerry Johnson, Manfred Lange, Renji Naruse and Joe Walder — have agreed to serve another term. They will be joined by Kurt Cuffey, Christine Hvidberg, Jacques Meysonnier and Ted Scambos who have agreed to join the Editorial Board and who will ensure that we have enough editors covering a sufficiently broad range to deal with your papers expeditiously.

Editors rely on quality reviews to assist authors in improving papers and making them of more value to our readership. Many of you have provided this invaluable service. We have now begun to ask editors for the names of persons who they feel provided outstanding reviews so they can be acknowledged. Our first set of such recognitions for excellent reviews were published in ICE No. 122.

Last year saw the publication of two more volumes in our *Annals of Glaciology* series. Volume 30, a fairly slim volume by today's standards, contained 258 pages of selected papers from the EISMINT/EPICA Symposium on Ice Sheet Modelling and Deep Ice Drilling, held in The Hague in April 1999. Volume 31, a more substantial issue at almost 500 pages, contained papers from the International Symposium on the Verification of

Cryospheric Models, held in Zürich in August 1999.

This year the first *Annals of Glaciology* to be published will be Volume 32. This 364-page volume contains 59 papers from the International Symposium on Snow, Avalanches and Impact of the Forest Cover held in Innsbruck in May 2000 and should be printed this week. The second will be Volume 33 which will contain 89 papers from the International Symposium on Sea Ice and its Interactions with the Ocean, Atmosphere and Biosphere, held in Fairbanks, Alaska, last June. It will be published later this summer and will contain more than 600 pages.

Many of the papers presented here, at the Fourth International Symposium on Remote Sensing in Glaciology, will be accepted for publication in *Annals of Glaciology* Volume 34. I commend the co-Chief Editors, Jan-Gunnar Winther and Rune Solberg along with their team of Scientific Editors — Alfred T.C. Chang, Dorothy K. Hall, Kenneth C. Jezek, Ian R. Joughin, Jeffrey R. Key, W. Gareth Rees, Eric Rignot, Helmut Rott, Theodore A. Scambos, Richard S. Williams Jr, Duncan Wingham and Neal W. Young — for the excellent job they are doing.

I will also take this opportunity to thank again Dorothy Hall and her local organizing team. I had the pleasure of serving on that committee, along with Waleed Abdalati, Donald J. Cavalieri, Alfred T.C. Chang, Joey C. Comiso, Mark A. Fahnestock, James L. Foster, Sirpa Häkkinen, Christopher A. Shuman and Mary Floyd. Mary is in the business of arranging meeting support and worked especially hard in negotiating all the details with the facilities staff of the University of Maryland Conference Center. That staff, as well as our staff in Cambridge, have also contributed their energy to make this symposium a success. Organization and hard work can never fully replace financial backing and we thank the National Science Foundation, NASA, the ICESat Project and the Earth System Science Interdisciplinary Center at the University of Maryland for the funds to help support this symposium.

Later this summer, we will be hosting a second IGS meeting, this time on Ice Cores and Climate, in Kangerlussuaq, Greenland. The response for this meeting has been unbelievable with more than 200 abstracts submitted and most presenters planning to contribute papers for *Annals of Glaciology* Volume 35. This will be a severe test for our Chief Editor, Eric Wolff and the Editorial Board, consisting of Richard Alley, Kumiko Goto-Azuma, Jo Jacka, Sigfús Johnsen, Valerie Masson, Dave Morse, Bernhard Stauffer, J.-P. Steffensen, Eric Steig. This board is smaller than usual and, considering the large number of submitted papers, we expect to invite a few others to join the board. Such a response will also be a challenge to the local organizing group of Dorthe Dahl-Jensen, Gary Clow and Heinz Miller.

Since my last report to you we have accepted an invitation from Keith Echelmeyer, of the University of Alaska Fairbanks, to host an International Symposium on Fast Glacier Flow, that will be held in Yakutat, Alaska, in June 2002. Later in the year we will also host an International Symposium on Physical and Mechanical Processes in Ice in Relation to Glacier and Ice-Sheet Modelling, in Chamonix Mont-Blanc, France.

As usual, we have been planning ahead on your behalf and have already agreed with Walter Ammann to host the next International Symposium on Snow and Avalanches in Davos, Switzerland in 2003. That year we are also looking forward to collaborating with the Scientific Committee on Antarctic Research on the next symposium on Antarctic Glaciology. We are discussing the possibility of a 2004 meeting on Arctic Glaciers in collaboration with the International Arctic Science Committee's Working Group on Arctic Glaciology and are planning for our next meeting on sea ice in New Zealand in 2005.

As part of our ongoing efforts to promote glaciology and facilitate the dissemination of information, we co-sponsored the meeting on Snow and Ice, in collaboration with the Eastern Snow Conference and the Canadian Geophysical Union, in Ottawa, Ontario, Canada. Unfortunately, the meeting we were co-sponsoring on Millennial-scale Events in the North Atlantic Region during Termination I, in Northern Ireland later this month has been postponed due to the foot-and-mouth crisis in the U.K.

The first issue of *ICE* for 2001 was published earlier this year and reports from the United Kingdom and New Zealand are in hand for the second issue. If your work has not been featured in a recent issue of *ICE* please contact your National Correspondent to find out when the next submission will be prepared. These periodic reports on glaciological work being undertaken by different countries are a good way to promote your own work and ensure it is not being duplicated elsewhere.

Some final news on publications. We have been very pleased with the response to our co-publication venture with the University of Washington Press that resulted in the revised edition of *Glacier Ice*: so much so that we have now entered into another venture with them to co-publish *Secrets of the snow: visual clues to avalanche and ski conditions* by Ed LaChapelle. This will be a companion volume to his *Field guide to snow crystals* that was reprinted by the Society and which has enjoyed steady sales over the years. The University of Washington Press will be marketing both books together.

There are a few other individuals whose services to the Society deserve recognition. The chairs of our three standing committees are Charlie Raymond, who heads the Nominations Committee; Julian Dowdeswell, who directs the Publications Committee; and Willy Weeks, who leads the Awards Committee. I would also like to thank the members of these committees who help these chairpersons accomplish the committees' important tasks. And last, but not least, I'd like to thank the members of Council. Leaving Council this year are Vice President Kolumban Hutter and Members Sridhar Anandakrishnan, Heinz Blatter, Yoshiyuki Fujii and Eric Wolff. I thank them for three excellent years of service. Joining Council, I would like to welcome Atsumu Ohmura as Vice President and Keith Echelmeyer, Adrian Jenkins, Kumiko Goto-Azuma and Niels Reeh as Members.

Our Society has suffered a few losses this past year. In January we heard of the unexpected death of Loris Seligman, our Founder's widow. Her niece advised us that she has made a most generous bequest to the Society of £5000. Council has made the very fitting decision that this money be allocated to the fund set up for the Seligman Crystal.

In February, Sylva Gethin, who verified and checked references for all our publications, died unexpectedly. More recently, a well-known and very active member, Ian Whillans passed away after a prolonged battle with cancer. In the same week, we also lost Norm Davis, a long-time member from Cambridge. I was able to represent the Society at Ian's funeral and spoke to how I felt Ian embodied what the IGS is truly about. His colleagues at Ohio State are collecting remembrances of him for a book being prepared for his widow and their children and an obituary will appear in a future issue of *ICE*. In addition, the Byrd Polar Research Center is establishing a Whillans Glaciology Lecture Series.

Two persons left our home office last year, thinning our already small staff: Dave Garbett, our Production Manager followed his heart to Holland; and Liz Farmar, who worked part-time setting papers, left to focus on her other job. To cope with the increasing workload created by larger and more frequent IGS meetings and more issues of the *Journal*, council has set up an Appointments Committee to advertise and shortlist candidates for a new Production Assistant.

On a matter of critical importance, the Secretary-General informed Council of his intention to stick with his plan to serve the Society in this capacity for ten years. This means he will vacate the position in two years. Council has approved the establishment of a Search Committee as the first step of a concerted effort to recruit the next Secretary-General. The goal is to have a Secretary-General designate within 12 months to provide for a substantial overlap with Simon and lessen the impact of the transition on the Society.

I won't say much about financial matters because we are fortunate to have our Treasurer, John Heap, with us today. I will leave it to him to give us some good news in his presentation of the accounts.

I will only add one financial footnote to those Society members who live and work in the United States. Last year, the IGS became a member of the American Fund for Charities. This organization accepts donations on behalf of its member charities and is exempt from US federal income tax. Thus, US glaciologists can take advantage of this substantial benefit when making donations or bequests to the Society.

In summary, the Society has enjoyed a very productive year, devoid of financial crises. Of most concern to me is our inadequate Cambridge staff. I feel Council has taken appropriate steps to address this situation and I hope to have more positive news on this front in next year's report.

You, the membership, are doing a marvellous job, participating in conferences, submitting and reviewing papers for the *Journal* and *Annals*, and conducting compelling research. I can only ask that you keep up the good work. You all have helped me enjoy the honour of serving as your President.

Thank you for your attention.

T.H. Jacka proposed, and J.-G. Winther seconded, that the President's report be accepted. This was carried unanimously.

3. The Treasurer, Dr J.A. Heap, presented the following report with the audited Financial Statements for the year ended 31 December 2000.

"The state of the Society's finances is best summarised by considering the changes from 31 December 1999 to 31 December 2000 in the following funds, as shown on page 13 of the accounts:

Seligman Fund: decreased from £2421 to £2220, as a consequence of interest accrual and expenditure;

Contingencies Fund: maintained at the same level of £12,684;

Annals Fund: decreased from £75,893 to £68,846; this loss is not significant but merely reflects normal year-to-year operation of the account.

Publications Fund: increased from £16,681 to £21,092, as a consequence of sales, particularly of *Glacier Ice*, royalties and interest accrual;

Future Volumes: increased from £26,249 to £53,709 reflecting advanced income received with respect to Annals 32 and Annals 33;

Accumulated Fund: increased from £141,373 to £201,913 (page 6) consequent upon a profit in that account for the year of £59,284 plus a gain of £1,256 in the value of investments due to an adjustment to market value (page 12, note 7). The largest component of this increase arose from savings in salaries (over half).

In 2000, the Society published 716 pages in the *Journal of Glaciology* and 738 pages in the *Annals of Glaciology*. In 1999, the figures were 598 for the *Journal* and 600 for the *Annals*, a year with two issues of the *Annals*. As I always note, the Society's publications are still very much dependent on the provision of page charges; the revenue exceeds that derived from the total of members' dues. I wish to register once again the Society's warm thanks to all those authors who have been both able and ready to support the Society in this way.

May I, again, make a plea to all members of the Society to do all in their power to increase the membership. Although there has been a slight increase in membership we would very much like to reach a base of at least 1000. If you know of colleagues or students who are not members, please encourage them to join. I believe they will find it is extremely good value for money. Also, please ensure that libraries in any institutions in which you have influence either maintain their subscriptions or take one out."

After recording that £87,002 on page 6 should have been £83,907, T.H. Jacka proposed, and J.L. Bamber seconded, that the Treasurer's report be accepted. This was carried unanimously.

4. Election of auditors for the 2001 accounts.
R. Asher proposed, and C.L. Hulbe seconded, that Messrs Peters, Elworthy and Moore of Cambridge be elected auditors for the 2001 accounts. This was carried unanimously.

5. Election to the Council. After circulation to all members of the Society of the Council's suggested list of nominees for 2001–2004, no further nominations were received, and the following people were therefore elected unanimously:

Vice President:	Atsumu Ohmura
Elective Members:	K.A. Echelmeyer
	K. Goto-Azuma
	A. Jenkins
	N. Reeh

The AGM was adjourned on a motion from J.M. Palais seconded by S. Anandrakrishnan.

JOURNAL OF GLACIOLOGY

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

R Bintanja and C H Reijmer
Detailed observations of the rippled surface of Antarctic blue ice areas

L Copland and M Sharp
Mapping thermal and hydrological conditions beneath a polythermal glacier with radio-echo sounding

K M Cuffey
Interannual variability of elevation on the Greenland ice sheet: effects of firn densification, and establishment of a multi-century benchmark

O Eisen, W Harrison and C F Raymond
The surges of Variegated Glacier, Alaska, U.S.A., and their connection to climate and mass balance

S L Ensminger, R B Alley, E B Evenson, D E Lawson and G J Larson
Basal-crevasse-fill origin of laminated debris bands at Matanuska Glacier, Alaska

A C Fowler, T Murray and F S L Ng
Thermal regulation of glacier surging

N F Glasser and M J Hambrey
Tidewater glacier beds: insights from iceberg debris in Kongsfjorden, Svalbard

C Haas, D N Thomas and J Bareiss
Surface properties and processes of perennial Antarctic sea ice in summer

Han Jiankang, Xie Zichu, Zhang Xinping, Dai Dongsheng, P A Mayewski and M S Twickler
Methanesulphonate in the firn of King George Island, Antarctica

R C A Hindmarsh and E Le Meur
Dynamical processes involved in the retreat of marine ice sheets

E Isaksson, W Karlén, P Mayewski, M Twickler and S Whitlow
A high-altitude snow chemistry record from Amundsenisen, Dronning Maud Land, Antarctica

E Isaksson, V Pohjola, T Jauhiainen, J Moore, J-F Pinglot, R Vaikmäe, R S W van de Wal, J O Hagen, J Ivask, L Karlöf, T Martma, H A J Meijer, R Mulvaney, M Thomassen and M R van den Broeke
A new ice-core record from Lomonosovfonna, Svalbard: viewing the 1920–97 data in relation to present climate and environmental conditions

N R Iverson and R M Iverson
Distributed shear of subglacial till due to Coulomb slip

G Kaser
Glacier–climate interaction at low-latitudes

J L Kavanaugh and G K C Clarke
Abrupt glacier motion and reorganization of basal shear stress following the establishment of a connected drainage system

A Khazendar, J-L Tison, B Stenni, M Dini and A Bondesan
Significant marine-ice accumulation in the ablation zone beneath an Antarctic ice shelf

M König, J-G Winther, N T Knudsen and T Guneriussen
Firn-line detection on Austre Okstindbreen, Norway, with airborne multipolarization SAR

K J Kreutz, V B Aizen, L DeW Cecil and C P Wake
Oxygen isotope and soluble ionic composition of a shallow firn core, Inilchek glacier (central Tien Shan)

E Le Meur and R C A Hindmarsh
Coupled marine-ice-sheet/Earth dynamics using a dynamically consistent ice-sheet model and a self-gravitating viscous Earth model

C Lichey and H H Hellmer
Modeling giant iceberg drift under the influence of sea ice in the Weddell Sea

M P Lüthi and M Funk
Modelling heat flow in a cold, high-altitude glacier: interpretation of measurements from Colle Gnifetti, Swiss Alps

N A Nereson and C F Raymond
The elevation history of ice streams and the spatial accumulation pattern along the Siple Coast of West Antarctica inferred from ground-based radar data from three inter-ice-stream ridges

S V Nghiem, K Steffen, R Kwok and W-Y Tsai
Detection of snow melt regions on the Greenland ice sheet using diurnal backscatter change

S O'Neel, K A Echelmeyer and R J Motyka
Short-term flow dynamics of a retreating tidewater glacier: LeConte Glacier, Alaska, U.S.A

M S Pelto and C Hedlund
Terminus behavior and response time of North Cascade, Washington, glaciers

J F Pinglot, J O Hagen, K Melvold, T Eiken and C Vincent
A mean net accumulation pattern derived from radioactive layers and radar soundings on Austfonna, Nordaustlandet, Svalbard

S F Price, R A Bindschadler, C L Hulbe and I R Joughin
Post-stagnation behavior in the upstream regions of Ice Stream C, West Antarctica

L A Rasmussen and H Conway
Estimating South Cascade Glacier mass balance from a distant radiosonde and comparison with Blue Glacier

E Rignot
Evidence for rapid retreat and mass loss of Thwaites Glacier, West Antarctica

T Shiraiwa, Y D Murav'yev, T Kameda, F Nishio, Y Toyama, A Takahashi, A A Ovsyannikov, A N Salamatin and K Yamagata
Characteristics of a crater glacier at Ushkovsky volcano as revealed by the physical properties of ice cores and borehole thermometry

D Six, A Letréguilly and L Reynaud
Greenland ice sheet mass balance distribution: a variance analysis of existing field data

L H Smedsrud
Frazil ice entrainment of sediment — large tank laboratory experiments

T Thorsteinsson
Deformation of strongly anisotropic materials

A Vieli, M Funk and H Blatter
Flow dynamics of tidewater glaciers: a numerical modelling approach

J L Wadham, R J Cooper, M Tranter and R Hodgkins
Enhancement of glacial solute fluxes in the proglacial zone of a polythermal glacier

J S Wellner, A L Lowe, S S Shipp and J B Anderson
Distribution of glacial geomorphic features on the Antarctic continental shelf and correlation with substrate: implications for ice behavior

I M Whillans and C J van der Veen
Transmission of stress between an ice stream and interstream ridge

J-G Winther, M N Jespersen and G E Liston
Blue-ice areas in Antarctica derived from NOAA AVHRR satellite data

ANNALS OF GLACIOLOGY, VOLUME 33

The following papers from the International Symposium on Sea Ice and its Interactions with the Ocean, Atmosphere and Biosphere, held in Fairbanks, Alaska, U.S.A., 19–23 June 2000 have been accepted for publication in *Annals of Glaciology* Vol. 33, edited by M.O. Jeffries and H. Eicken

S F Ackley, C A Geiger, J C King, E C Hunke and J Comiso
The Ronne polynya of 1997/98: observations of air–ice–ocean interaction

Ye Aksenov and A C Coward
The Arctic Ocean Circulation as simulated in a very high-resolution global ocean model (OCCAM)

M R Anderson and S D Drobot
Spatial and temporal variability in snowmelt onset over Arctic sea ice

N L Bindoff, G D Williams and I Allison
Sea-ice growth and water-mass modification in the Mertz Glacier polynya, East Antarctica, during winter

B Cheng, J Launiainen, T Vihma and J Uotila
Modelling sea-ice thermodynamics in BALTEX-BASIS

H Chung and C Fox
Calculation of wave propagation into land-fast ice

J C Comiso
Satellite-observed variability and trend in sea-ice extent, surface temperature, albedo and clouds in the Arctic

I Dmitrenko, J A Hölemann, K Tyshko, V Churun, S Kirillov and H Kassens
The Laptev Sea flaw polynya, Russian Arctic: effects on the mesoscale hydrography

J Downer and T G Haskell
Ice-floe kinematics in the Ross Sea marginal ice zone using GPS and accelerometers

M R Drinkwater, X Liu and S Harms
Combined satellite- and ULS-derived sea-ice flux in the Weddell Sea, Antarctica

S D Drobot and M R Anderson
Comparison of interannual snowmelt-onset dates with atmospheric conditions

H Eicken, W B Tucker III and D K Perovich
Indirect measurements of the mass balance of summer Arctic sea ice with an electromagnetic induction technique

R R Forster, D G Long, K C Jezek, S D Drobot and M R Anderson
The onset of Arctic sea-ice snowmelt as detected with passive- and active-microwave remote sensing

C Fox and T G Haskell
Ocean wave speed in the Antarctic marginal ice zone

C Fox, T G Haskell and H Chung
Dynamic, in situ measurement of sea-ice characteristic length

C H Fritsen, S L Coale, D R Neenan, A H Gibson and D L Garrison
Biomass, production and microhabitat characteristics near the freeboard of ice floes in the Ross Sea, Antarctica, during the austral summer

V Giannelli, D N Thomas, C Haas, G Kattner, H Kennedy and G S Dieckmann
Behaviour of dissolved organic matter and inorganic nutrients during experimental sea-ice formation

H Gildor and E Tziperman
Sea ice, as the glacial cycles' climate switch, and interhemispheric thermohaline teleconnections

K Görgen, J Bareiss, A Helbig, A Rinke and K Dethloff
An observational and modelling analysis of Laptev Sea (Arctic Ocean) ice variations during summer

K M Golden
Brine percolation and the transport properties of sea ice

H Goosse, F M Selten, R J Haarsma and J D Opsteegh
Decadal variability in high northern latitudes as simulated by an intermediate-complexity climate model

M A Granskog and J Virkanen
Observations on sea-ice and surface-water geochemistry — implications for importance of sea ice in geochemical cycles in the northern Baltic Sea

S Günther and G S Dieckmann
Vertical zonation and community transition of sea-ice diatoms in fast ice and platelet layer, Weddell Sea, Antarctica

J Haapala, A Juottonen, M Marnela, M Leppäranta and H Tuomenvirta
Modelling the variability of the sea-ice conditions in the Baltic Sea under different climate conditions

J Haarpaintner, P M Haugan and J-C Gascard
Interannual variability of the Storfjorden (Svalbard) ice cover and ice production observed by ERS-2 SAR

J Haarpaintner, J O'Dwyer, J-C Gascard, P M Haugan, U Schauer and S Österhus
Seasonal transformation of water masses, circulation and brine formation observed in Storfjorden, Svalbard

C Haas
The seasonal cycle of ERS scatterometer signatures over perennial Antarctic sea ice and associated surface ice properties and processes

P Heil, C W Fowler, J A Maslanik, W J Emery and I Allison
A comparison of East Antarctic sea-ice motion derived using drifting buoys and remote sensing

W D Hibler III
Modeling the formation and evolution of oriented fractures in sea ice

M A Hopkins and H H Shen
Simulation of pancake-ice dynamics in a wave field

S Jeffers, T A Agnew, B T Alt, R De Abreu and S McCourt
Investigating the anomalous sea-ice conditions in the Canadian High Arctic (Queen Elizabeth Islands) during summer 1998

M O Jeffries, H R Krouse, B Hurst-Cushing and T Maksym
Snow-ice accretion and snow-cover depletion on Antarctic first-year sea-ice floes

S J Jones and B T Hill
Structure of sea ice in McMurdo Sound, Antarctica

K Junge, C Krembs, J Deming, A Stierle and H Eicken
A microscopic approach to investigate bacteria under in situ conditions in sea-ice samples

T Kawamura, K Shirasawa, N Ishikawa, A Lindfors, K Rasmus, M Granskog, J Ehn, M Leppäranta, T Martma and R Vaikmäe
Time-series observations of the structure and properties of brackish ice in the Gulf of Finland

S Kern and G Heygster
Sea-ice concentration retrieval in the Antarctic based on the SSM/I 85.5 GHz polarization

P J Langhorne, V A Squire, C Fox and T G Haskell
Lifetime estimation for a land-fast ice sheet subjected to ocean swell

J Launiainen, C Bin, J Uotila and T Vihma
Turbulent surface fluxes and air–ice coupling in Baltic–Air–Sea–Ice Study (BASIS)

M Leppäranta, Z Zhang, J Haapala and T Stipa
Sea-ice kinematics measured with GPS drifters

R W Lindsay
Arctic sea-ice albedo derived from RGPS-based ice-thickness estimates

V I Lytle and S F Ackley
Snow-ice growth: a fresh-water flux inhibiting deep convection in the Weddell Sea, Antarctica

V I Lytle, A P Worby, R A Massom, M Paget, I Allison, X Wu and A Roberts
Ice formation in the Mertz Glacier polynya, East Antarctica, during winter

T Maksym and M O Jeffries
Phase and compositional evolution of the flooded layer during snow-ice formation on Antarctic sea ice

W Maslowski, D C Marble, W Walczowski and A J Semtner
On large-scale shifts in the Arctic Ocean and sea-ice conditions during 1979–98

R A Massom, K L Hill, V I Lytle, A P Worby, M J Paget and I Allison
Effects of regional fast-ice and iceberg distributions on the behaviour of the Mertz Glacier polynya, East Antarctica

T Matsuoka, S Uratsuka, M Satake, T Kobayashi, A Nadai, T Umehara, H Maeno, H Wakabayashi, K Nakamura and F Nishio
CRL/NASDA airborne SAR (Pi-SAR) observations of sea ice in the Sea of Okhotsk

M J McGuinness, K A Landman, H J Trodahl and A E Pantoja
Solar radiative heating in first-year sea ice

W N Meier and J A Maslanik
Synoptic-scale ice-motion case-studies using assimilated motion fields

W N Meier, M L Van Woert and C Bertoia
Evaluation of operational SSM/I ice-concentration algorithms

K Morris and M O Jeffries
Seasonal contrasts in snow-cover characteristics on Ross Sea ice floes

L Nazarenko, J Hansen, N Tausnev and R Ruedy
Response of the Northern Hemisphere sea ice to greenhouse forcing in a global climate model

L Nazarenko and N Tausnev
Modeling of the Beaufort ice–ocean climatology change

M J Paget, A P Worby and K J Michael
Determining the floe-size distribution of East Antarctic sea ice from digital aerial photographs

W S Pegau and C A Paulson
The albedo of Arctic leads in summer

D K Perovich and B C Elder
Temporal evolution of Arctic sea-ice temperature

D K Perovich, J A Richter-Menge and W B Tucker III
Seasonal changes in Arctic sea-ice morphology

A Proshutinsky, M Johnson and T Proshutinsky
Understanding climatic controls on sea-ice transport pathways in the Arctic Ocean

N Reeh, H H Thomsen, A K Higgins and A Weidick
Sea ice and the stability of north and northeast Greenland floating glaciers

J A Richter-Menge, D K Perovich and S Pegau
Summer ice dynamics during SHEBA and its effect on the ocean heat content

A Roberts, I Allison and V I Lytle
Sensible- and latent-heat-flux estimates over the Mertz Glacier polynya, East Antarctica, from in-flight measurements

H H Shen, S F Ackley and M A Hopkins
A conceptual model for pancake-ice formation in a wave field

I J Smith, P J Langhorne, T G Haskell, H J Trodahl, R Frew and M R Vennell
Platelet ice and the land-fast sea ice of McMurdo Sound, Antarctica

R C Smith and S E Stammerjohn
Variations of surface air temperature and sea-ice extent in the western Antarctic Peninsula region

V A Squire and T W Dixon
How a region of cracked sea ice affects ice-coupled wave propagation

N Steiner
Introduction of variable drag coefficients into sea-ice models

M Sturm, J Holmgren and D K Perovich
Spatial variations in the winter heat flux at SHEBA: estimates from snow–ice interface temperatures

K Tateyama and H Enomoto
Observation of sea-ice thickness fluctuation in the seasonal ice-covered area during 1992–99 winters

D N Thomas, G Kattner, R Engbrodt, V Giannelli, H Kennedy, C Haas and G S Dieckmann
Dissolved organic matter in Antarctic sea ice

R Timmermann, A Beckmann and H H Hellmer
The role of sea ice in the fresh-water budget of the Weddell Sea, Antarctica

T Tin and M O Jeffries
Sea-ice thickness and roughness in the Ross Sea, Antarctica

J-L Tison and V Verbeke
Chlorinity/salinity distribution patterns in experimental granular sea ice

L Toudal and M D Coon
Interannual variability of the sea-ice-induced salt flux in the Greenland Sea

T Toyota and M Wakatsuchi
Characteristics of the surface heat budget during the ice-growth season in the southern Sea of Okhotsk

J Turner, W Connolley, D Cresswell and S Harangozo
The simulation of Antarctic sea ice in the Hadley Centre Climate Model (HadCM3)

J Ukita and D G Martinson
An efficient adjustable-layering thermodynamic sea-ice model formulation for high-frequency forcing

M L Van Woert, W N Meier, Cheng-Z Zou, A Archer, A Pellegrini, P Grigioni and C Bertoia
Satellite observations of upper-ocean currents in Terra Nova Bay, Antarctica

P Wadhams and N R Davis
Arctic sea-ice morphological characteristics in summer 1996

H Wakabayashi, T Matsuoka, K Nakamura and F Nishio
Estimation of sea-ice physical parameters using polarimetric SAR: results from Okhotsk and Lake Saroma campaign

J E Walsh and W L Chapman
20th-century sea-ice variations from observational data

J Wang and M Ikeda
Arctic sea-ice oscillation: regional and seasonal perspectives

X Wang and J R Key
Spatial variability of the sea-ice radiation budget and its effect on aggregate-area fluxes

J W Weatherly and J M Arblaster
Sea ice and climate in 20th- and 21st-century simulations with a global atmosphere–ocean–ice model

G Wendler and A P Worby
The surface energy budget in the Antarctic summer sea-ice pack

K J Wilson, D J King and D G Barber
A case-study in tracking 1998 polynya ice dynamics in Smith Sound, North Water polynya region, Canadian Arctic, using RADARSAT-1 data

A P Worby, G M Bush and I Allison
Seasonal development of sea-ice thickness distribution in East Antarctica: measurements from upward-looking sonar data

X Wu, W F Budd, A P Worby and I Allison
Sensitivity of the Antarctic sea-ice distribution to oceanic heat flux in a coupled atmosphere–sea-ice model

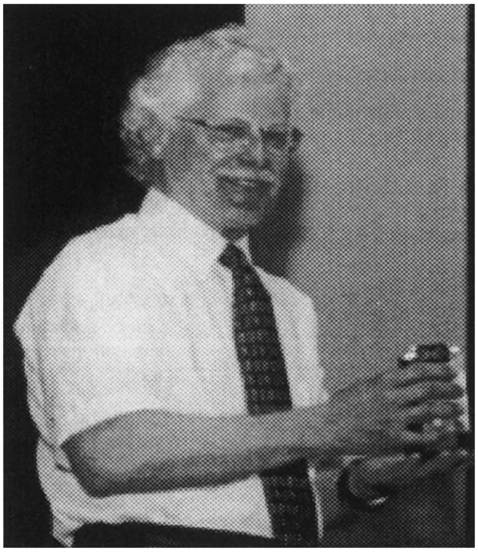
Y Zhang and A J Semtner
The Antarctic Circumpolar Wave in a global, high-resolution, coupled ice–ocean model

Y Zhao and A K Liu
Principal-component analysis of sea-ice motion from satellite data

X Zhou, S Li and K Morris
Measurement of all-wave and spectral albedos of snow-covered summer sea ice in the Ross Sea, Antarctica

2000 SELIGMAN CRYSTAL AWARD
Samuel C. Colbeck
5 June 2001, College Park, Maryland, U.S.A.

The Society's Council agreed unanimously in 2000 that a Seligman Crystal be awarded to Samuel C. Colbeck. The Crystal was presented at the 4th International Symposium on Remote Sensing in Glaciology after the following introduction, by the IGS President, Bob Bindschadler.



Last year, I had the pleasure of presenting the Seligman Crystal to Charlie Raymond. Preparing those introductory remarks was easy because he was my thesis advisor and our research overlapped so much over the years. Tonight we are here to honor Sam Colbeck, whom I only knew through his sterling reputation, the occasional conversation at a meeting such as this, and the reading of only a few of his many well-written papers.

This certainly wasn't enough information on which to construct an introduction for such an accomplished glaciologist. So I went to my bookshelves to peruse more of his papers and scanned the extensive list of his publications. This gave me a better view of Sam's scientific side, but what I was after was a more holistic perspective of Sam as an individual. The answers to questions I had about "what made him a success in glaciology" and "why so many people wanted him to receive this award" couldn't be found there. I contacted as many people as I could who knew Sam: those who mentored him, those who studied alongside him and those who learned from him. As expected, I discovered a great deal about Sam. I enjoyed fitting the pieces of Sam's career together and want to share with you some of what I feel are the more compelling vignettes of his professional life.

I've already told Sam I won't attempt to recreate the good-natured roasting Sam received at CRREL on the occasion of his recent retirement. My profile will be brief, but I hope you will find it an interesting perspective of our honoree.

One thing I did know about Sam is that we share the same roots. We were both born and raised in Pittsburgh, Pennsylvania. It is hard to imagine this dirty steel town, as it was many decades ago, being a breeding ground for glaciologists. In Sam's case he began his college education in petroleum engineering, a field close to the industrial persona of Pittsburgh, and earned a MSc at the University of Pittsburgh. You might think that this field is quite far from where Sam eventually ended up, but it turned out that his interest in multi-phase flow was ideal preparation for the glaciological advances Sam would eventually make through his treatments of the role of water vapor transport in snow metamorphism and of water movement through snow.

But Sam had not yet made the switch to a cooler subject and with Masters degree in hand, chose to pursue a Ph.D. at the University of Washington. Once in Seattle, Sam was to experience what a number of people have experienced when exposed to the excellent glaciology program at the University of Washington — an unavoidable pull into the world of glaciology. Sam's doctoral thesis was titled "The flow law for temperate ice", but be had a close connection with the venerate avalanche expert, Ed LaChapelle, and it was through that connection that Sam started to learn about snow and took up skiing – a love that he has kept the rest of his life.

With Ph.D. in hand, what better place for this "engineer cum glaciologist" to go than the Cold Regions Research and Engineering Laboratory (CRREL). CRREL, as an institution, had an applications perspective, but Sam also took advantage of its open research environment. This freedom allowed Sam to take the time to develop the basis for the fundamental insights he was about to formulate that would alter his field forever.

Theory and observation both play key roles in Sam's research--tradition does not. Sam has repeatedly shown the courage to step outside acceptable norms of thought and offer bold new interpretations of phenomena that prematurely have been regarded as thoroughly understood.

One of Sam's major contributions has been the study of snow metamorphism and he played a leading role in creating a much improved, user-friendly classification of snow used by literally thousands of proponents. His descriptions of two pathways in snow metamorphism, kinetic and equilibrium, established a new way of viewing metamorphism that is now universally accepted and used.

He addressed snow wetness and water movement through snow with an engineer's thoroughness. He formulated the fundamental equations to describe the coupled mechanical and thermal processes, studied the resultant interrelationships, identified the consequences of the interdependencies, and authored a series of seminal papers that allowed us to follow his penetrating insights. The obvious testimonial here is that his work is still the standard in this field.

Sam then turned his attention to sliding friction of snow. This is where we can best see Sam's contributions extending well beyond the scientific community. Literally millions of people enjoy snow. Most love to slide on it, using either skis or snowboards. Often, their enjoyment is correlated with their top speed, making friction a key consideration. They enjoy the advances made in their sliding apparatus, blissfully ignorant of the hours of dedicated research from Sam allowing them to increase their enjoyment.

Beyond his research, Sam has been a tireless servant of the Society. He served two terms on Council, served as Vice President and then President (from 1987–90). He also is a two-time Chief Editor of the *Annals of Glaciology*: on Volume #4, the Second Symposium on Applied Glaciology at Hanover, New Hampshire, in 1982; and Volume #18, the Symposium on Snow and Snow-related problems at Nagaoka, Japan, in 1992. But Sam's service, like his research, has extended well beyond IGS. He edited *Water Resources Research* for AGU, received its Horton Award in 1980 for excellence in research in Hydrology, and was made a Fellow of AGU in 1992.

I'll close with one of the most telling characteristics about Sam. He has demonstrated his unselfishness repeatedly by nominating a large number of colleagues for a variety of awards and other honors. Well, tonight it is his turn to be honored by this Society that he has served so well by his service and his unparalleled research. It is fitting that he receive the Seligman Crystal from the International Glaciological Society, and it is my pleasure to ask him to step forward and receive it now.

Thanks Mr. President, and all of the members of the Society for this award. I have to admit that when I got your phone message that you wanted to talk to me, I thought that you were just going to ask me to chair a committee or something, so I wasn't looking forward to your next call. Then, when you informed me of this award, I thought I had better start thinking hard to come up with something to say to justify this honor. Since I probably can't do that, I'll just try to say how I got to this point, and describe some of the fun along the way. In fact, I always try to impress upon young people that research is fun, and that if you not having fun, you're probably in the wrong field.

You may already know about many of the things I've published — I hesitate to use the word contributed — but the real story is all the good times that I have had along the way. Much of life seems to me to be a random walk. I suppose I could summarize my walk through life as following the path of least resistance; that is, doing whatever seemed like the easy thing at the time. As a researcher, there is a danger in doing this because as somebody once said, "We solve the problems we can solve rather than the problems we should solve." I always felt guilty that I was working on small problems and leaving the big problems to other people. I think my only salvation was integral calculus; it shows that if you do enough small things, they can accumulate into something worth noticing.

As a researcher, I have always been surprised to find that from time to time people noticed what I was doing. While this was certainly gratifying, I am not sure that I ever really understood why. Thus I find myself standing here, trying to explain myself as a glaciologist, and finding that a simple account of how I spent my time is the best I can do.

One thing I've learned is to try not to impose myself too much into the life of my three sons. As a father it's difficult not to impose my "wisdom and experience" on them, and yet I know that I rebelled against my father doing that to me. My own experience suggests that it is not a good idea to complain about your son or daughter switching majors in college. I went from Geological Engineering, to Petroleum Engineering, to Mathematics, to Petroleum Engineering, to Atmospheric Sciences, to Geophysics. I found that most of what I learned along the way came in handy later. While still in my first phase of petroleum engineering, I discovered three things. First, I liked all aspects of petroleum engineering. Second, there wasn't any snow and ice where they did it at that time. Third, I discovered climbing. During my second phase of petroleum engineering, when all of the heavenly bodies lined up at the same moment, I became aware of a field called glaciology that would give me the opportunity to do science and technology in the mountains. At that time I also read Alfred Lansing's *Endurance*, which started a love affair with Antarctica. Unfortunately, once I got into snow studies, the dream of Antarctica faded. There were just too many interesting problems to work on in snow.

When I went off to the University of Washington in 1965 to study glaciology, I had two degrees in petroleum engineering, which actually helped me get started in snow studies. At that time, the Geophysics Program was just starting a sub-program in glaciology. Norbert Untersteiner and Ed LaChapelle were in desperate need of graduate students and were happy to have me, until they found out how bad I was at jumping through hoops, and I had always found too much of our formal education to be just that. But I was fortunate to work on the Blue Glacier for four summers with Ed, and found Jim Evans in Civil Engineering who taught me engineering mechanics. That relationship worked well for Jim too; he starting applying his understanding of mechanics to problems in snow and ice. Toward the end of my career there, Charlie Raymond, a fresh PhD, arrived from Cal Tech to assume a new faculty position, and John Glen spent a sabbatical as a visitor. John's presence was enormously helpful since I was struggling to write a dissertation. I think John wrote more words of criticism on the document than I had written as text. I like to think that he made a positive impression on my ability to write. John made one other contribution to my random walk through life: he suggested that with my background in unsaturated flow from petroleum engineering, I should study water flow in snow. Since at the time I had absolutely no interest in snow, his suggestion seemed strange. When I barely succeeded in graduating and went off to CRREL, the UW faculty probably figured that I couldn't do too much harm to their reputation.

CRREL turned out to be a place of incredible opportunity. The support functions were excellent, the facilities were great, I enjoyed the support of Willy Weeks and Andrew Assur, and, although Army money was being cut back, I somehow managed to produce publications that helped justify the Army's basic research money. John Glen's casual suggestion about water flow in snow jump-started a research program that somehow led to a never-ending sequence of research problems that appeared one after the other. When I arrived at CRREL, I was interested in glaciers first and ice physics second. Snow was the last thing on my mind, but somehow snow as a material had been ignored by the brightest minds in glaciology and there were lots of problems left for ordinary minds. There still are lots.

I can remember Mark Meier saying that people were not putting physics into snow hydrology and, as it turned out, I guess that is what I was doing. First came unsaturated flow, then two-dimensional flow, and flow due to structures within the snow. Fortunately, these problems had essentially been solved in other fields, so transferring the information to snow was not difficult or ground breaking. At this point in my life I discovered the value of a good library, which is essential if you're going to copy other people's work. My work on water flow led to an interest in thermodynamics to explain some of the peculiar phenomena that occurred in wet snow. That work led to an interest in wet snow mechanics and grain growth; these were controlled by the thermodynamics. Again, the CRREL library came to my rescue by providing a book that laid out the thermodynamics of a multi-phase material in porous media. Using that work as a starting point to understand snow was straightforward. I can remember one time along this path when I was trying to figure out what wet snow should look like at the granular scale. How should all those phase boundaries arrange themselves? While I had always just assumed that wet snow looked like wet sand, the thermodynamics was telling me that it couldn't. Every day on the blackboard, I would draw my latest idea of what it should look like on the granular scale. People would stop by to look at my latest creation and laugh at it, and then the thermodynamics would tell me that idea was wrong too. Finally, out of desperation, I put a microscope in a cold room and looked. I immediately said "Why couldn't I have thought of that?" Why is Nature so much smarter than I am? The best part of that experience was that it started a love affair with the microscope. It turned out that the same problem existed in frozen soils: nobody really knew what the stuff looked like. People argued from theory about what shapes the phase boundaries should take in frozen soils, but no one had looked. This gave rise to what George Ashton termed Colbeck's First Law: "Go Look!"

About this same time, people were saying that the current system of snow classification was misleading. Not having a lot of self-control, I threw myself into the middle of that controversy. I took credit for what many people were saying anyway: "We need a new classification system."

I found that it was easier to make the transition from wet to dry snow in the technical sense than in the personal sense. This had been a problem when I first started working on wet snow, and Mark Meier had come to my rescue. However, at this point in my career I was on my own and I felt like a babe in the woods having to fight for new territory. When I think back on it, I've published in about 30 journals in many fields and each time I was a new "kid on the block" trying to get a new idea or approach accepted by a resistant community. Today I might do that to young and upcoming scientists, and just don't realize it. Having "territory" to carry with you through life is a burden to be avoided as much as possible. Every scientific contribution is like a record in sports: it should simply be a milestone for the next guy to surpass and we should feel like proud parents when our work is extended by the next good publication. Publishing in a variety of fields may be challenging, but it has its rewards. I took liberally from other fields but I also tried to give them something back. I also took great satisfaction in putting old questions to rest.

The blockbuster event in my assault on dry snow was simply the quantification of somebody else's idea of how grains grow in dry snow. I applied existing solutions from potential theory, as outlined in the *Handbook of Physics*, to Yosida's idea that grains grew by the "hand-to-hand delivery of water vapor." Did I mention what a difference a library makes? The theory was complemented by a series of crystal growth experiments that Paul Föhn pointed me towards when I was working in Davos in 1981/82. Again I was using someone else's approach. About this time, I was fortunate enough to arrange a pilgrimage to see Charles Frank who helped me see that I was actually doing something useful.

In 1986 the Rosignol Race Team invited me to a World Cup Race because they were interested in looking at snow. Funny isn't it: the world's largest ski company with the most successful race team had never actually looked at snow. I spent so much of the time there arguing with them about why skis actually slide that when I got back I published a theory of snow friction; that showed them. This led to an exciting series of measurements on the thermal characteristics of gliding skis, in cooperation with Rosignol, other ski companies, TOKO wax, and ski teams. I also made some electrical measurements on sliding skis, the best of which I could not have done without the support of Bruce Jamieson and Mike Weigele Heliski. I had to put myself at risk by using Mike's helicopters to get to bottomless powder so I could make long ski runs in deep snow to get the measurements. Did I mention that science is fun?

People said: "But pressure melting could still account for ice skating because the pressures are higher." That led to theoretical arguments against it, but more importantly, a series of thermal measurements done with two freshmen students from Dartmouth, which showed that ice skates behave just like skis.

Somewhere along the way, the avalanche community began to notice my existence. I was never really quite sure why they cared about me. I don't solve any of their problems. As far as I can see, I don't help them improve their forecasts. However, most of them are just naturally curious people, and snow is the medium they care about. It has been gratifying that people like Ed LaChapelle, Dave McClung, Hans Gubler, and Richard Armstrong were supportive of my efforts. My knowledge of avalanches was increased enormously through the generosity of Mike Wiegele by working in the field with

Bruce Jamieson, and I am now fortunate to be teaching high-level avalanche courses as the guest of Rod Newcomb and Kelly Elder. Spending an hour listening to one of them, or one of their field instructors, describe a snow pit is a humbling experience. The press might call me "Dr. Snow," but that's only because they don't know how much I have learned from ski patrollers and mountain guides.

Speaking of learning, I never cease to be amazed at how a good graduate student can take over your life. I think that working with graduate students is like having children: you just can't appreciate the experience until you've done it yourself. Bruce Sweeny got me into electromagnetics, Dan Powers explained convection in snow to me, Guy Warren raised the ski work to a higher level, and Ted Arons introduced me to new ways of describing the geometry of snow while solving other problems along the way.

The random walk through life sometimes takes you over ground you thought you had already covered. About ten years ago I was convinced that we had nailed the physics of snow and all we needed was to understand the geometry of snow, to which we would apply our understanding of the physics. Ted Arons did a thorough job of investigating this type of work in other areas of porous media. Although he collaborated with several colleagues from those fields in an attempt to apply related work to snow, it became clear that there would be no easy solutions to these problems. At the same time, I began to realize that some of the things we "knew" about snow we had wrong. Bonding between grains for example. There were several problems with the existing theory of sintering in snow and, one day while daydreaming at my desk, I realized that the problem was that we had blindly accepted the wrong geometry for the bond. The classical shape we had always assumed could not, in fact, exist. Since the shape of the bond dictates the physics, we had it all wrong, both the physics and the geometry. I immediately went to look through the microscope, only to discover that the classical shape, in fact, did not exist, because it cannot exist. The resulting work led to an understanding of such basic phenomena as why snow doesn't bond to ice. As Karl Birkeland suggested, this gets at the heart of the release of avalanches due to weak layers. Does failure occur because of weakness within the weak layer, or does failure occur because the weak layer, which is often a large-grained layer, cannot bond to an adjacent fine-grained layer? Are weak layers even necessary or can failure occur between two strong layers?

Well, there's nothing like leaving some hard prob-lems for the next generation. As the world changed, especially the U. S. Army's part of the world, I found myself becoming somewhat of a dinosaur. As the military went through a significant downsizing, researchers no longer had the chance to pursue their interests in the way that I did. Thus, I now look back on a very enjoyable 30 years at CRREL where I made many friends around the world and enjoyed the collaboration of colleagues in many different ways. One of my great regrets is that Hilda Richardson isn't here to enjoy this with me today. No doubt if she were she would once again correct my pronunciation of the "Seligman" Crystal.

SELIGMAN CRYSTALS FOR BOULTON AND CLARKE

At a meeting in Kangerlussuaq, Greenland, on Monday, 20 August 2001, the Council of the International Glaciological Society unanimously passed the following resolutions. That:

The Seligman Crystal is to be awarded to Geoffrey S. Boulton for advancing our understanding of the nature of glaciomarine sedimentation and of deposition from glaciers, from both a glaciological and geological perspective: work that has led to a widespread reappraisal of glacier deposits of all ages, from the Precambrian to the Tertiary, and to the improved interpretation of past environments and of glacier dynamics.

The Seligman Crystal is to be awarded to Garry K.C. Clarke for fundamental contributions to a wide variety of glaciological problems bridging both theory and applications, including glacier surge-control mechanisms, flow instabilities, outburst flooding, and the ventilation of polar snow and firn and its effect on ice-core interpretation, as well as for his pioneering work on developing the geophysical and mechanical systems necessary for studying these problems.

It is expected that the Crystals will be presented at the International Symposium on Fast Glacier Flow to be held in Yakutat, Alaska in June 2002.

WHILLANS ICE STREAM (83°40′ S, 145°00′ W)

Ice Stream B has been renamed Whillans Ice Stream. The new name honors Professor Ian M. Whillans (1944–2001) glaciologist, Byrd Polar Research Center and Department of Geological Sciences, Ohio State University, whose work in Antarctica spanned the years from 1967 until his death. Whillans was a major figure in the study of West Antarctic ice streams, particularly this one, and he had a central role in recognizing from the earliest years that these ice streams hold the key to determining the stability of the West Antarctic ice sheet.

In response to an overwhelming desire by many who knew Ian for the IGS to recognize his passing, the Council voted to override the guidelines for ICE and include his obituary on page 44.

INTERNATIONAL SYMPOSIUM ON FAST GLACIER FLOW

Yakutat, Alaska, U.S.A., 10–14 June 2002

CO-SPONSORED BY

Geophysical Institute, University of Alaska Fairbanks
International Arctic Research Center, University of Alaska Fairbanks
Arctic Research Consortium of the United States
National Science Foundation
National Aeronautics and Space Administration

SECOND CIRCULAR

The International Glaciological Society will hold an International Symposium on Fast Glacier Flow in 2002. It will take place at the high school in Yakutat, Alaska, U.S.A. with registration on 9 June, and sessions from 10–14 June 2002.

SYMPOSIUM ORGANIZATION
C. Simon L. Ommanney

LOCAL ARRANGEMENTS COMMITTEE
Keith Echelmeyer (Chair), Craig Lingle, Roman Motyka, Martin Truffer, Mary Farrell, Mary Jo Brebner

EDITORIAL BOARD
Charles Raymond & C.J. van der Veen (Chief Editors), Keith Echelmeyer and others to be appointed

PARTICIPATION
This circular includes forms for registration and accommodation. Due to limited facilities, the accommodation interest form should be returned by 15 January 2002 to the address listed. Priority will be given to those with accepted abstracts and existing members of the International Glaciological Society. The registration form and accompanying payment should be returned before 8 March 2002. There will be a £50 surcharge for late registrations. The participant's registration fee covers organization costs, a set of abstracts, the icebreaker, the mid-week land excursion, bus transportation during the symposium and a copy of the *Annals of Glaciology*. The accompanying person's registration fee includes organization costs, the icebreaker, and the mid-week land excursion. There will be organized (but optional) flightseeing excursions mid-week and pre/post-symposium boat tours if interest exists. There is an administration charge for participants who are not members of the International Glaciological Society.

REGISTRATION FEES	UK £
Participant (IGS member)	300
Participant (not IGS member)	350
Student and Retired IGS members	150
Accompanying person aged 18 or over	100
Late registration surcharge (after 8 March)	50

Refunds on registration fees will be made on a sliding scale, according to date of receipt of notification, up to 25 May 2002. After that date, it may be impossible to make any refund. See registration form for methods of making payment. All who pre-register will receive a copy of the third circular and programme prior to the meeting.

THEME
Glacier surges, glacier calving, and ice-stream and outlet-glacier flow are among the most dynamic of glacier phenomena. Such fast glacier flow is, and has been, important in the balance and geometry of large ice sheets. Prediction of future ice-sheet changes requires knowledge of fast glacier-flow mechanisms. Understanding of these dynamic features has advanced in recent decades, with new measurement techniques, advances in remote sensing and detailed numerical modeling. This symposium will provide a forum for presenting recent advances and promoting discussion of the various phenomena of fast glacier flow and interrelations amongst them.

TOPICS
The suggested topics include:
1. Surge-type glaciers;
2. Tidewater glaciers, including iceberg calving;
3. Ice streams and outlet glaciers, including their interactions with surrounding ice sheets and ice shelves;
4. Basal and marginal boundary conditions that lead to fast glacier flow; and
5. The role of fast glacier flow in continental glaciation, sea-level and climate change.

SESSIONS
Oral presentations will be held on two full days and three half-days. There will also be two poster sessions.

PAPERS
(I) SUBMISSION OF ABSTRACTS
Participants who want to contribute to the Symposium should submit an abstract of their proposed paper. This abstract must contain sufficient detail to enable us to judge the scientific merit and relevance of the proposed paper. It should not exceed one page of typescript, on international-size paper A4 (210 x 297 mm). References and illustrations should not be included. Place the title and author(s) names and address(es) at the top of the abstract, not on a separate sheet. Indicate at the bottom which specific topic(s) it intends to address, and whether a poster or oral presentation is preferred. When selecting material, authors should bear in mind that the final version of the paper should not exceed 5 printed pages in the *Annals*; extra pages will be charged at the

rate of £90 per page. Honoring page charges (also £90 per page) for up to the first five pages is encouraged. Send abstracts by e-mail, fax or regular mail to: Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, U.K.

LAST DATE FOR RECEIPT OF ABSTRACTS: 1 DECEMBER 2001

(II) SELECTION OF PAPERS
Each abstract will be assessed on its scientific quality and relevance to the topics of the Symposium. Authors whose abstracts are accepted will be invited to make either an oral or poster presentation at the Symposium. There will be no distinction between oral or poster papers in the *Annals of Glaciology*. First or corresponding authors will be advised in mid December of the acceptance or otherwise; other authors will not be informed separately. Authors who have not received notification by the end of December should contact the IGS office in Cambridge in case their abstract was not received. Acceptance of an abstract means that the paper based on it should be submitted to the *Annals of Glaciology* and not to another publication. Note: Abstracts alone will not be published in the *Annals of Glaciology*.

(III) DISTRIBUTION OF ABSTRACTS
A set of the accepted abstracts will be provided to all registered participants upon registration on 9 June 2002.

(IV) SUBMISSION OF PAPERS AND PUBLICATION
Five copies of each paper, doubled-spaced with wide margins, should be sent to the Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, U.K. by 1 April 2002. ALL AUTHORS ARE EXPECTED TO ADHERE TO THIS DEADLINE. Papers should be prepared in accordance with the style instructions sent to authors with the abstract acceptance notification. Papers will be refereed according to the usual standards of the Society before being accepted for publication. Final papers, presented at the Symposium, which have been submitted and accepted by the Editorial Board, following review, will be published in English in the *Annals of Glaciology* (Vol. 36). Final, revised versions of papers, diskettes and original art work must be submitted by 31 July 2002. Speedy publication of the *Annals of Glaciology* will depend upon strict adherence to deadlines.

**LAST DATE FOR RECEIPT OF PAPERS
1 April 2002**

MID-WEEK EXCURSIONS
As part of the registration fee, a mid-week land excursion to view the glacial history of the Yakutat area is planned. In addition, optional glacier flight-seeing trips are planned mid-week, weather permitting. Participants will view several surge-type/tidewater glaciers including Variegated, Hubbard, Malaspina, Turner, Yakutat, and others near Harlequin Lake. Round trip time is about two hours. It is anticipated that the cost for the flight-seeing trip will be approximately $125 per person.

PRE/POST-SYMPOSIUM TOUR
If there is sufficient interest, boat tours to Hubbard Glacier can be organized for Sunday, 9 June or Saturday, 15 June. Cost for this is anticipated to be approximately $125 per person for a four-hour trip. Personal excursions (e.g. fishing trips) can be arranged locally. Yakutat is a world class fishery boasting record numbers of Steelhead, King (Chinook), Sockeye, Pink (Humpy), and Coho (Silver) Salmon as well as Halibut. Information is available from the Yakutat web site (http://www.yakutat.net/).

TRAVEL AND ACCOMMODATION
Yakutat, Alaska, is a small community located on beautiful Monti Bay with spectacular views of the St Elias mountains. Alaska Airlines provides the only scheduled jet service into Yakutat, with two flights daily: northbound from Seattle, Washington (flight #61) or southbound from Anchorage, Alaska (flight #66). **The Symposium coincides with prime fishing and tourist season in Alaska, so participants should book airline reservations as early as possible.** Travel arrangements can be made through US Travel by contacting Larissa Jimenez at [1](800)622-6449, extension 237, [1](907) 452-8992, fax: [1](907)452-3839 or at ljimenez@ustravelak.com. Mention codeword YAKUTAT.

Accommodation and meals will be at Leonard's Landing Lodge (http://www. leonardslanding.com/). The lodge consists of units that are fully self-contained as well as dormitory-style buildings (rooms with community bathrooms down the hall). Rates are $65 and $45 per person per day, respectively. **Participants should expect to share lodging with others attending the Symposium.** Meals will be $28 per person per day and include breakfast, lunch and dinner.

Oral and poster sessions will be in the Yakutat High School. Bus transport to and from the airport, the lodge, the high school and other activities will be provided. Due to space constraints at the high school, conference attendance has to be limited to 125.

IMPORTANT DATES:

Abstracts due	**1 December 2001**
Notification of acceptance	5 January 2002
Accommodations deadline	15 January 2002
Pre-registration deadline	8 March 2002
Papers due	**1 April 2002**
Deadline for full refund	22 April 2002
Deadline for refund	25 May 2002
Conference starts	10 June 2002
Final revised papers	**31 July 2002**

To avoid disappointment, please respect the above deadlines

SYMPOSIUM ON FAST GLACIER FLOW

Yakutat, Alaska, U.S.A., 10–14 June 2002

REGISTRATION FORM

Family Name: ____________________

First Name: ____________________

Address: ____________________

____

____

Tel: ________ FAX: _______ E-mail: ____________

Accompanied by:

Name: ____________________ Age (if under 18)

Name: ____________________ Age (if under 18)

Name: ____________________ Age (if under 18)

REGISTRATION FEES	£	£
Participant (Member of the IGS)	300	___
Participant (not a member of the IGS)	350	___
Student or Retired IGS Member	150	___
Accompanying person aged 18 or over	100	___
Late registration surcharge (after 8 March)	50	___
Total registration fees sent		___

Payment, in pounds sterling drawn on a UK bank, may be made by cheque to:

INTERNATIONAL GLACIOLOGICAL SOCIETY

or by Access/Eurocard/MasterCard or VISA/Delta

Name on card: ____________________

Signature: ____________________

Expires: _________

Payment may also be made to: National Westminster Bank plc, Account no: 54770084, 56 St. Andrew's Street, Cambridge CB2 3DA, UK, (please include any Bank or Transfer charges).

Mail to:
Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, UK

If payment made after 8 March 2002, add £50 for each person

SYMPOSIUM ON FAST GLACIER FLOW

Yakutat, Alaska, U.S.A., 10–14 June 2002

ACCOMMODATION INTEREST FORM
(do not send payment now)

Family Name: ____________________

First Name: ____________________

Address: ____________________

____

Tel: ____________________

FAX: ____________________

E-mail: ____________________

I will be accompanied by or prefer to room with: *(use back page if necessary)*

Name: ____________________

Name: ____________________

Room preference *(check one)*: ❑ self-contained cabin

OR ❑ dormitory room

Note: Preferences will be filled on a first come, first served basis.

Airport pickup:

I plan to arrive in Yakutat on Alaska Airlines flight *(circle one)* #61 or #66

on *(date)* ____________________ and depart on *(date)* ________________

I am interested in *(please check all that apply)*:

❑ The mid-week land excursion (cost included in registration)

❑ A 4-hour boat tour on Sunday, June 9. Number in party _____

❑ A 4-hour boat tour on Saturday, June 15. Number in party ____

❑ A 2-hour glacier flight-seeing trip mid-week.

Mail to:
Mary Farrell, Geophysical Institute, University of Alaska Fairbanks, P.O. Box 757320, Fairbanks, Alaska, 99775-7320 U.S.A.

Early reservations are highly recommended. Payment is not due at this time.

INTERNATIONAL SYMPOSIUM ON PHYSICAL AND MECHANICAL PROCESSES IN ICE IN RELATION TO GLACIER AND ICE-SHEET MODELLING

Chamonix Mont-Blanc, France, 26–30 August 2002

CO-SPONSORED BY

Laboratoire de Glaciologie et Géophysique de l'Environnement (CNRS)
École Nationale de Ski et d'Alpinisme (ENSA, Ministère de la Jeunesse et des Sports)

SECOND CIRCULAR

The International Glaciological Society will hold an International Symposium on Physical and Mechanical Processes in Ice in Relation to Glacier and Ice-sheet Modelling in 2002, at the École Nationale de Ski et d'Alpinisme (ENSA), Chamonix Mont-Blanc, with registration on 25 August and sessions from 26–30 August.

SYMPOSIUM ORGANIZATION
C. Simon L. Ommanney

LOCAL ARRANGEMENTS COMMITTEE
J. Meyssonnier (Chairman), A. Demongeot, G. Durand, P. Duval, J.-L. Gabarre, O. Gagliardini, A. Philip, L. Reynaud, C. Ritz, C. Vincent, P. Wagnon, J. Weiss

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PARTICIPATION
This circular includes forms for registration and accommodation. The registration form and accompanying payment should be returned before 1 June 2002. There will be a £50 surcharge for late registrations. The participant's registration fee covers organization costs, a set of abstracts, the icebreaker, banquet, mid-day lunches and a copy of the *Annals of Glaciology*. The accompanying person's registration fee includes organization costs, the icebreaker and the banquet. It will be possible to organize additional trips through the local tourist office. There is an administration charge for participants who are not members of the International Glaciological Society.

REGISTRATION FEES	**UK £**
Participant (IGS member)	250
Participant (not IGS member)	300
Student and Retired IGS members	100
Accompanying person aged 18 or over	55
Late registration surcharge (after 1 June)	50

Refunds on registration fees will be made on a sliding scale, according to date of receipt of notification, up to 10 August 2002. After that date it may be impossible to make any refund. See booking form for methods of making payment. All who pre-register will receive a copy of the third circular and programme prior to the meeting.

THEME
Accurate modelling of major past and present ice sheets is essential to understanding the Earth's climate. Mathematical modelling of ice sheets requires a better knowledge (and modelling) of its physical basis. The aim of the symposium is to improve modelling of the mechanisms involved in the flow of ice sheets by bringing together field data with experimental and theoretical results, as well as results from modelling. Interest is not limited to studies of polar ice sheets, since many processes involved in the deformation of the basal layer of ice sheets also take place in temperate glaciers.

A session on extraterrestrial ice will provide an opportunity to establish links between the planetary ice (especially the Martian ice) and terrestrial ice communities.

TOPICS
The suggested topics include:
1) Physical and mechanical processes involved in the deformation of ice.
2) Physical processes and interpretation of field data:
   radar surveys;
   surface velocity;
   borehole measurements;
   satellite altimetry and interferometry;
   other geophysical measurements.
3) Physical and mechanical processes involved in basal sliding.
4) Models at different scales and their interactions:
   mechanical behaviour and texture development in polar ice;
   basal conditions (ice-sediment mixture behaviour, sliding, subglacial hydrology);
   glacier, ice-sheet and ice-shelf flow modelling;
   multi-scale modelling.
5) Ice-sheet and glacier crevassing and discharge.
6) Ice behaviour and ice mass evolution in extraterrestrial environments.

SESSIONS
Oral presentations will be held on four full days and one half-day. There will be ample opportunity for poster displays.

PAPERS

(I) SUBMISSION OF ABSTRACTS

Participants who want to contribute to the Symposium should submit an abstract of their proposed paper. This abstract must contain sufficient detail to enable us to judge the scientific merit and relevance of the proposed paper. It should not exceed one page of typescript, on international-size paper A4 (210 x 297 mm). References and illustrations should not be included. Place the title and author(s) names and address(es) at the top of the abstract, not on a separate sheet. Indicate at the bottom which specific topic(s) it intends to address, and whether a poster or oral presentation is preferred. When selecting material, authors should bear in mind that the final version of the paper should not exceed 5 printed pages in the *Annals*; extra pages will be charged at the rate of £90 per page. Honoring page charges (also £90 per page) for up to the first five pages is encouraged. Send abstracts by e-mail, fax or regular mail to: Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, U.K.

LAST DATE FOR RECEIPT OF ABSTRACTS: 31 JANUARY 2002

(II) SELECTION OF PAPERS

Each abstract will be assessed on its scientific quality and relevance to the topics of the Symposium. Authors whose abstracts are acceptable will be invited to make either an oral or poster presentation at the Symposium. There will be no distinction between oral or poster papers in the *Annals of Glaciology*. First or corresponding authors will be advised in late March of the acceptance or otherwise; other authors will not be informed separately. Authors who have not received notification by mid-April should contact the IGS office in Cambridge in case their abstract was not received. Acceptance of an abstract means that the paper based on it should be submitted to the *Annals of Glaciology* and not to another publication. Note: Abstracts alone will not be published in the *Annals of Glaciology*.

(III) DISTRIBUTION OF ABSTRACTS

A set of the accepted abstracts will be provided to all registered participants upon registration on 25 August 2002.

(IV) SUBMISSION OF PAPERS AND PUBLICATION

Four copies of each paper, single-sided and doubled-spaced with wide margins, should be sent to the Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, U.K. by 24 June 2002. ALL AUTHORS ARE EXPECTED TO ADHERE TO THIS DEADLINE. Papers should be prepared in accordance with the style instructions sent to authors with the abstract acceptance notification. Papers will be refereed according to the usual standards of the Society before being accepted for publication. Final papers, presented at the Symposium, which have been submitted and accepted by the Editorial Board, following review, will be published in English in the *Annals of Glaciology* (Vol. 37). Final, revised versions of papers, diskettes and original art work must be submitted by 7 October 2002. Speedy publication of the *Annals of Glaciology* will depend upon strict adherence to deadlines.

LAST DATE FOR RECEIPT OF PAPERS 24 JUNE 2002

MID-WEEK EXCURSION

There will be a mid-week excursion to Mer de Glace (Montenvers) and/or Aiguille du Midi depending on weather conditions and the number of participants. Sign-up for these will be on 25 August 2002 during registration. The additional charge will be between about £10 (15€) and £20 (30€) depending on the excursion.

POST-SYMPOSIUM TOUR

Although no post-symposium group tour is planned, personal excursions may be arranged locally. See Chamonix web site (http://www.chamonix.com).

ACCOMMODATION

Chamonix provides a wide range of hotel accommodation from 2 to 4 stars. Participants are strongly encouraged to consult the Tourist Office internet site (www.chamonix.com, e-mail: reservation@chamonix.com) and to make reservations early. Please ensure your hotel is located downtown (ENSA is at Place du Mont-Blanc, close to the skating ring, i.e. right in the town centre). The symposium will probably end late Friday afternoon, so you may need to spend Friday night in Chamonix. For further advice and information, please feel free to contact the Local Arrangements Committee (jacques@glaciog.ujf-grenoble.fr).

ENSA has many student-residence type double-rooms (two participants/room) for about £25(37€)/person, including breakfast and dinner (payment in Euros at the symposium registration desk). Rooms are equipped with washbasins and shower. Sheets and blankets are provided, but towels are not.

IMPORTANT DATES:

Abstracts due	**31 January 2002**
Notification of acceptance	1 April 2002
Pre-registration deadline	1 June 2002
Papers due	**24 June 2002**
Deadline for full refund	8 July 2002
Deadline for refund	10 August 2002
Conference starts	26 August 2002
Final revised papers	**7 October 2002**

To avoid disappointment, please respect the above deadlines

http://www-lgge.ujf-grenoble.fr/igs-cham2002/

SYMPOSIUM ON PHYSICAL AND MECHANICAL PROCESSES IN ICE

Chamonix – Mont Blanc, France, 26–30 August 2002

REGISTRATION FORM

Family Name: ______________________________

First Name: ______________________________

Address: ______________________________

____

____

Tel: ______________ FAX: ______________

E-mail: ____________________

Accompanied by:

Name:____________________ Age (if under 18)

Name:____________________ Age (if under 18)

Name:____________________ Age (if under 18)

REGISTRATION FEES	£	£
Participant (Member of the IGS)	250	___
Participant (Not a member of the IGS)	300	___
Student or Retired IGS Member	100	___
Accompanying person aged 18 or over	50	___
Late registration surcharge (after 1 June)	50	___
TOTAL REGISTRATION FEES AND DEPOSITS SENT		___

If payment made after 1 June 2002, add £50 for each person

ACCOMMODATION

❑ I will arrange my own hotel reservation at www.chamonix.com

❑ I require ENSA accommodation in a double-room

(❑ preferably alone)

Sharing with ______________________________

Payment, in pounds sterling drawn on a UK bank, may be made by cheque to:

INTERNATIONAL GLACIOLOGICAL SOCIETY

or by Access/Eurocard/MasterCard or VISA/Delta

Name on card: ______________________________

Signature: ______________________________

Expires: _________

Payment may also be made to: National Westminster Bank plc, Account no: 54770084, 56 St. Andrew's Street, Cambridge CB2 3DA, UK, (any Bank or Transfer charges must be included).

Mail to:

Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, UK

RECENT MEETINGS (of other organizations)

WORKSHOP ON ANTARCTIC AUTONOMOUS SCIENTIFIC VEHICLES AND TRAVERSES

National Geographic Society, Washington DC, 14 and 15 February 2001

A small, focused workshop on Antarctic Autonomous Scientific Vehicles and Traverses was held at the National Geographic Society on February 14 and 15 to discuss scientific objectives and benefits of the use of rovers such as are being developed for use in planetary exploration. At the meeting were US, British, French, and German participants; from the US there were members of the academic, scientific, and technical communities, including representation from NASA centers and the National Science Foundation; specialties included Earth and planetary polar science, autonomous robotic vehicles, and polar logistics. The participants enthusiastically agreed that rovers would be uniquely valuable for such tasks as data-taking on tedious or repetitive routes, traverses in polar night, data acquisition on difficult or hazardous routes, surveys in extremely remote regions, traverses requiring only simple instrumentation, traverses that must be conducted at low speed, augments of manned traverses, and scientific procedures not compatible with the presence of humans or combustion engines. The workshop concluded that instrumented autonomous vehicles, of the type being developed for the next generation of planetary exploration, specifically rovers with large (1–2 m diameter) spherical wheels, have the potential to contribute significantly to the way science is conducted in ice sheets and sea ice, while also aiding planetary technology development and engaging the public's interest. Specific objectives can be supported in understanding ice sheet mass balance, sea ice heat and momentum exchange, small-scale magnetometer and gravimeter phenomena, and surface-air chemistry processes. There are issues of rover capability and scientific instrumentation that require additional development, but even in the immediate future there are useful implementations that would serve to initiate use of science rovers. The participants recommend that this general concept be pursued further in the scientific and autonomy communities so that an international, multi-agency program can be generated to address technology development and Earth science. Additional workshops in this area are anticipated on specific topics such as robotic systems, instrumentation, and international planning.

Frank Carsey

JPL, CIT, Pasadena CA 91109, U.S.A.

METHODS OF APPLIED MATHEMATICS AND MECHANICS IN AN ENVIRONMENTAL, GEOPHYSICAL AND CLIMATOLOGICAL CONTEXT

Conference to Celebrate the 60th Birthday of Professor Kolumban Hutter
18-23 March 2001, Seeheim-Jugenheim, Germany

This Conference, and an accompanying Springer book *Continuum Mechanics and Applications in Geophysics and the Environment*, edited by B. Straughan, R. Greve, H. Ehrentraut and Y. Wang, was initiated by Brian Straughan and Ralf Greve in honour of Koli's extensive contributions to theoretical mechanics and geophysics.

The book contains 19 invited articles under the sub-headings: Applied Continuum Mechanics, Soil Mechanics and Porous Media, Glacier and Ice Dynamics, and Climatology and Lake Physics — reflecting the wide areas of Koli's interests.

The Conference was held in the Lufthansa Centre, which provided both accommodation, a lecture theatre and other facilities, which kept participants together throughout the day and evening, assisted by the weather conditions. The preparation and day-to-day organisation by the above people and other Darmstadt colleagues was excellent, and ensured a smooth operation.

It was Koli's wish that the Conference should be a proper working meeting, and this was certainly the case. There were over 100 participants from 13 countries, with 70 or more present on some days, and over 60 presentations covering a wider range of topics than the book. One alert person on the front row had questions for each lecturer, and John G. was not far behind, nor less alert. The Conference was opened by a short address from the President of the International Glaciological Society, who paid tribute to Koli's major contributions to the Society and to glaciology in general.

The programme was divided into sessions under 5 headings: 3 sessions on Continuum Mechanics and Thermodynamics; 3 on Applied Mathematics; 3 on Climatology, Oceanography and Limnology; 3 on Granular and Porous Continua; 3 on Glaciology; and 1 on Celestial Mechanics. In addition, there was a longer delightful evening lecture by a colleague of Koli at TUD on the History of Mechanics, which discussed Newton's experimental and theoretical work on the resistance of falling spheres (through a viscous fluid), including the experiments in a newly constructed St. Paul's Cathedral. Descriptions were presented in the original Latin (with translations for the uneducated). Koli has himself been very active in the history of mechanics and translation of original papers.

The continuum mechanics topics included crystal and micropolar plasticity, viscoplasticity, polymer melts, viscoelastic fluids and phase boundaries. Applied mathematics included computational methods, phase transition, liquid crystals and wave propagation. Climatology etc. included hydrodynamic, biological-hydrodynamical and ecosystem lake models, pollution of aquifers, paleoclimate modelling and the greenhouse effect. Granular and porous continua topics included avalanche modelling, debris flow, sand dunes, rock mechanics and waves. The 2 celestial mechanics topics were the structure of planetary rings and tethered satellites. Glaciology covered the modelling of glaciers and ice sheets, stability of glaciers, sensitivity of ice sheets to climate change, accuracy and stability of glacier flow computation, induced anisotropy in polar ice and the influence of basal topography. Not only did Koli have questions on all these topics, but there was also widespread reference to his contributions and proposals, including celestial mechanics! This recognition of his extensive contributions is a fitting tribute to Koli's stature in the mechanics community. KH60 was finally put to rest with a (glacier) Bed Time story.

One participant revealed his artistic talent (?) with the following poem:

"Koli the Hutter is sixty years old.
He studies glaciers, or so I am told.
So when ice sheets get thick, and your grad. student panics,
Remember the power of continuum mechanics."

L.W. Morland

Bob Bindschadler, representing the International Glaciological Society, was introduced by Ralf Greve and made the following comments.

I have made a special trip to this conference because Professor Kolumban Hutter is a very special glaciologist. My responsibilities as the current President of the International Glaciological Society include acknowledging the outstanding members of our Society. There is no one I can think of that deserves such acknowledgement more than Koli Hutter. As this conference amply illustrates, Koli's strengths in applied mathematics and mechanics extend to disciplines well beyond glaciology. But Koli has been and continues to be one of the most prolific and compelling contributors to glaciology and our Society is very grateful for his sustained involvement in our science.

I have had the benefit of knowing Koli since I was a "wet-behind-the ears" glaciologist spending my first year after my PhD working at the ETH in Zürich. I recall walking down the hallway past his office and, when I dared glance in his office, seeing him seated at his table, bent over a pad of paper writing furiously. He undoubtedly was in the middle of some horribly complex and intricate mathematical formulation. I likened the intensity with which he worked to the passion Beethoven brought to the composition of his timeless symphonies. At the time, Koli was in the process of putting together a major work, his book *Theoretical glaciology*. I can admit now that Koli caused me to spend the last few months of my time at ETH in fear because he had asked me to read his draft when it was finished — he was almost finished — and I dared not refuse. However I doubted I would even understand much of it and heaven help me if I thought I found a mistake in his draft! I was relieved to have escaped Switzerland before he finished the book, but I have since learned that I refer to it often when I must recall the assumptions behind the simplified equations I use in my research. And Koli, I am happy to report that I still have not found any mistakes in your book.

The book well represents much of what Koli has contributed to glaciology. His mathematical rigor exceeded that of most glaciologists of the time. Such uncompromising attention to detail has elevated mathematical glaciology to a level on par with the mathematical treatments of the atmosphere and the ocean. The achievement reminds me of another personal anecdote. I believe the conversation with Koli took place at an airport. He was telling me how the *Journal of Glaciology* had just rejected his paper because he introduced a technique called "non-dimensionalization" to the standard equations of motion glaciologists used so often. This seemed to be regarded by the reviewers as some near-criminal abuse of the equations. I probably don't have to tell you that Koli did not take this reason for rejecting his paper quietly. He fought for the principles of the analysis that he knew were sound, even if it was uncomfortably new to the readers of the journal. They would simply have to work a little harder to understand the paper. By refusing to settle for the conventional mathematical approaches of that era, he lifted us all to a new research level. This is a remarkable achievement and one that has had a lasting impact on glaciological research.

I was surprised to learn that Koli's initial publications in glaciology were in sea-ice research. Since then he has migrated through glacier and ice flow and for the last few years has made major contributions to the field of avalanche research and the mechanics of flowing snow. Thus, nearly every subdiscipline of glaciology has been enhanced by Koli's scrutiny of its mathematical underpinnings. I can think of no other member of our Society who has contributed so much to so many areas of glaciology.

Applied mathematics is not the only venue in which Koli applies full rigor. Those of you who know Koli, know that in whatever task he accepts, he eagerly takes the lead and is willing to shoulder a disproportionate share of the work load. The IGS has benefited many times from Koli's zeal in quality editorial work. He served as a Scientific Editor of the *Journal of Glaciology* for more than ten years and no other person has served as Chief Editor of the *Annals of Glaciology* three times. I can only think of one other person who has served even twice in this capacity. The *Annals* is a series the Society has sought to have reach the high standards of a front-line research publication and Koli's unwavering demands on the quality of papers accepted for this publication have led this effort. A professional society is often judged by the quality of its publications, so our Society is indebted to Koli for his tireless efforts on behalf of IGS publications.

Another of Koli's lasting contributions to glaciology is realized by his training of exceptional students. I won't list them all here, some of them will give papers at this conference. Koli, I'm sure that you are energized to work alongside your proteges as well as to see them mature and make their own contributions. Through them you have amplified your contributions to glaciology and, again, we are the richer for it.

In closing, I want to add one final personal footnote to these descriptions of how much you, as a remarkable mathematician and scientist, have meant to the advance of glaciology. It has been my pleasure to know you as a professional colleague and as a friend. I am but one of many glaciologists who can say that you have made me a better glaciologist and I thank you for what you have done for my career.

So, Koli, on behalf of the International Glaciological Society, thank you for all you have done for glaciology. We wish you a very happy 60th year and hope you enjoy this conference organized to honor you and your professional achievements!!

Robert A. Bindschadler
President, International Glaciological Society

BOOKS RECEIVED

Alley, R.B. and R.A. Bindschadler, *eds.* 2001. *The West Antarctic ice sheet: behavior and environment.* Washington, DC, American Geophysical Union, xii + 296 pp. (Antarctic Research Series 77.) (ISBN 0-87590-957-4, ISSN 0066-4634, $65)

Bischof, J. 2000. *Ice drift, ocean circulation and climate change.* Berlin, etc., Springer-Verlag; Praxis Publishing, xvi + 215 pp. (ISBN 1-85233-648-X, DM210/GBP70/US$105)

Davis, N. 2001. *Permafrost: a guide to frozen ground in transition.* Fairbanks, AK, University of Alaska Press, xvi + 352 pp. (ISBN 1-889963-19-4 (cloth), US$35.95)

Molnia, B.F. 2001. Glaciers of Alaska. *Alaska Geogr.,* **28**(2), 112 pp.

Mulherin, N.D., W.B. Tucker, III, O.P. Smith and W.J. Lee. 2001. Marine ice atlas for Cook Inlet, Alaska. *EDRC/CRREL Tech. Rep.* 01-10, 145 pp.

Osmaston, H. and G. Kaser. 2001. *Glaciers and glaciations: Rwenzori Mountains National Park, Uganda and Parc National des Virungas, Democratic Republic of Congo.* Henry Osmaston and Bartholomew Ltd., Glasgow, maps with text. (Scale 1:65,000 and 1:100,000, cartography by Elisabeth Gärtner and Christian Georges, ISBN 0-95180394-8.)

Siegert, M.J. 2001. *Ice sheets and late Quaternary environmental change.* Chichester, etc., John Wiley and Sons Ltd., xvi pp. + 231 pp. (ISBN 0471-98569-4 Hardback £60; ISBN 0471-98570-8 Paperback £19.99)

OBITUARY

Ian M. Whillans (1944–2001)

Dr. Ian M. Whillans, Professor in the Department of Geological Sciences and Member of the Byrd Polar Research Center at The Ohio State University, passed away on May 9, 2001.

Dr. Whillans was born in 1944 in Toronto, Canada, and received his B.S. degree (Mathematics and Physics) with honors from the University of Bristol, United Kingdom, in 1966, and his Ph.D. (Geology and Mineralogy) from The Ohio State University in 1975. He moved to the Byrd Polar Research Center (then called the Institute of Polar Studies) in 1966 and joined the faculty of the Department of Geological Sciences in 1977. Over the course of his career, his fieldwork led him to such places as the Devon Ice Cap, Nunavut, Canada, the Greenland ice sheet, and the ice streams in West Antarctica. In 1966–67 he wintered over at Palmer Station in the Antarctic Peninsula. He published more than 60 papers on topics ranging from the interaction between ice-sheet surface topography and inversion winds, past and current changes in the Antarctic and Greenland ice sheets, to the flow dynamics of the West Antarctic ice streams.

Ian Whillans focused especially on establishing a rigorous, quantitative, and mathematical underpinning for modern observations of glaciers and ice sheets. Building on earlier and simplified views about the growth and decay of ice sheets and processes controlling their flow, he explored the real and complex behavior of ice masses and their response to climate forcing. He was one of the first scientists to study the physical nature of long, continuous internal layers observed by radio-echo sounding of polar ice sheets. That work established that these layers are isochrons, some of great age, thereby catapulting the significance of internal layers from interesting curiosities to fundamental indicators of ice deformation and flow history. The impact of this work extends from better understanding the nature of forces acting on the glacier bed, to interpreting and extrapolating the powerful record of paleoclimate preserved in deep ice cores. Until the time of his death, Ian remained active in studies of the West Antarctic ice streams, considered to be of global significance because of their potential to quickly discharge large amounts of ice from the ice sheet interior to the world's oceans. His research on this topic challenged conventional theories about ice-stream motion, forcing the glaciological community to reassess the fundamental controls that initiate and restrain fast-moving ice streams. Most importantly, along with others, Ian's work has shown that streaming flow is constrained by forces along the lateral margins of ice streams, that these forces arise from within the ice itself and that the lateral shearing is often the primary resistance to flow. This suggests there may be important controls on the streaming behavior of ice driven independently from changes in climate.

Ian was one of a handful of glaciologists who combined theoretical analyses with careful observations and experiments. His pioneering work on strain grids set the standard for measuring surface deformation on glaciers, and many glaciologists have adopted his methods to study flow near ice divides, flow leading to deep boreholes, and processes acting at the lateral margins of fast-moving ice streams. The techniques developed by him for inferring mechanical controls on glacier motion from measurements of surface strain have revolutionized the way glaciologists study glaciers. His fieldwork always involved the latest techniques available, but without falling into the trap of techniques overshadowing the science. Early glacier surveys were conducted with theodolites and TRANSIT satellite receivers, but when the Global Positioning System (GPS) became available, he was among the first to explore its application in Antarctica, developing his own numerical code for data interpretation. He continued to push the limits of GPS surveying, being the first to apply this technique to measure directly the vertical motion of the ice-sheet surface to infer changes in ice thickness. His use of repeat photogrammetry resulted in the first descriptive map of Ice Stream B in West Antarctica and, later, the first description of the large-scale pattern of motion in this region. Subsequent work involved satellite images and provided insight to recent changes in the ice streams and the Ross Ice Shelf. Throughout all his studies Ian never lost track of the "big picture" of why doing science, and why studying glaciers, are important.

Ian Whillans made many contributions to the international science community. He served as a Council Member of the International Glaciological Society and as Assistant Editor and Chief Scientific Editor for the *Annals of Glaciology*. In addition, he served on the Committee of Snow and Ice of the American Geophysical Union, was a member of an ad hoc committee on Information Storage and Retrieval under the Committee on Glaciology of the National Academy of Sciences, and participated in the Committee on Glaciology of the Polar Research Board of the National Academy of Sciences. From the inception of the West Antarctic Ice Sheet Program (WISP) in 1975, he remained actively involved in the planning and execution of the US scientific investigations in West Antarctica. He had long-term working relationships with the Laboratoire de Glaciologie et Géophysique de l'Environnement in Grenoble, France, and the Norsk Polarinstitutt in Bergen, Norway, as well as with many individual scientists from around the world. He was an active educator, teaching at all levels. Numerous former students and post-doctoral fellows remain active in the field. He received the Antarctic Service Medal in 1967, and the BPRC Golthwait Polar Medal in October, 2000. Mount Whillans, 870 m a.s.l., 4 miles southwest of Mt. Stroschein in the Anderson Hills in northern Patuxent Range, Pensacola Mountains, Antarctica, was named to recognize the numerous significant contributions of this outstanding glaciologist. Earlier this year, Ice Stream B was renamed the Whillans Ice Stream as further recognition of his contribution to our knowledge of Antarctica (see page 35).

Dr. Whillans leaves behind his wife Emily, son Andrew, daughter Claire; father Morley Whillans; brother and sister Tim and Penny Whillans; niece and nephew, Martin and Ana Whillans; aunt Evelyn Penny; and mother-in-law Mary Joan Baird.

Kees van der Veen
Richard B. Alley

In memory of Ian Whillans (from the eulogy by Robert A. Bindschadler, President of the International Glaciological Society, at Ian's funeral).

I'm honoring Ian today not only as his friend, but because he was an exceptional scientist who contributed so much to the practice of glaciology. Glaciology was a love and a passion of his for so many of his highly productive years.

I am the current President of the International Glaciological Society and in my reflections upon Ian's life and career as a glaciologist, I realize that his life perfectly embodied what that Society is all about. To illustrate that viewpoint, I'd like to take the name of the International Glaciological Society, one word at a time, and say how I think it describes Ian's life so well.

INTERNATIONAL — certainly Ian was. Ian travelled here and abroad and is known throughout the world for all the excellent research he did. Because he left us just a few days ago, I expect there are many of his colleagues around the world that do not yet know that he has passed on. As this sorrowful news spreads across the globe, it will sadden the hearts of all those who knew Ian and those who knew OF him through his writings. The grief will be global.

GLACIOLOGICAL is the second word. Clearly, Ian excelled as a glaciologist. This is not the place to enumerate his many scientific accomplishments, but rest assured, this will be done in the months to come. Suffice it to say here that his science was brilliant. He proposed new idea after new idea — ideas that often flew in the face of traditional wisdom. This is the type of scientific courage that leads to dramatic advances in one's field - and Ian repeatedly displayed this brand of courage. Those of us here who worked with Ian, all, at one time or other, had to defend our research in the bright glare of Ian's penetrating insight and eternal curiosity. But we also know that, just as often, it was his own older ideas he had to push aside to lead us all forward. These traits were evident in Ian's research, in his teaching and in his mentoring. Those who he taught and worked with are a large part of Ian's legacy. In addition, his many papers will continue to be read and studied long after each of us has passed on.

The third word is SOCIETY and refers to the sense of community for, when the day's work is done, we are all still people. Again, in this regard, Ian was exceptional. No one was ever more willing to sit and discuss old or new theories, a new measurement methodology, or any other aspect of our science. He brought to his research a bubbly enthusiasm that is all too rare today. He always seemed to be happy. The world didn't always spin his way, but he accepted it, made the best of it, and moved on. And so, it seems to me, this is how he accepted the tragic events during the last few months of his life — with this characteristically unassuming attitude.

The moments I spent with Ian during this difficult period showed me his true nature more than all the other time we spent together. I saw a man in love with Nature, in love with his wife, in love with his family — indeed, in love with the entire world. It is a fitting way to remember him.

Ian was the complete embodiment of the International Glaciological Society, but he was so much more.

I loved him and I will miss him very much. I thank God I had the pleasure to know him, to work alongside him and to learn from him. He was a remarkable gift to our world.

FUTURE MEETINGS (of other organizations)

EUROPEAN GEOPHYSICAL SOCIETY MEETING, 22–26 APRIL 2002, NICE, FRANCE

The Glaciology sessions are being co-sponsored by the International Glaciological Society. Further information on these is available from see http://www.copernicus.org/EGS/egsga/nice02/programme/CAG.program.htm. For information oon the general EGS programme see http://www.copernicus.org/EGS/egsga/nice02/programme/overview.htm. Note, the abstract deadline is 11 January 2002.

OA28.01 Glaciers and ice sheets: OPEN SESSION
Convener: G.K.C. Clarke
Co-Convener: G.H. Gudmundsson

This session is a general session for contributions related to glaciers, ice sheets, and sea ice not explicitly covered by other sessions. We welcome contributions on modeling and observational studies from small alpine glaciers to ice-sheet-scale investigations of both contemporary and paleo ice masses. A special subsession will focus on glacier hazards and applied glaciology. The session will be divided into further subsessions depending on the nature of the contributions.

OA28.02 Glaciers and ice sheets: ADVANCES IN REMOTE SENSING OF THE CRYOSPHERE
Convener: J.L. Bamber
Co-Convener: M.R. Drinkwater

The logistical difficulty of making routine measurements in the polar regions makes remote sensing, and particularly satellite remote sensing an attractive tool. Recent advances have been made in the development and implementation of new concepts for cryosphere-dedicated space missions, as well as the development and maturation of methods for retrieving a variety of important geophysical parameters. This year sees the launch of the first ever satellite mission with a primary focus on the cryosphere (ICESat), reflecting its importance in the climate system and in global climate-change research. The purpose of this session is to highlight advances in the state of the art of remote sensing of the cryosphere. The scope includes the application of satellite, airborne and in situ techniques for the purpose of quantifying characteristics of high-latitude and high-altitude snow, sea-ice and terrestrial ice surfaces. Results of studies combining field and remote-sensing data are welcome, as well as work on the development of datasets aimed at calibrating or validating new and novel remote-sensing measurements.

OA28.03 Glaciers and ice sheets: ENERGY AND MASS EXCHANGE OVER SNOW AND ICE
Convener: W. Greuell
Co-Convener: D. Scherer

The cryosphere responds directly to climatic fluctuations through changes in the surface mass balance. From a physical point of view, the most correct way to describe the relation between conditions in the atmosphere and ablation is by consideration of the surface-energy balance. In this session we intend to deal with the surface-energy and mass balance of the different parts of the cryosphere, notably glaciers, ice sheets, seasonal snow and sea ice. Contributions about various aspects and methods are welcome, e.g.:

- ground-based measurements of the surface-energy and mass balance
- remote-sensing data dealing with aspects of the surface-energy and mass balance
- simulations of the mass balance with atmospheric (e.g. general circulation models), energy-balance, degree-day and regression models
- the incoming radiative fluxes, the albedo, the turbulent fluxes and subsurface processes related to the surface-mass and energy balance
- the boundary layer over the cryosphere (e.g. katabatic wind phenomena)
- drifting and blowing snow.

OA28.04 Glaciers and ice sheets: CONTROL OF BASAL PROCESSES ON MOTION AND MASS BALANCE
Convener: S. Tulaczyk
Co-Convener: U.H. Fischer

Subglacial environments are characterized by complex interactions between hydrological, mechanical, and thermodynamic processes. Coupling of these processes determines the magnitude of basal resistance to ice motion, thereby influencing the velocity and mass balance of an ice mass. It is particularly challenging to integrate existing observations and theory describing basal processes on relatively short spatial scales into quantitative models of ice flow that are concerned with much longer spatial scales. We solicit scientific contributions that relate to this complex relationship between basal processes and ice motion/mass balance. Suitable areas of research include, but are not limited to: (1) field-based observations of basal processes in different glaciodynamic environments, (2) work on parameterization of basal processes in numerical ice-flow models, and (3) laboratory simulations of basal processes.

HSA4.02 Hydrology and rainfall processes: HYDROLOGICAL AND METEOROLOGICAL COUPLING IN MOUNTAIN AREAS
Convener: C. de Jong
Co-Convener: R. Ranzi

The coupling of meteorological and hydrological components in high mountain environments is of utmost importance when considering hydrological and climatological change in addition to increasing water demand. Not only are entire mountain basins challenging environments sensitive to small hydrometeorological changes, it is also the interrelations between individual zoning and sub-basin that build up complex interactive reactions. The aim of this session is to present the symbiosis of meteorological and hydrological processes at a range of high elevation scales, extending from single sites to basins and mountain ranges and time steps, ranging from annual to hourly. This session invites contributions on understanding, monitoring and modelling of individual or coupled meteorological and hydrological issues in mountain environments. From a meteorological viewpoint, contributions are welcome on fundamental interface processes: evapotranspiration, precipitation, temperature, humidity and wind profiles. From a hydrological viewpoint, work can include topography-related evaporation, transpiration, slope-water dynamics, glacier mass balance, snow melt, and discharge with special emphasis on floods. Since measurement and modelling of key hydrological and meteorological variables often pose logistical and scientific problems in mountain regions, an introduction to alternative instrumentation, remote sensing (space- and airborne) and new approaches is welcome.

ICE: SURFACE STRUCTURE AND DYNAMICS

Ice Focus Session, APS Meeting,18–22 March 2002, Indianapolis, Indiana, U.S.A.

Ice is a ubiquitous material in the environment and its various forms are now recognized to influence life on Earth in multiple ways. For instance, ice clouds affect the chemical composition and radiative budget of the atmosphere, ice sheets and glaciers influence local and global climate and geomorphic processes, and frozen ground water causes frost heave in soils. Within this context, significant emphasis has been placed on the importance of physical and chemical processes occurring at ice surfaces. However, there is a continued need for further understanding of the surface physics and chemistry of this high-vapor pressure molecular solid. Thus, in an effort to advance our existing knowledge of the physics and chemistry of ice surfaces, we are soliciting papers on the following topics:

1. Ice surface structure and dynamics;
2. Impurity effects on surface structure;
3. Mechanisms of growth and dissolution at ice surfaces;
4. Kinetics and thermodynamics of adsorption, diffusion, and desorption of foreign molecules;
5. Chemical reactions at ice surfaces;
6. Photochemistry at ice surfaces.

We emphasize both novel experimental and computational and theoretical approaches.

For further information see
http://www.chem.northwestern.edu/~geigerf/APS1.html
or contact:
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E-mail: geigerf@chem.northwestern.edu
Abstract submission deadline is 7 December 2001

ICE — FROM MOLECULES TO ICE SHEETS: A SPECIAL SESSION IN HONOR OF W. BARCLAY KAMB

AGU Fall Meeting, 10–14 December 2001, San Francisco, California, U.S.A.

At the 2001 AGU meeting in San Francisco, there will be a special session in honor of Barclay Kamb's contributions to glaciology. Reflecting the broad impact his work has had on geosciences, the session will be co-sponsored by several AGU sections (H, HGC, MRP, NG, SIP, T). In the course of his productive career, Barclay Kamb has studied an unusually broad spectrum of glaciological topics ranging in scale from molecular-level ice physics to ice-sheet dynamics. Through field work, laboratory experiments and modeling, he has tackled pivotal glaciological problems, such as ice crystallography and phase changes, ice rheology, subglacial water drainage, glacier motion and surges and the mechanism of ice streaming.

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IGS NORDIC BRANCH MEETING, 27–28 OCTOBER 2001, ROVANIEMI, FINLAND

The IGS Nordic Branch will meet in Rovaniemi, Finland, on 27 and 28 October. Details about the meeting are available at:
http://www.urova.fi/home/hkunta/jmoore/nigs_roi.html
or from
John C. Moore
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jmoore@urova.fi

GLACIOLOGICAL DIARY

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2001

25–27 October 2001
Arctic Feedbacks to Global Change, Arctic Centre, Rovaniemi, Finland
P. Kuhry, Arctic Centre, University of Lapland, P.O. Box 122, FIN-96101 Rovaniemi, Finland (Fax [358](16)324-777; peter.kuhry@urova.fi; http://www.urova.fi/home/arktinen/feedback.htm)

27–28 October 2001
* IGS Nordic Branch Meeting, Rovaniemi, Finland
J.C. Moore, Arctic Centre, University of Lapland, P.O. Box 122, FIN-96101 Rovaniemi, Finland (Tel [358](16)324-757; Fax [358](16)324-777; jmoore@levi.urova.fi; http://www.urova.fi/home/hkunta/jmoore/nigs_roi.html)

22–24 November 2001
International Seminar on Snow Avalanche Test Sites, Grenoble, France
M. Naaim, Division ETNA, CEMAGREF, B.P. 76, F-38402 Saint-Martin-d'Hères, France (Tel [33](4)76-76-27-22; Fax [33](4)76-51-38-03; mohamed.naaim@cemagref.fr)

10–14 December, 2001
AGU Fall Meeting, Moscone Center, San Francisco, California, USA (http://www.agu.org)
Glaciology-related Sessions
PP06 *Last Glacial Maximum Circulation Revisited*
PP09 *Antarctic Glacial Evolution: the Marine Geologic Record*
IP01 *General Snow, Ice, & Permafrost Contributions*
IP02 *Monitoring and Evolving Cryosphere: the 25th Anniversary of the National Snow & Ice Data Center*
IP03 *Glacier Change: Rates and Resolution*
IP04 *Glacial Sediment Systems from Source to Sink*
IP05 *Ice —From Molecules to Ice Sheets* (a Special Session in Honor of W. Barclay Kamb)
IP06 *Monitoring, Measuring, and Modeling Snow Processes*

2002

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

18–22 March 2002
Ice: Surface Structure and Dynamics, 2002 APS Meeting, Indianapolis, Indiana, USA
F.M. Geiger, Department of Chemistry K-332, Northwestern University, 2145 Sheridan Road, Evanston, IL 60208, USA (Tel [1](847) 467-6553; Fax [1](847) 491-7713; geigerf@chem.nwu.edu)

19–23 March 2002
The Changing Cryosphere: Implications for Recent Climate and Environmental Changes, Special session 98th Annual Meeting of the Association of American Geographers, Los Angeles, California, USA
E. Mosley-Thompson, Byrd Polar Research Center, The Ohio State University 108 Scott Hall 1090 Carmack Road Columbus OH 43210 (Tel [1](614)-292-6662; Fax [1](614)-292-4697; email: thompson.4@osu.edu; http://www.aag.org/)

22–26 April 2002
* European Geophysical Society XXVII General Assembly, Nice, France (http://www.copernicus.org/EGS/egsga/nice02/programme/overview.htm)
Glaciology-related Symposia (http://www.copernicus.org/EGS/egsga/nice02/programme/CAG.program.htm)
OA28.01 *Glaciers and ice sheets: Open Session* (Conveners: G.K.C. Clarke; G.H. Gudmundsson)
OA28.02 *Glaciers and ice sheets: Advances in Remote Sesning of the Cryosphere* (Conveners: J.L. Bamber; M.R. Drinkwater)
OA28.03 *Glaciers and ice sheets: Energy and Mass Exchange over Snow and Ice* (Conveners: W. Greuell; D. Scherer)
OA28.04 *Glaciers and ice sheets: Control of Basal Processes on Motion and Mass Balance* (Conveners: S. Tulaczyk; U.H. Fischer)
HSA4.02 *Hydrology and Rainfall Processes: Hydrological and Meteorological Coupling in Mountain Areas* (Conveners: C. de Jong; R. Ranzi)

26–31 May 2002
ISOPE-2002, 12th Annual International Offshore and Polar Engineering Conference, Kitakyushu, Japan
ISOPE-2002 TPC, P.O. Box 189, Cupertino, CA 95015-0189, USA (Tel [1](408)980-1784; Fax: [1](408)980-1787; meetings@isope.org; http://ww.isope.org)

9–14 June 2002
** International Symposium on Fast Glacier Flow, Yakutat, Alaska, USA
Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, UK (www.spri.cam.ac.uk/igs/home.htm)

4–19 July 2002
International Conference on the Physics and Chemistry of Ice, St. John's, Newfoundland, Canada
S.J. Jones, National Research Council of Canada, Institute for Marine Dynamics, P.O. Box 12093, Stn. A, St. John's, Newfoundland A1B 3T5, Canada (Tel [1](709)772-5403; Fax [1](709)772-2462; Stephen.Jones@nrc.ca)

26–30 August 2002
** International Symposium on Physical and Mechanical Processes in Ice in Relation to Glacier and Ice-Sheet Modelling, Chamonix Mont-Blanc, France
Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, UK (www.spri.cam.ac.uk/igs/home.htm)

2003

2–6 June 2003
** International Symposium on Snow and Avalanches, Davos, Switzerland
Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, UK (www.spri.cam.ac.uk/igs/home.htm)

21–25 July 2003
* 8th International Conference on Permafrost, Zürich, Switzerland
W. Haeberli, Department of Geography, University of Zürich-Irchel, Winterthurerstrasse 190, CH-8057 Zürich, Switzerland (Tel [41](1)635-51-20; Fax [41](1)635-68-48; haeberli@gis.geogr.unizh.ch)

25 29 August 2003
* Seventh International Symposium on Antarctic Glaciology (ISAG-7), Milan, Italy
G. Orombelli, Department of Environmental Sciences, Via Emanueli 15, I-20126 Milano, Italy (Tel [39](2)6447-4403; Fax [39](2)6447-4400; 2a@alpha.disat.unimi.it)

8–12 September 2003
International Symposium on Antarctic Earth Sciences (ISAES IX), Potsdam, Germany
H.-W. Hubberten, Alfred-Wegener-Institut für Polar- und Meeresforschung, Forschungsstelle Potsdam, Telegrafenberg A43, D-14473 Potsdam, Germany (Tel [49](331)288-2100; Fax [49](331)288-2137; isaes@awi-potsdam.de)

2004

August/September 2004
** International Symposium on Arctic Glaciology, Scandinavia
Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, UK (www.spri.cam.ac.uk/igs/home.htm)

2005

** International Symposium on Sea Ice, New Zealand
Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, UK (www.spri.cam.ac.uk/igs/home.htm)

** International Symposium on High-Elevation Glaciers and Climate Records, Lanzhou, China
Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, UK (www.spri.cam.ac.uk/igs/home.htm)

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