Number 140 *1st Issue 2006*

ICE

NEWS BULLETIN OF THE INTERNATIONAL GLACIOLOGICAL SOCIETY

This issue of ICE is dedicated to the memory of John Arnfield Heap, the Society's Honorary Treasurer for 32 years

ISSN 0019–1043

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Contents

Cover picture: In the 'Crystal Cave', Hansbreen, Svalbard. The climber is rappelling down a recently formed moulin, which follows a vertical fracture in the ice (visible behind climber's head). The fracture appears to have formed by hydrofracturing, associated with surface meltwater. (Photograph by Jason Gulley.)

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

From the Editor

Dear IGS member

As we are now getting to the stage where we have caught up on our publications it is time to look forward and contemplate our next challenge. We have drastically reduced our publication time although there is still some work to be done in reducing the time that papers are with the authors and reviewers. Our Chief Editor is working hard on this and it is our belief that authors and reviewers will respond positively to this as they realize that this is where the bottleneck is at present.

So now we here at the IGS office are looking towards our members and wondering what we can do to improve the value of an IGS membership. You will already have noticed that we have started publishing *Journal* and *Annals* papers online as soon as they have been typeset, proofread and corrected. We have also initiated a new 'Profiling' procedure, in which we take a paper that we consider to be of scientific importance and of general interest to the scientific community as a whole and to the general public. We will process those papers at an accelerated rate and will work together with the authors' institutes to produce a press release to increase the profile of the paper and the IGS and its publications.

But we can do more. We are looking to implement a modern web-based membership management system where members can log in and update their details. You will also be able pay your subscription online and purchase back issues and IGS published books. We are hoping to include online registration for our symposia where you can pay your registration fee and any other charges and print out your own receipt.

We have also started investigating online paper submission and review process for both *Journal* and *Annals* papers and are hoping to implement that next year.

We would also like to ask you, our members, what you want from the IGS. What would you like to see us do for you? Would you like to have a 'members site' where you can post material yourselves, e.g. positions available at your institute or department? Please contact us at igsoc@igsoc.org with your ideas and suggestions and we will do our best to implement them.

Finally I would like to say few words in memory of John Heap, to whom this issue of ICE is dedicated. I only met John just before I moved to Cambridge, so in practice I only knew him for three years. But it feels as if I knew him for a very long time. He became a very good friend to whom I could always turn to for sound advice and a sympathetic ear. John and his wife Peggy made our move to Cambridge very welcoming and pleasant. My two sons took to John and Peggy as if they were family, I believe they became sort of surrogate grandparents, since our two extended families are in two different countries. The Sunday roast dinners at the Heaps' are something they will treasure for a very long time.

Magnús Már Magnússson
Secretary General

Recent work

United Kingdom

ICE CORES

European Project for Ice Coring in Antarctica (EPICA)

E. Wolff (BAS)

EPICA is a consortium from 10 nations. In the last two years, it has completed two ice cores to bedrock in Antarctica – at Dome C and in Dronning Maud Land. BAS has played an enthusiastic role in this, and has been particularly responsible for the electrical measurements and for leading the chemical analysis of the Dome C core. The major ionic chemistry was recently published showing how sea salt, terrestrial elements (calcium and iron) and sulfate have varied over the last 740,000 years. This provides important boundary conditions for modellers, as well as suggesting constraints on the processes at work during major glacial-interglacial changes. In particular, sea salt (which we interpret as a sea ice indicator) follows Antarctic temperature closely. Iron and calcium show huge increases in cold periods, apparently reflecting climate change in Patagonia. Sulfate shows very little change between glacial and interglacial periods, in contrast to MSA, whose record at central Antarctic sites is confused by post-depositional effects.

Berkner Island Ice Core Drilling Project

R. Mulvaney (BAS)

In January 2005, BAS, with its French partners (from Laboratoire de Glaciologie et Géophysique de l'Environnement, and the Institut Polaire Français - Paul Emile Victor), completed the 948 m deep ice core to bedrock at Berkner Island. The drilling brought up sand from the bed, and this will be analysed, but first work has concentrated on understanding to what extent the ice record is influenced by climate and how much by the changing size of the ice sheet. Previous ice sheet modelling had suggested that Berkner Island was over-ridden by the main Antarctic ice sheet during the LGM, around 21 kyr ago. However, initial indications (from the Raymond bump observed near the summit, from air content and isotopic measurements) suggest that, although the ice was thicker at the LGM, the island was not overridden by inland ice. The ice near the bed appears to be at least 80,000 years old, and a climate record from the Weddell Sea region will be obtained in the next year or so.

Rapid climate change from Greenland ice

E. Wolff, E. Thomas (BAS)

We have carried out (under the UK's Rapid climate change programme) chemical and isotopic analysis of two rapid climate changes in Greenland at unprecedented resolution, in collaboration with colleagues at University of Copenhagen. The cooling event at 8200 years before present is the most prominent climate fluctuation in the Holocene period. By combining data from four Greenland ice cores, we have defined its length and structure in a way that provides a target for modellers. The chemical changes seen across the event are now shown to be more subdued than was previously believed, suggesting that the event was primarily recorded in the North Atlantic. Dansgaard-Oeschger event 8 is one of the strongest warmings in the last glacial period. We have analysed the transition into and out of the event at a resolution (2 mm) where annual layers in some chemical components are clearly seen, and we will be in a position to define not only the phasing between different parameters but also the changing seasonality across the transition.

MSA as a sea salt proxy in Antarctica

N. Abram (BAS)

It has been shown that concentrations of methanesulfonic acid in some regions of Antarctica are highly correlated with sea ice extent in the previous winter. We have studied this correlation in the Weddell Sea/Antarctic Peninsula region, using a range of ice core sites. We find that, for sites in the western Weddell Sea, the correlation is, if anything reversed. Although the winter sea ice may prime the ocean for greater production of MSA's precursor in the following summer, this is only effective if the summer ice edge is near the site of the ice core. In much of East Antarctica, the ice breaks back to the coast every summer; in the Weddell Sea, this is not the case. Thus a winter with a large ice extent is often followed by a summer with much residual ice, so that the ice edge is far from our sites, and the MSA cannot be effectively transported. In the western Antarctic Peninsula, influenced by the Amundsen and Bellingshausen Seas, the normal relationship appears to be observed. The work emphasises that the relationship between MSA and sea ice may be complex, and interpretation must be done cautiously.

GLACIER CHANGE AND MASS BALANCE

Impact of debris cover on melt rates at Miage Glacier, Italian Alps

B. Brock, M. Cutler, M. Kirkbride (UDun), C. Smiraglia, G. Diolaiuti, C. Mihalcea, C. D'Agata (UMil), M. Citterio (PMil)

We are conducting a detailed investigation into the thermal properties of rock debris and their influence on surface melt rates at debris-covered Miage Glacier, located on the south side of the Mont Blanc Massif. At 25 widely-spaced sample points, sub-debris melt, using ablation stakes, and debris temperatures, using thermistors, were measured between mid June and late September 2005. At 4 sites temperature and humidity were also measured at 4 levels in the debris using microsensors. Clean ice ablation was recorded at 3 sites. Meteorological conditions were monitored throughout at 2 automatic weather stations sited on debris-covered ice. Debris thickness is the most important influence on the surface melt rate, with the typical clean ice melt rate of ~6 cm d^{-1} reduced to one half for debris of ~10 cm thickness and to one quarter for debris of ~25 cm thickness. However, local variations in debris thermal properties and site factors, particularly elevation, are also important influences sub-debris melt rates. Debris thermal conductivity ranged between 0.7 and 1.4 W m^{-1} K^{-1} and increased slightly at most sites over the ablation season. Evaporation of melt water is found to be an important 'sink' of energy in debris covers.

Energy balance programme on Volcán Villarrica, Chile

B. Brock (UDun); A. Rivera (CECS, UCH); G. Casassa, F. Bown, C. Acuña (CECS)

An automatic weather station has been installed at 1800 m on Glacier Pichillancahue on the eastern flank of Volcán Villarrica, southern Chile since January 2004. The station records incoming and outgoing shortwave radiation fluxes, net longwave radiation, air temperature, humidity, wind speed and wind direction. In January 2006 a second station, recording incoming shortwave radiation, air temperature and humidity, was installed at 2300 m on a small nunatack on the northern flank of the Volcano. In addition, surface temperatures of different thicknesses of supraglacial tephra have been measured simultaneously with the melt rates of buried and tephra-free ice and snow. The mean daily ablation season snow melt rate is 55 mm water equivalent, due to strong insolation and almost continuously positive temperatures. In contrast, the melt rate of ice covered by >10 cm of tephra is just 6–8 % of bare surfaces, where the thermal conductivity of the tephra yielded a very low value of 0.45 W m^{-1} K^{-1}. Although snow ablation is accelerated by small particles of windblown tephra, which increase radiation absorption by reducing albedo, the extensive cover of low conductivity tephra in ablation zones strongly reduces ablation and has a positive impact overall on glacier mass balance.

The age and extent of past glaciation in the Cordillera Blanca, Peru.

N. Glasser, S. Clemmens (UWA)

Tropical glaciers are highly sensitive components of the environment and appear to react more immediately to fluctuations in climate than glaciers in the mid- and high-latitudes. The rate and timing of glacier recession within the tropics is important to understanding global environmental change. This project aims to establish the age of moraine-building episodes by obtaining cosmogenic isotope ages for boulders on moraines in the Jeullesh, Uquian, Paron and Tuco Valleys of the Cordillera Blanca, Peru. Calculations of the snowline depression associated with each phase of moraine-building in the studied valleys will be used to draw conclusions regarding the long-term (i.e. Late Pleistocene/Holocene) behaviour and sensitivity of Peruvian glaciers to externally-forced climate change. In particular we would like to determine whether the moraine sequences confirm or refute the recently published hypothesis that the local last glacial maximum (LLGM) in the tropical Andes was earlier than elsewhere globally.

Glacier change in British Columbia.

I.S. Evans (UDurh)

Glaciers and LIA (Little Ice Age) moraines have been mapped from air photos of several dates for the southern Coast Mountains. The characteristics of 1990s glaciers are compared with those of their mid-twentieth century and LIA predecessors, and with LIA glaciers which have wasted away. A multi-temporal glacier inventory is being produced for the Bendor and Shulaps Ranges. The aim is to establish the role of glacier size, gradient, aspect and topographic position in 20th-century change of cirque and valley glaciers.

World glacier distributions

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

Studies of between- and within-region variations in glacier altitude and aspect have now been completed and published, for the 66,084 mountain glaciers available on-line in the World Glacier Inventory in 2004, and in more detail for the European Alps. Azimuthal asymmetry is measured by regression on the circle, and a new model for its variation with latitude is proposed. However, there are many more glaciers in China, south Asia, the Americas and Polar regions for which inventories are still awaited, and second-generation inventories provide further opportunities to complete and update the global picture. Various corrections have been made, notably

to glacier aspects in the Soviet/Eurasian data set. Work continues on relating style of glaciation to patterns of mountain uplift and glacial erosion.

Reconstructing the extent and configuration of the Patagonian icefields

Neil Glasser, Geoff Duller (UWA), Stephan Harrison (UExe), Krister Jansson (USto), Susan Ivy-Ochs, Peter Kubik (ETH), Andres Rivera (CECS)

We are using geomorphological evidence of the patterns of glacier behaviour around the North Patagonian Icefield to reconstruct the extent and configuration of the Patagonian Icefields during the Last Glacial Maximum (LGM) and Holocene. Mapping is based on visual interpretation of Landsat 7 ETM+ and Terra ASTER satellite images, including the contemporary glaciers, areas of ice-scoured bedrock, trimlines, glacial lineations, terminal moraines, sandur and fluvial sediments, deltas and ice-contact deposits, and alluvial fans. These data on the extent of the North Patagonian Icefield during the Late Pleistocene-Holocene transition are being combined with cosmogenic nuclide exposure age dating of boulders on moraines and optically stimulated luminescence dating of ice-contact glacial landforms to establish a chronology for glacier recession since the LGM.

Reconstructing the glacial history of Wales

James Etienne (ETH), Neil Glasser, Michael Hambrey (UWA), Jerry Davies, Dick Waters (BGS), Krister Jansson (USto)

Combining documentation of coastal sections, coring of a glacial lake, mapping of glacial landforms (especially meltwater channels), the late Devensian (Last Glacial Maximum) glacial history of the Irish Sea Basin has been determined for southwest Wales and the Teifi Valley, and shows no evidence to support the glaciomarine hypothesis that was initially promoted in the 1980s. We are also making regional-scale palaeoglaciological reconstructions, based on the distribution of glacial lineations interpreted from satellite imagery. These reconstructions consider the extent, thickness and dynamics of the Welsh Ice Cap and its interaction with the British-Irish Ice Sheet. Two major ice-flow events have been identified. The oldest phase of ice flow (Event I) is characterised by ice flowing from an ice dispersal centre situated over the higher terrain in north-central Wales and by ice thick enough to cover the mountain summits. At this time the interior of the ice cap is inferred to have been dominated by cold-based ice. During the growth of the Welsh Ice Cap it became confluent with the British-Irish Ice Sheet. The Welsh Ice Cap at this time was again sufficiently thick to submerge the highest mountain summits. The youngest detected phase of ice-flow (Event II) was marked by an abrupt change in the dynamics of the Welsh Ice Cap. During Event II the Welsh Ice Cap was drained by at least four ice-streams, which followed major troughs in northern and eastern Wales.

Linking boundary-layer climatology and surface mass-balance to synoptic circulation over the Langjökull ice cap, Iceland.

Richard Hodgkins (ULough), Simon Carr (UOxB)

Glacier-climate research has generally emphasized the boundary-layer, mainly through energy-balance studies. Surface climate has rarely been linked with large-scale atmospheric circulation in a quantitative fashion. However, a synoptic climatological approach offers a link between atmospheric circulation and surface processes through the association of air mass types with boundary-layer conditions. This project is based on continuous meteorological measurements at two locations on a southern outlet glacier of the Langjökull ice cap in Iceland, which began in August 2002: (1) 597 m a.s.l., MAAT 0.0°C, annual mass-balance c. –2.7 m w.e.; (2) 998 m a.s.l., MAAT –1.9°C, annual mass-balance c. 0.0 m w.e. The potential for synoptic typing via statistical analyses (principal components/clustering) is being determined: distinct synoptic patterns are associated with specific surface climatologies, representing particular accumulation/ablation conditions. Observed climate-glacier links can be used to predict the impact of a shift in air-mass type/frequency on the ice cap, including changing mass balance conditions and water supply to river basins. These methods offer a realistic approach to climate change, because variation in surface mass-balance is related to the type and frequency of air masses, integrating the full range of meteorological variables in time and space.

Multi-decadal mass-balance change at a Svalbard glacier from combined geodetic and surface measurements.

Richard Hodgkins (ULough), Adrian Fox (BAS), Anne-Marie Nuttal (ULJM)

Mass-balance measurements are only available for about 0.5% of the glaciers on Svalbard, with long-term records dominated by small glaciers of the Brøggerhalvøya peninsula. There is therefore a need for mass balance data from a wider range of glacier size classes in Svalbard, as elsewhere. The purpose of this project is to analyse multi-decadal mass-balance data from the 30 km^2 glacier Finsterwalderbeen in southern Spitsbergen. These data have been derived from digitisation of published maps, photogrammetry and surface measurements by kinematic GPS profiling over the interval 1970–2003. Thinning has previously been observed at all elevations up to about 350 m a.s.l. between 1970 and 1990 on Finsterwalderbreen. Over the interval 1990–2003, thinning occurred at all elevations up to about 550 m a.s.l., and the mean annual centreline

mass balance varied between –2.08 and –1.11 m w.e. a^{-1}. This pattern appears to be consistent with the widely-observed global acceleration of glacier wasting from the 1990s, and is interpreted in terms of regional climate variation: the shift to positive NAO conditions has been associated with a more negative mass-balance situation since 1990, with a dominant influence of warmer winter temperatures and a shorter accumulation season.

Evaluating surface ice velocities and elevation change: Chacra Glacier, Peru

B. Hubbard, S. Clemmens (UWA)

Field observations and remote sensing indicate that many low-latitude, high altitude glaciers are currently receding rapidly. In this study we have measured by optical surveying high-resolution surface change at the debris-covered tongue of Chacra Glacier, Cordillera Blanca, Peru, over a one-year period. Change was measured at two resolutions: (a) over the entire glacier tongue via several hundred points spaced on average some tens of metres apart, and (b) over three smaller areas of the tongue via several thousand points spaced some tens of centimetres apart. Glacier surface velocities were also measured at nine fixed prisms to investigate the relationships between lateral and vertical velocities.

Changes in glacier geometry and Eextent in Svalbard: Implications for sea-level rise during the 20th and 21st centuries (SLICES)

T. Murray, T.D. James, N.E. Barrand, A.J. Luckman (UWS), S.L. Barr, P.J. Clarke, M.A. King, J.P. Mills (UNew), A.J. Payne, J.L. Wadham, A.P. Wright (UBris), J. Kohler (NPI).

The SLICES project aims to estimate the contribution of glacier melt to 20th century sea-level rise for the Svalbard archipelago and to forecast contributions into the 21st century. Digital elevation models (DEMs) of selected benchmark glaciers in Svalbard are made using historical aerial photographs and contemporary lidar DEMs. This method, which uses ground control points extracted from the high resolution, lidar data sets to control the archived imagery, is producing topographic models of unprecedented quality and spatial distribution. A central component of the project has been to address the short-baseline limitation of laser altimetry. Using improved global positioning system (GPS) data processing methods, long baselines up to 2500 km have been tested. This has greatly facilitated the collection of airborne data in remote areas. The derivation of 20th century mass balance estimates for a representative sample of Svalbard glaciers will provide a well distributed and long-term record that will be upscaled to the whole archipelago and used to forecast sea-level rise contributions for the 21st century under different climatic scenarios.

Mass balance and hydrology of Brewster Glacier, New Zealand

Ian Willis (UCam), Wendy Lawson, Ian Owens, Penny Clendon (UCan), Bob Jacobel (StO)

This work forms part of a larger glacier monitoring and modelling programme coordinated by New Zealand glaciologists from the Universities of Canterbury, Victoria and Otago. The specific work referred to here has involved a combination of surface GPS and GPR work to produce a surface and bed DEM of the glacier. These, in turn, have been used to calculate the distribution of subglacial hydraulic potential and the likely position of subglacial drainage axes for various assumptions about the subglacial water pressure. Dye tracing experiments from crevasses and moulins have been used to identify the drainage system morphology and its changes through a melt season. The combination of data suggests the glacier's drainage system evolves from a high pressure distributed system to a lower pressure channelised system through the summer. Another aspect of the work has involved comparing surface DEMs derived from a combination of GPS and digitised map contours between 1986 and 2005. Analysis shows the glacier gained mass between 1986 and 1997 and loss mass thereafter, so that over the whole time period the mass balance was close to zero. These long term changes compare well with airborne measurements of late summer snowline position that have been made each year since the 1970s.

GLACIER PROCESSES AND CHEMICAL, BIOLOGICAL AND PHYSICAL PROPERTIES

Measurement of englacial ice and snowpack temperatures at Glacier de Tsanfleuron, Switzerland.

O. Bayley, B. Hubbard, R. Essery, N. Rutter, D. Chandler (UWA)

Three boreholes varying in depth from 60 to 130 m, drilled to the bed during field seasons in spring 2004 and summer 2005 have been instrumented with thermistor strings to measure the englacial ice temperatures of Glacier de Tsanfleuron. Additional thermistors were installed above the surface to measure snowpack temperatures, the ice and snow temperature profiles are being used to quantify glacier heat sources and sinks, in interpretation of GPR studies and for incorporation into numerical models of glacier ice motion. To quantify heat fluxes at the glacier surface and within the glacier, meteorological measurements (air temperature, relative humidity, wind speed, wind direction, net radiation and snow depth) have been continuously recorded over the past 14 months, supplemented with short duration eddy correlation measurements. Winter snow pit analysis has allowed determination of snowpack

physical and thermal characteristics while laboratory ice core density analysis will aid determination of similar ice properties. Results suggest Glacier de Tsanfleuron may not be a completely temperate glacier with areas of cold ice and complex heat transfers occur at the glacier bed between the ice and the macro porous karst limestone bedrock.

Glacier dynamics; polythermal glaciers in Svalbard

Tavi Murray, Adrian Luckman (UWS), Michael Hambrey, Neil Glasser, Bryn Hubbard (UWA), Jack Kohler (NPI), Siri Hansen (UCop)

Changes in the dynamics of polythermal glaciers, notably Midre Lovenbreen, have been investigated by means of structural mapping, isotopic investigations to differentiate different origins of ice, ground-penetrating surveys for internal structure and interpretation of serial aerial photographs since 1936. Key results were published in JGR in 2005.

Biogeochemistry of maritime Antarctic glacier basins

Andy Hodson (USheff), Tim Heaton (BGS), Kevin Newsham (BAS)

Solute mass balances, stable isotopes and hydrological process data have been used to characterise biogeochemical processes during melt on a Signy Island glacier in the South Orkneys. It was found that a snowmelt elution phase causes extremely concentrated solutions to develop just centimetres from the melting snowpack surface. The solutions are dominated by sea salt aerosol and are rich in nutrients, although the latter become rapidly sequestered by microbes following melt. Thus the decoupling of nutrient dynamics from other snowpack solutes occurs almost immediately after melt and testifies to the presence of an important microbial ecosystem. The estimated rates of nutrient uptake are equivalent to 66 and 74 % of the total annual atmospheric inputs of NH_4^+ and PO_4^{3-} respectively, although the absolute rates (0.025 g $NH_4^-N/m^2/a$ and 0.0011 g $PO_4^-P/m^2/a$) are far lower than those reported in temperate snowpacks. However, very significant NO_3^- production (0.030 g $NO_3^-N/m^2/a$, or three times total atmospheric inputs) also takes place within zones of high rock-water contact at the ice margin, and isotopic data indicates that nitrification is responsible. After the early snowpack elution phase, nutrient abundance is also greatly influenced by penguin and seal excreta. Thus a combination of atmospheric, crustal and marine nutrient sources fertilise the glacial and ice-marginal ecosystems that are present.

Cryoconite ecosystems upon Svalbard glaciers

Andy Hodson (USheff), Alexandre Anesio (UWA), Mark Osborn (USheff), Birgit Sattler (UInns), Johanna Laybourn-Parry (UKeele), Christin Säwström (ULund), Chris Clark (USheff)

The cryoconite ecosystem of Midtre Lovénbreen, Svalbard is being constrained by a range of molecular – ecosystem – glacier scale observations. Biomass mapping at the glacier scale using a uninhabited aerial vehicle has shown that up to 6% of the glacier surface in the upper ablation area is covered by cryoconite, although the cover drops significantly in both up-glacier and down-glacier directions. In addition to the well-known cryoconite hole, supraglacial streams also represent an important habitat, accounting for up to 25% of cryoconite cover on the glacier surface in the lower ablation area. However, the proportion of cryoconite in supraglacial streams drops markedly with increasing elevation. Despite a strong phosphorus and temperature limitation to bacterial activity in both cryoconite habitats, their impact upon carbon, nitrogen and phosphorus cycling in the glacier basin is marked. For example, significant rates of both photosynthesis (0.41–10^2 mg $C/m^2/d$) and respiration (0.40–42 mg $C/m^2/d$) have been observed. Genetic markers for these and other key biogeochemical processes are thus being sought. This has yielded clear markers for bacterial photosynthesis and we are now beginning to establish what functional role (if any) is being played by nitrogen fixing and nitrifying bacteria.

Development of a spatially-distributed ice flow model: Tsanfleuron Glacier, Switzerland

B. Hubbard, O. Bayley, D. Chandler, A. Hubbard (UWA), T. Murray, H. Freeman, B. Kulessa (UWS), D. Rippin (UHull), H. Mader (UBris), J. West (ULeeds)

Field investigations have been undertaken over the past two years at Tsanfleuron Glacier, Switzerland, with the aim of developing a numerical model of glacier ice motion that incorporates spatial variability in both ice rheology, via an enhancement factor, and basal sliding. Field studies include surface velocity surveying and borehole-based measurements of ice temperature, ice deformation and basal sliding. GPR has been used to determine the glacier's geometry for numerical modelling purposes and the glacier's internal water content to determine a spatial distribution for the enhancement factor. Laboratory investigations have been carried out to investigate the relationship between different types of ice (from cores recovered from the glacier) and its dielectric properties. Parallel numerical modelling has adapted existing 3D code to allow a spatially-variable enhancement factor to be included as well as a spatially-variable basal sliding condition.

Photochemistry in ice and snow

M.D. King (RHUL)

The photochemistry of nitrate and other chemicals in snow, ice and sea ice are being measured and modelled to predict gaseous chemical fluxes (such as nitrogen dioxide) from snow and ice. Fieldwork has concentrated on measuring the spectral optical properties (albedos, penetration depths and snowpack stratigraphy) on snowpacks and sea-ice in Ny-Alesund (Svalbard) and Terra Nova Bay (Antarctica). A Radiative transfer model is used to describe the light field in the snowpack, and predict the photolysis rates of chemical in the snow and ice. The work is collaborative effort with Harry Biene (CNR-IIA –Rome) measuring the gaseous fluxes and Florent Dominé (LGGE, CNRS Grenoble), studying snow physics. The photochemistries of organic and biological molecules are to be studied this year.
http://www.gl.rhul.ac.uk/~king/index.html

Diagnostic criteria for ice formed by supercooling subglacial water.

P.G.Knight, D.A.Knight, S.J.Cook, (UKeele)

With funding from The Leverhulme Trust we are working to develop criteria by which to test the hypothesis that supercooling of subglacial water by rapid pressure reduction during flow towards the glacier margin can create thick basal ice sequences beneath temperate glaciers. One obstacle to our understanding is the lack of diagnostic physical or chemical criteria that relate the supercooling process to specific ice facies. To identify the characteristics that would be expected of basal ice formed by freezing supercooled subglacial water, we are simulating the supercooling process in the low-temperature laboratory and determining the specific chemical, crystallographic and sedimentological characteristics of ice facies associated with the process. Our experiments to date indicate that freezing water in varying pressure/turbulence environments produces a variety of chemically and physically distinctive facies, the characteristics of which can be used to reconstruct the freezing environment. Our continuing work to elucidate the significance, or otherwise, of supercooling in the formation of basal ice beneath glaciers will compare experimental evidence of how process controls facies character with field-based observations of basal ice at supercooling and non-supercooling sites.

Ice friction on engineering materials

B.A. Marmo, V. Koutsos, C.E. Jeffree, A.E. Elfick, J.R. Blackford (UEdin).

Processes related to the sliding friction of ice and engineering materials affect the grip of vehicles on ice-covered roads, the performance of winter sports equipment and the maintenance of high latitude structures. We conduct ice friction research funded by EPSRC in conjunction with Ford, Jaguar, UK Sport and the Scottish institute of Sport. A pin-on-disk tribometer has been developed to measure friction of ice against materials including rubber, steel, nylon and granite over velocities between 0.001 and 0.30 ms-1 and temperature between -35°C to 0°C. Tribology data are used to produce ice friction maps that relate the change in friction with parameters such as velocity, temperature and surface roughness. We have pioneered the use of low temperature scanning electron microscopy to examine wear surfaces on ice and have been identified morphologies that are indicative of fully and partially lubricated sliding. We are developing a method using infrared thermography to examine the relationship between a sliding systems thermal history and ice friction. Tribology and infrared thermography are used to constrain numerical models that optimise the thermal effects of sweeping in the sport of curling. These models are being extended to make them applicable to vehicle tyre traction.

Constraining ice water contents using radar velocity and attenuation measurements

T. Murray, B. Kulessa (UWS), J. West (ULeeds), D. Rippin (UHull), T.J. Endres (UWat), H. Mader (UBris), B. Hubbard, O. Bayley (UWA)

The rheology of ice is strongly controlled by its liquid water content. Since water content and its distribution also exert a strong control on radar propagation velocity and attenuation, this provides a remote technique for measuring ice-water content. A suite of surface and borehole ground-penetrating radar (GPR) surveys have been undertaken at the Tsanfleuron Glacier in the European Alps and are being used to assess the methodology and its limitations. Laboratory measurements and theoretical modelling is used to develop new mixing models to improve the interpretation of water content from radar-derived parameters.

Investigations of spatial and temporal variations in near surface snow and firn properties on the Greenland Ice Sheet and Devon Ice Cap

C. Bell (UAbdn), R. Bingham (UBris), R. Hawley, B. Hubbard (UWA), D. Mair (UAbdn), E. Morris (UCam), P. Nienow, V. Parry , J. Scott (UEdin), J. Wadham (UBris).

In June 1999, the European Space Agency (ESA) selected the CryoSat mission as the first mission in its Earth Explorer Opportunity Mission series. The satellite will determine fluctuations in the mass of the Earth's major land ice fields using high-resolution radar altimeter measurements. To meet the CryoSat mission objectives, independent ground-based measurements are necessary to provide estimates of uncertainty in the radar height measurement. The mission therefore has an associated period of CalVal (calibration/validation) activity to determine spatial and temporal variations in near surface snow and firn properties that will impact on satellite-measured

surface elevation. Fieldwork was undertaken along transects on the Greenland Ice Sheet and Devon Ice Cap in spring and autumn 2004, funded through a NERC consortium grant and ESA. The work involved determination of spatial and temporal variations in: 1) annual surface accumulation; 2) snow/firn density; and 3) snow/firn ionic and particulate chemistry. Densities were obtained using standard snowpit work, shallow ice cores and neutron-probes. A linked campaign, with a radar altimeter mounted on an aircraft platform, was conducted by the Alfred Wegener Institute for Polar and Marine Science. Similar experiments will be conducted in 2006 with an airborne campaign supported by the Danish National Space Center. The results will help place error bars on the accuracy to which changes in satellite-measured ice-mass surface elevation represent real changes in ice mass gain or loss.

Biogeochemistry of subglacial Lake Vostok, Antarctica.

G. Royston-Bishop, M. Tranter, M.J. Siegert (UBris)

We are investigating the biogeochemistry of Lake Vostok through a combination of ice core analyses and simple modelling of the lake system. Over 20 new samples of accretion ice, ice that formed when lake water froze onto the bottom of the ice sheet, have been analysed for major ions, dissolved organic carbon, insoluble impurities and biomass. Suitable ice-water partition coefficients were applied to the accretion ice to infer the composition of the lake's surface waters. Our results suggest that there are large (orders of magnitude) concurrent variations in the concentrations of the above constituents in the lake water. We are currently testing several hypotheses that can explain these observations. Given the enormous logistic effort required to cleanly sample subglacial lakes, this work provides useful background information on the biogeochemical conditions within Lake Vostok and will also help shape the planned exploration of Lake Ellsworth in West Antarctica. This research is collaboration with B.C. Christner, C.F. Foreman and J.C Priscu of Montana State University (USA). http://www.bgc.bris.ac.uk

RABID: Basal conditions on Rutford Ice Stream, West Antarctica: Hot-water drilling and downhole instrumentation

Andy Smith, Keith Nicholls, Keith Makinson (BAS), Tavi Murray, Tolly A_algeirsdóttir (UWS), Alberto Behar (NASA-JPL)

The RABID project was carried out on Rutford Ice Stream during 2004/05. Techniques included drilling to the bed, ice coring, active and passive seismics, and ice flow measurements. Together these formed an integrated programme studying ice dynamics, basal conditions and both climate and glacial history. Technical failures halted the drilling approximately 100 m above the bed (ice thickness ~2200 m) but the rest of the project went largely as planned. Preliminary observations include: Extreme rates of subglacial erosion (1 m/a), followed by the rapid formation of a new drumlin. The drumlin formed from fully-mobilised sediment. Movement of significant quantities of water within the sediment at the glacier bed. Both mobilisation and compaction of basal sediment. The ice stream is capable of reorganising its bed rapidly, suggesting that ice dynamic models do not yet simulate all the relevant subglacial processes. Unlike other ice streams, no stick-slip motion is seen on Rutford Ice Stream. There is a strong correlation between ice stream velocity changes and ocean tides. The amplitude of the changes decays with distance upstream and is more rapid for higher frequency constituents (diurnal and semi-diurnal) than for longer period ones (bi-weekly).

The RABID report can be seen at http://ralph.swan.ac.uk/glaciology/projects/rabid/

Thermal regime, hydrology and dynamics of Arctic glaciers

David Rippin (UHull), Ian Willis (UCam), Jack Kohler (NPI), Andy Hodson (USheff), Jiawen Ren (CAREE), Ming Yan (PRIC).

We have recently undertaken a study on the polythermal glacier Midre Lovénbreen which involved mapping its geometry and thermal structure (using Ground Penetrating Radar (GPR)), investigating its hydrology (from calculations of surface melt and measurements of proglacial stream discharge) and monitoring its surface velocity and strain patterns. One of the main conclusions of this work is that water is stored beneath the warm based core of the glacier in early summer and penetrates through the cold-based margin during a "breakthrough event" in mid summer. The surface dynamics are affected with high surface velocities during rapid inputs to storage in the summer, which are directly forced by high basal motion beneath the warm based core but indirectly forced in the cold-based margin due to longitudinal pushing from upglacier. The reverse is true during the breakthrough event, with direct basal forcing beneath the lower margin and indirect forcing in the upper tongue due to pulling from downglacier. We plan to extend this work to the adjacent Austre Lovénbreen and surge-type Pedersenbreen. As a precursor to a larger study, we will use GPR to map the geometry and thermal regime of these glaciers. All three glaciers are currently being monitored for surface mass balance and dynamics.

Geophysical exploration of a West Antarctic subglacial lake

M. Siegert, A. Payne (UBris), A. Smith, R. Hindmarsh, H. Corr, D. Vaughan, E. King (BAS), J. Woodward (UNN).

Antarctic subglacial lakes are expected to contain unique microbial lifeforms and detailed records of past climate change. Examination of these contents

requires in-situ measurement, which can only take place once a lake has been characterised fully by geophysical methods. Of the ~145 known subglacial lakes in Antarctica none have been measured to the level required for meaningful direct sampling to take place. A project funded by the Natural Environment Research Council (NERC) aims to undertake a comprehensive geophysical exploration of Subglacial Lake Ellsworth, a 10 km long subglacial lake in West Antarctica (near the Ellsworth Mountains). Ice thickness will be determined from ice-penetrating radar, water depths and sediment thickness will be found using seismic exploration, and ice flow and accumulation will be obtained from direct surface measurements. A series of numerical models will be used to understand the history of the lake, the flow of ice across the lake and the circulation of water within the lake. The result of the project will be the first fully characterised subglacial lake environment and the establishment of a candidate for future in-situ analysis. Fieldwork is scheduled to take place in the austral summer of 2007/08, within the timeframe of the International Polar Year (IPY).

GLACIMARINE PROCESSES AND SEA ICE

Morphology and sedimentary processes on the continental slope off Pine Island Bay, Amundsen Sea, West Antarctica

Julian Dowdeswell, Jeff Evans (UCam), Colm Ó Cofaigh (UDurh)

The nature of the continental slope and shelf break in the isolated Amundsen Sea sector of the Antarctic margin, south of the Pacific Ocean, was examined during a recent cruise of the RRS James Clark Ross. Marine-geophysical methods were used to investigate a 750 km-long section of this margin between 100° and 115°W, beyond the wide continental shelf forming Pine Island Bay. About 300 000 km^2 of the modern West Antarctic Ice Sheet drains into this bay, mainly through two major ice streams named Pine Island and Thwaites glaciers. Morphological evidence, in the form of large-scale streamlined sedimentary bedforms, suggests that fast-flowing ice streams extended to the shelf edge under full-glacial conditions about 18 000 years ago and have retreated about 350-400 km since then. Networks of gullies and channels dominate the slope adjacent to Pine Island Bay and act as conduits for coarse-grained sediment transfer. Sandy turbidites interbedded with hemipelagic muds occur on the continental rise and adjacent deep-ocean basin. Submarine channels on the upper slope continue into the abyssal plain as far north as about 67° S. They are separated by sediment drifts and sediment waves resulting from the interaction between downslope turbidity-current processes and along-slope bottom currents. Similar deep-sea sedimentary processes operate along much of the West Antarctic and the western side of the Antarctic Peninsula. The work is collaborative with Prof. J.B. Anderson of Rice University, Texas.

Assemblages of submarine landforms produced by surging tidewater glaciers

Julian Dowdeswell (UCam)

In order to interpret the geological record of past glacier and ice-sheet advances, it is important to distinguish between sediments and landforms relating to dynamic behaviour internal to glaciers, surges, and those linked to external climatic factors. The suite of landforms characteristic of past glacier surges is an important inferential tool in this regard. High-resolution swath bathymetry from the marine margins of several Svalbard glaciers shows an assemblage of submarine landforms that appears characteristic of surging glaciers. These landforms are essentially unmodified since their initial deposition over the past hundred years or so because they have not been subjected to subaerial erosion or periglacial activity. A simple descriptive landsystem model for tidewater glaciers of surge-type is derived from these observations. It is the assemblage of landforms in this model that is of diagnostic significance, and individual landform elements, found in isolation in the geological record, are not necessarily indicative of former surge activity. This work is being undertaken in collaboration with Dag Ottesen of the Geological Survey of Norway.

Flow-switching and large-scale deposition by ice streams draining former ice sheets

Julian Dowdeswell (UCam)

Today, fast-flowing ice streams and outlet glaciers drain over half of the mass from the Antarctic and Greenland ice sheets. Some temporal and spatial variability has been observed in the flow of modern West Antarctic ice streams, but major shifts in the location of ice streams flowing in deep channels has not been observed. We use extensive three-dimensional seismic data from the western Norwegian margin to explain how a 400 km-long ice stream has undergone major switching in flow direction from one glaciation to the next. The direction of ice flow is inferred from the pattern of build-up of 104 km^3 of glacier-derived debris and observations of large-scale streamlined landforms on former subglacial beds. We demonstrate that ice streams can undergo major changes in flow direction through modification of their large-scale topographic setting. Whereas ice-stream switching in modern ice sheets has been regarded mainly as a reflection of internal changes in ice-sheet dynamics, switching over successive 100 000 year glacial cycles is in this case a response to the effects of continuing sediment deposition and the large-scale development of ice-influenced continental margins. This work was undertaken in collaboration with Dag Ottesen and Lief Rise of the Norwegian Geological Survey.

Geologic record of fast glacier flow on the continental shelf off the Antarctic Peninsula
B. Reinardy, T. Murray, J. Hiemstra (UWS), C.-D. Hillenbrand, R. Larter (BAS), Jeff Evans (UCam)
A significant warming trend over the last 50 years has led to the break-up and retreat of many ice shelves fringing the Antarctic Peninsula. Glaciers draining the inland ice sheet into areas formally occupied by these ice shelves have also sped up. This research uses micromorphological evidence along with geophysical data to look at the past dynamics of the Antarctic Peninsula Ice Sheet, focusing on palaeo-ice streams that had had a significant role during the late Quaternary deglaciation of the Weddell Sea embayment, thus providing an analogue for future ice sheet behavior. This is a CASE studentship between Swansea and BAS.

Submarine ice thickness profiling in the Arctic Basin
Peter Wadhams (UCam), Nick Hughes (SAMS)
Some 9000 km of upward and sidescan sonar data were obtained by HMS *Tireless* during an operation in the Arctic Basin in spring 2004. N Hughes travelled aboard the vessel. The data include gridded coverage of the area occupied by the GreenICE ice camp at 85° N 65° W as well as transects which repeated those of earlier UK cruises (1996, 1987) to test for continued thinning of the ice cover.

Ice ridging in the Gulf of Bothnia
Peter Wadhams (UCam), N. Hughes, M. Doble, J. Wilkinson (SAMS)
As part of the EU IRIS project on ridging and its effect on navigation, drilling and coring studies of pressure ridges in the Gulf of Bothnia were carried out in winter 2006 (also 2005 and 2004) from the research ship *Aranda*. Validation was provided by helicopter EM (C Haas, Alfred Wegener Institute).

Modelling of chimney formation and decay in the Greenland Sea
Maxine Von Eye, Peter Wadhams (UCam)
Using data collected during winter and summer cruises from 2001 to 2004 in the EU CONVECTION project, M. Von Eye has begun the modelling of the formation, propagation and decay of convective chimneys in the Greenland Sea, including the role of salt flux from sea ice production.

Use of tiltmeter buoys to monitor modal ice thickness in arctic basin
Peter Wadhams (UCam), Martin Doble (SAMS)
The EU GreenICE project (Greenland Arctic Shelf Ice and Climate Project), co-ordinated by P. Wadhams, involved the deployment in spring 2004 of five 2-axis tiltmeter buoys in a 200 km scale pentagon on the sea ice north of Ellesmere Island (about 85° N 65° W). The spectrum of flexural gravity waves is derived and transmitted by Iridium low-orbit satellite communication, with the peak frequency being a measure of modal ice thickness. A further buoy was added in spring 2005 together with another, in summer 2005, off NE Greenland. Four buoys are transmitting as of April 2006, and two have passed through Nares Strait into Baffin Bay, the others remaining in the Arctic Basin. Thickness values were validated from helicopter EM measurements by Alfred Wegener Institute (C Haas) and airborne swath laser overflights by Danish National Space Centre (R Forsberg).

AUV measurements of under-ice topography by multibeam sonar
Peter Wadhams (UCam), Steve McPhail (SOC), Jeremy Wilkinson (SAMS)
In August 2004 the Autosub AUV was used in NE Greenland from RRS *James Clark Ross* to obtain some 500 km of high quality multibeam sonar data of the underside of first and multiyear fast ice over the Belgica Bank and Norske Oer Trough. The vehicle also mapped the bathymetry of the trough and used its ADCP to discover a new southward flowing current in the trough, which is a countercurrent to the known northward flow. The sonar data show the structure of pressure ridges and underside undulations in melting multiyear ice. Data consist of long track lines (100 m width of imaging) and gridded areas. Validation came from drilling and surface EM carried out by FS *Polarstern*, which joined for one day.

Updating of sea ice representation in Admiralty pilots
João Rodrigues (UCam)
On behalf of UKHO, the large number of Admiralty Pilots that feature sea ice information are being updated using recent ice data in order to take account of the retreat of sea ice over the past two decades.

MODELLING AND REMOTE SENSING

Remote sensing of glacier velocities
A.J. Luckman, R. de Lange, S. Bevan, H. Sykes, T. Murray (UWS)
Glacier dynamics are a key component of glacier and ice sheet mass balance. Interferometry and tracking using SAR data is used to derive time series of velocity measurements and reveal changes in flow rates and the delivery of ice to the ocean. Currently our projects are concentrating on Greenland outlet glaciers, Svalbard, Antarctic ice streams and Alaska.

Modelling the hydrology and dynamics of the Greenland Ice Sheet
Nick Hulton, Mehmet Karatay, Pete Nienow (UEdin), Tony Payne, Andrew Sole (UBris), Sergei Zapetsin (UEdin)
This project is investigating the dynamic sensitivity of the Greenland Ice Sheet (GIS) to variations in subglacial water pressure in response to changes in

both meltwater runoff and subglacial drainage configuration. The project involves the conceptualisation and implementation of a glacio-hydrological module to compliment the existing British community ice sheet model (Glimmer). More specifically it incorporates the production of surface and basal meltwaters, the thermodynamics of water transfer through the glacial system (including refreezing of surface derived meltwaters within the ice sheet) and the routing of water through a variety of different subglacial drainage systems. The model will be used to determine how changes in surface runoff impact on subglacial water pressures and therefore on rates of basal sliding and ice dynamics. Variations in volumes of surface runoff will be generated using different IPCC predictions of warming for the GIS. Clearly, the distribution of different drainage components (channelised v distributed configurations) will impact on the sensitivity of the GIS and the modeling will investigate the extent to which changes in meltwater flux impact on water pressure through different subglacial drainage configurations. The model will be run assuming numerous runoff scenarios and subglacial drainage configurations thereby testing the sensitivity of the ice sheet to changes in runoff and drainage system structure. The water pressure patterns necessary to induce a significant change in ice sheet dynamics will be established providing an indication of the likely stability of the GIS in response to predicted global warming.

Satellite investigations of the impact of supraglacial lake drainage on ice dynamics at the margins of the Greenland Ice Sheet

Kate Briggs, Malcolm McMillan, Pete Nienow, Andrew Shepherd (UEdin)

This project uses remote sensing techniques to determine whether the seasonal development and subsequent drainage of large supraglacial lakes causes a seasonal evolution in ice dynamics along the margin of the Greenland Ice Sheet. The project is investigating the 37 000 km^2 Russell Glacier drainage basin, a section of the GIS draining westwards between the 66°45' N and 67°30' N meridians, at the centre of which lies Russell Glacier. The work aims to determine: 1) seasonal fluctuations in the areal extent and volume of supraglacial lakes across the Russell Glacier drainage basin; and 2) inter-annual and seasonal velocity fluctuations in the Russell Glacier drainage basin. Analysis of the satellite data will reveal the extent to which lake drainage events impact on seasonal ice dynamics within the catchment basin and whether the magnitude and frequency of these events has changed in response to the increasing temperatures observed across the GIS between 1979 and 2002.

Remote sensing techniques for the assessment of glacial hazards

J.M. Reynolds, S.D. Richardson (RGSL), D.J. Quincey, R.M. Lucas, N.F. Glasser, M.J. Hambrey (UWA)

Remote sensing studies have shown that glaciers and their proximal environments exhibit unique temporal, spatial and spectral characteristics that can be analysed to better quantify glacial hazard potential. The integration of a variety of remote sensing data sources can provide information about glacial lakes and lake development, glacier dynamics, avalanche sources and ice-marginal fluctuations. Such data can be used to complement and, in many cases, improve field-based glacial hazard assessments. Aerial photography still remains the main source of data for measuring a number of glacier characteristics, but fine to moderate spatial resolution satellite sensors (e.g. ASTER, SPOT 5 HRVIR, Landsat ETM+) also provide useful information that can be used to support the assessment of hazards in high-mountain glacierised terrain. The methodologies have been used to assess the glacial hazards within an entire catchment of ~2500 km^2 in Tibet (China), mapping and characterising all the glacial lakes evident within the resolution of the imagery. The remote sensing data also provided information to be able to determine the areal extent of debris-covered glacial surfaces within the ablation zones where the surface gradients are shallower than 2° and thus prone to the subsequent formation of potentially hazardous glacial lakes.

Evaluation of forest snow process models (SnowMIP2)

N. Rutter, R Essery (UWA).

Current land-surface models either neglect or use highly simplified representations of physical processes controlling the accumulation and melt of snow in forests. To improve these representations the Snow Model Intercomparison Project 2 (SnowMIP2) has been designed to (1) quantify uncertainty in simulations of forest snow processes from current land-surface models and, (2) implement improvements suggested by these comparisons. SnowMIP2 will compare results of land-surface models, over a wide range of snow and forest canopy conditions, at the following five locations: Colorado (USA), Alptal (Switzerland), Hitsujigaoka (Japan), Hyytiälä (Finland) and Saskatchewan (Canada). Further analyses will compare process observations with model algorithms to investigate the sensitivity of snowpack models to canopy processes through two alternative, yet complementary, methods: (1) Isolation of individual processes represented within models, and comparison of process observations with these model algorithms; and (2) use of a bespoke, complete surface energy- and mass-balance model (currently under

development) that allows adjustable and interchangeable process representations spanning the range used by models participating in SnowMIP2. We are currently inviting modellers to participate in SnowMIP2; driving and initialisation data will be disseminated in the early summer of 2006. We welcome any parties interested in collaborating, and further information about SnowMIP2 can be found at http://users.aber.ac.uk/rie/snowmip2.html or via email to SnowMIP2@aber.ac.uk.

GLACIAL GEOMORPHOLOGY AND LANDSCAPE EVOLUTION

A quantified timescale for glacial valley evolution

M. Brook (UMass), M. Kirkbride, B. Brock (UDun)

Space is used as a proxy for time in determining the role of glaciation in the shaping of valley cross-profiles in the Two Thumb Range, Southern Alps, New Zealand. The range is undergoing rapid tectonic transport and uplift as it is advected towards the Alpine Fault. Repeated cycles of glacial erosion during the Quaternary have fashioned U-shaped valleys in the north of the range, close to the Main Divide and Alpine Fault, whilst valleys in the less glaciated south of the range have rounded divides and convex fluvial cross-profiles. Tectonic transport and uplift rates, coupled with an offshore oxygen isotope ($\delta^{18}O$) record and glacio-geological reconstructions, allow time constraints to be applied to valley development along the length of the range. Valley width and depth measurements and power-law equations were used to quantify the shape of cross-profile transects in each of 37 valleys. These valleys in this environment evolved into a typically U-shaped cross-profile morphology over ≥ 400 ka of glacial occupancy. Increased glacial occupancy is shown by increasingly U-shaped valleys. This indicates that alpine glaciation excavates greater volumes of rock, indicating that glaciers are a more effective erosional agent than fluvial activity in alpine mountain belts.

Formation of the supraglacial cover at Glacier d'Estelette, Italy

M. Kirkbride (UDun), P. Deline (USav)

On this small cirque glacier, since 2004 we have established monitoring of glacier topography, structure, flow, ablation and debris load, and process-based field experiments. The purpose is to understand the glaciological controls on supraglacial debris accumulation as the glacier reduces in thickness and velocity. At small scales, we are examining how the characteristics of inclined englacial debris septa control the rate and pattern of supraglacial mass loading during melt. At larger scales, we seek to understand how the debris cover evolves in response to changes in glaciological and surface-topographic controls. The research will help to understand the larger problem of how the surface condition of alpine glaciers will respond to warming climate, with implications for ablation and meltwater production.

Sample bias in clast fabric measurements

D.M. Chandler, B. Hubbard (UWA)

Clast fabrics are frequently used to identify processes that have occurred during or since deposition in glacial sediments. However, the probability of a clast being exposed at a face is a function of its shape and its orientation relative to the face, with clasts oriented perpendicular to the face having a higher probability of being sampled relative to those parallel to the face. When calculating fabric strength and orientation using the conventional eigenvalue/eigenvector approach, this probability function can lead to substantial difference between the exposed clast fabric and the true clast fabric. In an analytic solution for ellipsoidal clasts, we investigate how sample bias depends on (i) strength of the true fabric, defined as the size of the principal eigenvalue, and (ii) relative orientation of the face, defined as the angle between vectors normal to the face and parallel to the principal eigenvector. Strongest bias in exposed fabric strength occurs for true fabrics with (i) an isotropic fabric (positive bias), (ii) moderate fabric strength and orientation parallel to the face (positive bias) and (iii) moderate fabric strength and orientation perpendicular to the face (negative bias). Orientation of the exposed fabric is biased towards the orientation of the face, by an angle that increases with decreasing fabric strength and increasing relative orientation. Magnitudes of these biases are up to 0.11 in the principal eigenvalue and up to 90° in the fabric orientation, and cannot be countered by increasing sample size.

Processes and rates of high-altitude glacial debris transport

S. Clemmens, B. Hubbard, M. Hambrey (UWA)

Glacial lake outburst floods have a devastating impact on both the landscape and the population of many mountain regions. Some of the largest recorded floods have occurred within high-altitude mountain ranges such as the Himalayas and the Peruvian Andes. Typically, these floods are associated with the outburst of proglacial lakes impounded by massive terminal moraines. In this study, the structural sedimentology of several impressive impounding moraine dams in the Cordillera Blanca, Peru are analysed to elucidate their formation mechanism. A detailed study of glacial debris transport on Glacier Chacraraju provides a much needed reference of contemporary debris sources and processes on which to base sedimentological interpretations of Cordilleran moraine dams. In addition, the combination of debris depth maps and glacier surface

velocities allow for a calculation of sediment delivery rates and an estimate of the timeframe of moraine development. This is further enhanced by additional cosmogenic radionuclide (CRN) surface exposure dating which precisely define the timing of moraine ridge deposition.

Evolution of the Antarctic Ice Sheet and associated landscape evolution.
Michael Hambrey, Neil Glasser (UWA), David Sugden (UEdin), Martin Siegert, Tony Payne (UBris), John Smellie (BAS), Peter Barrett (UWell), Barrie McKelvey (UNE), David Fink (UCanb), Jason Whitehead (UTas), Peter Webb (UOS), David Harwood (UNeb)
The evolution of the East Antarctic Ice Sheet since its inception around 34 million years ago continue to be investigated by means of examination of offshore sedimentary sequences (the Cape Roberts Drilling Project), inland exposure of glacigenic sediments (the Sirius Group and the Pagodroma Group), and the geomorphology of ice-free regions. Using these data as constraints, ice-sheet numerical models have been developed for the Lambert Glacier System to investigate the response to climate, topography, bathymetry and basal conditions. The history of interaction of the ice cap on James Ross Island and its volcanoes, and the role of the Antarctic Peninsula Ice Sheet, is also being studied.

Structural glaciology and sediment transport of alpine glaciers
Michael Hambrey, Becky Goodsell (UWA), Werner Ehrmann (ULei)
Detailed investigations have been carried out on Bas Glacier d'Arolla, Haut Glacier d'Arolla and Glacier de Tsijiore Nouve in the Valais region of Switzerland. Surface structural mapping established the relationships with debris transport, so defining the movement of sediment through the glacial system. Radar investigations led to understanding of 3D structure, and new insight into the origin of ogives. In New Zealand's Southern Alps, sediments were characterised on the surface, at the margins and in the proglacial areas of several glaciers around Aoraki/Mt Cook. This enabled the principal inputs, transport paths and depositional processes to be determined.

Glacial sedimentary processes in Iceland
Anna Nelson (BAS), Ian Willis (UCam), Colm Ó Cofaigh (UDurh)
We have recently completed a study employing macro- and micro-sedimentological techniques on sediments exposed on recently deglaciated forefields at nine surging and non-surging glaciers in Iceland. Macro-scale evidence includes particle-size distribution and individual clast shape, angularity and fabric. Micro-scale evidence involves the identification of rotational structures, fold structures and unistrial plasmic fabric (evidence for ductile deformation) and alignment of grains, shear lines and crushed grains (evidence for brittle deformation) in thin sections viewed under a micro-scope. The techniques have been used to identify the types of sediments and therefore the processes of deposition (deformation tills, lodgement tills, deglacigenic debris flow deposits, glaciofluvial or glaciolacustrine deposits). Many sediments show evidence of subglacial deformation (deformation tills or glacitectonites) and some also contain thin layers of water lain sediments within the deformation till units suggesting ice-bed separation and basal sliding. All the evidence can be used to estimate the relative importance of sliding vs. sediment deformation beneath the glaciers, the styles (ductile vs. brittle) and pervasiveness (depth) of deformation, and whether these vary in space and time. Some important conclusions are i) the classic two tier deformation till (upper ductile;lower brittle) is relatively uncommon in Iceland, despite its documentation in the literature at a few glaciers; ii) the relative importance of sliding and deformation varies throughout the glacier surge cycle, presumably in response to variations in subglacial water pressure; iii) the relative importance of ductile and brittle deformation often reflects the particle size characteristics of the sediments with courser material showing more evidence of brittle deformation.

GLACIER HAZARDS

Sediment/landform associations at hazardous glaciers in Nepal and Peru
M.J. Hambrey, R.M. Lucas, B. Hubbard, N.F. Glasser, D.J. Quincey, S. Clemmens (UWA), J.M. Reynolds, S.D. Richardson (RGSL), A. Luckman (UWS), M. Zapata, (INRENA), S.R. Pant (UTrib)
In a collaborative project with Reynolds Geo-Sciences Ltd, a combination of ground investigations involving glacial sediment/landform associations, and remote sensing techniques and aerial photography to map landforms, is being used to document the style of glacier recession for several glaciers in the Cordillera Blanca, Peru, and the Khumbu Himal in Nepal. Of particular concern from the hazard point of view is the growth of lakes behind moraine ramparts that are commonly over 100 m high and susceptible to failure. Study of the mode of debris entrainment in the glaciers and the subsequent release of sediment from them is providing insight to the structure and stability of moraine dams. Geophysical investigations (Electrical Resistivity Tomography and Ground Penetrating Radar) have also been undertaken to provide information about the internal composition and structure of large terminal moraines and debris-covered stagnating marginal ice bodies. These studies have also provided

opportunities for groundtruthing the remote sensing studies described elsewhere by Reynolds and others.

Objective hazard assessment of Himalayan and Andean glaciers and glacial lakes

J.M. Reynolds (RGSL)

The recession of glaciers in the Himalayas and Andes has led to the formation of many pro- and supra-glacial lakes. Mechanical failure of moraine dams has resulted in catastrophic glacial lake outburst floods (GLOFs) that have caused major damage downstream and loss of life. Assessment of the perceived 'danger' of existing lakes has often been emotive and subjective, resulting in panic within some local communities. An objective of the research has been the development of a semi-quantitative objective scoring system that relates glacial lake threshold parameters and trigger potential indices to obtain a unique GLOF Hazard score. This multi-criteria analysis (MCA) approach includes of a number of measurable parameters that can be used to gauge both the existing hazard and how the hazard may be reduced by the inclusion of man-made intervention measures or how it might increase with time through lack of intervention but in response to climate change. Work is ongoing to test the relationships between the various criteria in order to improve the sensitivity of the MCA method and refine its use in the management of glacial hazards.

Assessment and management of hazards associated with melting permafrost and glacial lakes in high-altitude mines

J.M. Reynolds (RGSL)

Economic development of high-altitude mines for precious metals is increasingly encountering a growing range of problems associated with thawing permafrost, enhanced rock glacier creep and the development of glacial lakes. Open pits are being developed by excavating into and through rock glaciers, areas of permafrost and ice glaciers. Access haul roads can be affected by the progressive creep of frozen material, open excavations impacted by collapsing pit walls dug into rock glaciers, and mine workings inundated by the catastrophic release of en-glacial water through blasting on ice glaciers are some of the problems being encountered. The mining community is increasingly becoming aware of the difficult interaction between mining operations and the frozen (but increasingly thawing) local environment encountered at high altitude. RGSL has been involved in the assessment of hazards associated with mining copper ore through rock and ice glaciers in the Chilean Andes and with mining gold near potentially hazardous glacial lakes in Kyrgyzstan. Methods to provide regional assessments of potential glacial hazards that can impact on high-altitude mines are being considered for parts of South America.

ABBREVIATIONS

BAS: British Antarctic Survey, Cambridge
BGS: British Geological Survey
CAREE: Cold & Arid Regions Environment & Engineering Institute, China
CECS: Centro de Estudios Científicos, Valdivia, Chile
ETH: Eidgenössische Technische Hochschule Zürich
INRENA: National Institute of Natural Resources, Peru
NPI: Norwegian Polar Institute
PMil: Polytechnic of Milan
PRIC: Polar Research Institute of China
RGSL: Reynolds Geo-Sciences Ltd, Mold
RHUL: Royal Holloway, University of London
SAMS: Scottish Association for Marine Science, Oban
SOC: National Oceanography Centre, Southampton
StO: St Olaf's College, USA
UAbdn: University of Aberdeen
UBris: Bristol University
UCam: University of Cambridge
UCan: University of Canterbury, New Zealand
UCanb: University of Canberra, Australia
UCH : Universidad de Chile, Santiago, Chile
UCop: University of Copenhagen
UDun : University of Dundee
UDurh: University of Durham
UEdin: University of Edinburgh
UExe: University of Exeter
UHull: University of Hull
UInns: University of Innsbruck, Austria
UKeele: Keele University
ULeeds: University of Leeds
ULei: University of Leipzig, Germany
ULJM: Liverpool John Moores University
ULough: Loughborough University
ULund: University of Lund, Sweden
UMass: Massey University, New Zealand
UMil: University of Milan, Italy
UNE: University of New England, Australia
UNeb: University of Nebraska, USA
UNew: University of Newcastle upon Tyne
UNN: University of Northumbria
UOS: Ohio State University, USA
UOxB: Oxford Brookes University
USav: University of Savoie, France
USheff: University of Sheffield
USto: University of Stockholm, Sweden
UTas: University of Tasmania, Australia
UTrib: Tribhuvan University, Nepal
UWA: University of Wales, Aberystwyth
UWat: University of Waterloo, Canada
UWell: Victoria University of Wellington, New Zealand
UWS: University of Wales, Swansea

Bryn Hubbard
4 May 2006

International Glaciological Society

JOURNAL OF GLACIOLOGY

Papers accepted for publication between 1 April 2006 and 30 September 2006. The papers are listed in alphabetical order by first author.

L.W. Morland and R. Staroszczyk
Steady radial ice sheet flow with fabric evolution

Larissa Nazarenko, Nickolai Tausnev and James Hansen
Sea ice and North Atlantic climate response to CO_2-induced warming and cooling conditions

Lindsey Nicholson and Douglas I. Benn
Calculating ablation beneath a debris layer from meteorological data

Rachel Obbard, Ian Barker and Katherine Sieg
Using electron backscatter diffraction patterns to understand fabric formation in polar ice sheets

Sergey V. Popov and Valery N. Masolov
Forty-seven new subglacial lakes in the 0'–110' sector of East Antarctica

D.M. Rippin, J.L. Bamber, M.J. Siegert, D.G. Vaughan and H.F.J. Corr
Basal conditions beneath the enhanced flow tributaries of Slessor Glacier, East Antarctica

Aurel Schwerzmann, Martin Funk and Heinz Blatter
Instruments and Methods: Borehole logging with an eight arm caliper-inclinometer probe

M.K. Spencer, R.B. Alley and J.J. Fitzpatrick
Developing a bubble number-density paleoclimatic indicator for glacier ice

Joseph S. Walder, Dennis C. Trabant, Michelle Cunico, Andrew G. Fountain, Suzanne P. Anderson, Robert S. Anderson and Andrew Malm
Local response of a glacier to annual filling and drainage of an ice-marginal lake

ANNALS OF GLACIOLOGY, VOLUME 44

Since the publication of ICE 139, the following papers from the International Symposium on Sea Ice held in Dunedin, New Zealand, 5–9 December 2005 have been accepted for publication in Annals of Glaciology *Vol. 44, edited by Patricia J. Langhorne and Vernon A. Squire*

Annette F.M. Foster, Mark A.J. Curran, Barbara T. Smith, Tas D. van Ommen and Vin I. Morgan
Covariation of sea ice and methanesulphonic acid in Wilhelm II Land, East Antarctica

W. D. Hibler III, A. Roberts, P. Heil, A. Y. Proshutinsky, H. L. Simmons and J. Lovick
Modeling M2 tidal variability in Arctic sea-ice drift and deformation

Christophe Kinnard, Christian M. Zdanowicz, David A. Fisher and Cameron Wake
Calibration of an ice-core glaciochemical (sea salt) record with sea ice variability in the Canadian Arctic

Takeshi Tamura, Kay I. Ohshima, Hiroyuki Enomoto, Kazutaka Tateyama, Atsuhiro Muto, Shuki Ushio and Robert A. Massom
Estimation of thin sea-ice thickness from NOAA AVHRR data in a polynya off the Wilkes Land coast, East Antarctica

Kazutaka Tateyama, Kunio Shirasawa, Shotaro Uto, Hiroyuki Enomoto, Toshiyuki Kawamura and Takenobu Toyota
Standardization of electromagnetic-induction measurements of sea-ice thickness in polar and sub-polar seas

Notes from the production team

Faster publication times
We are now publishing papers in PDF form on the IGS website as soon as they have been checked by the authors, proofread and corrected. This great leap forward came into effect from *Journal of Glaciology* Volume 52, Issue 178 (http://www.igsoc.org/journal/52/178/) and *Annals of Glaciology* 43 (http://www.igsoc.org/annals/43/published.html).

Figures submitted
You have responded well to our pleas on how to submit figures. This has helped us tremendously in reducing production time spent getting the figures ready for final publication. It has also enabled us to improve and maintain the final quality of the figures. Thank you. For those who have not yet adapted to our recommendations we would like to remind you that with improved production speeds, time spent on preparing the figures can make the difference whether the paper will be published in the next issue or the one after. So if speed is of the essence, please submit the figures according to our instructions. See 'Instructions for authors' for details: http://www.igsoc.org/production/FigsandEqn_instructions.pdf

Hello TeX authors out there!
We welcome final papers in TeX, and we would be grateful if you could use our IGS class file to write your paper. A copy and full details of how to use this can be found on our website: http://www.igsoc.org/

Corrections and errata

In *ICE* 137–138 we unfortunately omitted the name of the person who wrote the very interesting account of the IGS symposium in Lanzhou, China, 5–9 September 2005. His name is Horst Machguth from the Glaciology & Geomorphodynamics Group in the Department of Geography at the University of Zürich. This recent tradition of publishing a 'social' report from the IGS symposia has proved popular in *ICE* so the contributions of these roving correspondents are very valuable to us. It is important that they are credited properly.

In the *Journal of Glaciology,* **52**(177), 318–320, we published correspondence from Skvarca and Naruse entitled 'Overview of the ice-dam formation and collapse of Glaciar Perito Moreno, southern Patagonia, in 2003/04',. Unfortunately, Figure 1 was printed too dark for a reader to distinguish important details and Figures 4 and 5 contained erroneous black bars. Since there were errors on two out of the three pages of this short article, we have decided to republish the whole correspondence in issue 178 as an erratum.

INTERNATIONAL GLACIOLOGICAL SOCIETY

International Symposium on Snow Science

Moscow, Russia
3–7 September 2007

CO-SPONSORED BY:

Institute of Geography, Russian Academy of Sciences
Moscow State University
'Antistikhiya' Center of the Ministry of the Russian Federation
for Civil Defence, Emergencies and Elimination of Consequences of Natural Disasters
The Swiss Federal Institute for Snow and Avalanche Research

FIRST CIRCULAR

April 2006

Registered Charity

The International Glaciological Society will hold an International Symposium on Snow Science in 2007. The symposium will be held in Moscow, Russia, with registration on 2 September and sessions from 3–7 September 2007.

THEME

Snow is a complex and short-lived sediment with many effects on its surroundings. The emphasis will be on the internal processes and external interactions of snow with natural and man-made systems.

The goal of this Symposium is to provide a comprehensive overview of on-going research in the field of snow science. The main emphasis will be on the interaction of snow with natural and man-made systems. A better understanding of the interfacial properties of snow is required to define exchange mechanisms that drive chemical, ecological and hydrological processes in many regions of the world. The snow interface also determines how roads, buildings, ski-pistes and other man-made systems are designed and used. How atmospheric interactions contribute to the formation of snow avalanches and other cold-region natural hazards will be a further conference topic, as will be snow in motion and modelling snow under static and dynamic loadings, since these are key issues in engineering problems. We hope to bring together researchers working on the physical properties of snow with scientists working on ecological, hydrological and engineering problems in which the understanding snow processes plays a key role. Snow will be examined at all scales - from the microscale of snow structure to the megascale of remote sensing. The conference theme is to pay homage to the International Polar Year 2007–2008.

TOPICS

The suggested topics include:

1. Observing and modeling of snow at different scales:
   a) Snow cover distribution and variability
   b) Snow and its stratigraphy
   c) Snow microstructure
   d) Scaling issues
2. Snow as a component of climate and of landscape:
   a) Snow-atmosphere interactions
   b) Snow-ground interaction
   c) Perennial snow cover in the Arctic, Antarctic and mountains
3. Snow physics and chemistry
   a) Snow metamorphism- heat and mass transfer
   b) Snow chemistry and metamorphism
   c) Heat and mass transfer in snow
   d) Physical and mechanical properties of snows
4. Snow in motion
   a) Snow avalanches
   b) Snow drift
   c) Snow tribology
5. Snow engineering
   a) Avalanche engineering and warning
   b) Architecture and constructions in snowy regions
6. Snow and biosphere
   a) Vegetation
   b) Wildlife

SESSIONS

Oral presentations will be held on four full days and one half-day. There will be ample opportunity for poster displays. Poster presentations will be grouped in sessions and given time for discusssion.

PUBLICATION

Selected papers from the symposium will be published by the Society in the Annals of Glaciology. All papers (including those based on posters) will be refereed and edited according to the Society's regular standards before being accepted for publication.

ACCOMMODATION

Details will be given in the Second Circular.

FURTHER INFORMATION
If you wish to attend the symposium please return the attached form as soon as possible. The Second Circular will give further information about accommodation, the general programme, and preparation of abstracts and final papers as well as a registration form. Copies of the Second Circular will be sent to those who return the attached reply form. Members of the International Glaciological Society will automatically receive one.

SYMPOSIUM ORGANIZATION
Magnús Már Magnússon (International Glaciological Society)

SCIENCE STEERING AND EDITORIAL COMMITTEE
M. Schneebeli and J.B. Johnson (Chief Editors)
E. Adams, C. Ancey, P. Bartelt, K. Birkland, A. Bozhinskii, R. Essery, M. Eglit, P. Gauer, A.Glazovskii, F. Nicot, M. Parlange, P. Satyawali, A. Sato, S. Sokratov, V. Stöckli.

LOCAL ARRANGEMENTS COMMITTEE
V.M. Kotlyakov (chairman),
S.A. Sokratov (co-chairman),
A.N. Bozhinskii, V.R. Bolov, A.F. Glazovskii, M.Yu. Gnedovskaya, S.A. Dobrolyubov, N.S. Kasimov, N.I. Osokin, P.A. Chernous, A.L. Shnyparkov

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INTERNATIONAL SYMPOSIUM ON SNOW SCIENCE
Moscow, Russia, 3–7 September 2007

Family Name: _____

First Name(s): _____

Address: _____

_____

_____

Tel: _____ Fax: _____

E-mail: _____

I hope to participate in the Symposium in September 2007 ☐

I expect to submit an abstract ☐

My abstract will be most closely related to the following topic(s):

_____

_____

I am interested in an accompanying person's programme ☐

PLEASE RETURN AS SOON AS POSSIBLE TO:
Secretary General, International Glaciological Society,
Scott Polar Research Institute, Lensfield Road, Cambridge, CB2 1ER, UK
Tel: +44 (0)1223 355 974 Fax: +44 (0)1223 354 931
E-mail: igsoc@igsoc.org Web: http://www.igsoc.org

News

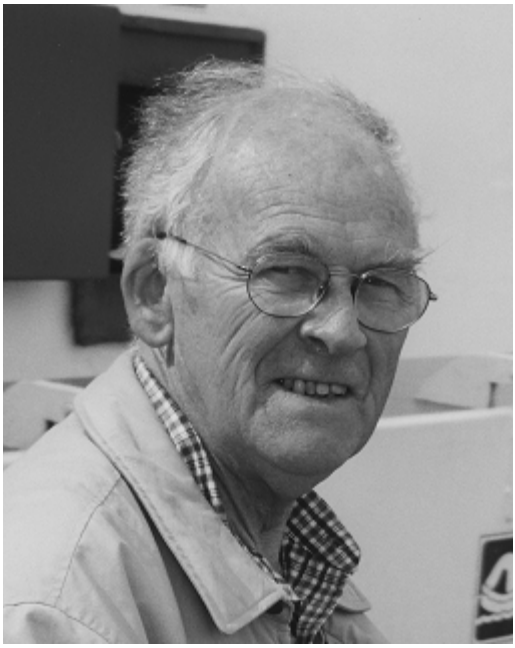
John Arnfield Heap (1932–2006)

John Heap, who died on 8 March 2006, was Honorary Treasurer of the International Glaciological Society for 32 years, a distinguished and respected polar diplomat and Director of the Scott Polar Research Institute.

For most of his career John Heap operated in the realm of international polar diplomacy. His contribution will be identified with the establishment of key regulatory frameworks under the Antarctic Treaty intended to protect the Antarctic environment from injudicious exploitation and safeguarding scientific research. His stamina, shrewd negotiating skills and above all personal knowledge of the Antarctic were contributory to the agreement in 1982 of the innovative and ecologically-based Convention on the Conservation of Antarctic Marine Living Resources. While Heap led the British delegation the tentacles of his influence spread much wider. He was one of the few permanent polar diplomats, which ensured consistency of policy, and, importantly, had undertaken scientific research in the Southern Ocean. Combined with an engaging and infectious personality these qualities enabled him to ease the CCAMLR deliberations towards pragmatic and sustainable measures.

These same attributes were in further demand later in the 1980s when the prospect of exploiting the putative mineral wealth of Antarctica demanded Treaty attention. At the outset Heap was clear of the need to create a stiff, compliance-driven regulatory regime. Intense lobbying and direct action by campaigning groups such as Greenpeace and the Southern Ocean Coalition raised the temperature of negotiations. Such was Heap's political judgements that he argued the proposed enabling measures be operated in reverse – turning them into a set of protectionist agreements, the most crucial of which was a 50-year moratorium on exploration.

Heap's ability to play an influential role in these often tense deliberations, exposed to the world's media, came from his close working relationship with internationally recognised scientific experts, mostly at the British Antarctic Survey, whose advice he sought and frequently deployed at Treaty Meetings.



John Arnfield Heap was born on 5 February 1932 in Manchester, UK, and was educated at Leighton Park School in Reading, a Quaker establishment that gave him a strong sense of values of equity, tolerance and respect for the individual. It engendered in him a consuming and profoundly good-humoured interest in other people.

He went to Edinburgh University to study Geography in 1951. Already stimulated by reading about the polar regions, he organised and led an expedition to the then still remote Lyngen Peninsula of Arctic Norway. Despite his youth and inexperience he was able to enthuse two university lecturers, a research student, two final year and four other students to accompany him. The eight week expedition carried out glaciological, geomorphological and biological research. It was a seminal time for Heap; he endured exhilarating but demanding climbing on the Jekkevare ice cap, was harassed by inquisitive bulls, dug 5 m snow pits and endured wind and rainy conditions. Characteristic of Heap his report of the expedition was down to earth, 'It is clear..that our..work was too ambitious …. We probably suffered from having a glaciological programme too wide in its scope.' Such comments will possess a familiar ring even to experienced field scientists! Nevertheless the expedition produced several publications and its overall cost, including sea and land transporation, was £875 ($1160).

Upon graduating, Heap went to Cambridge, to Clare College and the Scott Polar Research Institute (contact had been made in organising his Norwegian venture) as a Falkland Islands Dependencies research student examining sea ice in the Weddell Sea. Investigations were problematic then, only being undertaken by ship, in limited areas, for short time periods which seriously subsampled seasonal changes let alone inter-annual variations. The Weddell Sea offered prospects of combining historical and contemporary data from whaling vessels with Heap's own observations made on two summer programmes in 1955–56 on the RRS *John Biscoe* and 1956-57 on the MV *Theron*. The sea ice atlas resulting from his PhD was published in 1962 – a 'worstseller', Heap declared, having shifted 11 copies!

Following marriage in 1961, Heap and his wife Peggy moved to the USA, to Ann Arbor to work at the University of Michigan, where Jim Zumberge was energetically leading a large glaciology group. Heap became involved in two projects – first, he was closely linked to Zumberge's own work in Antarctica, mainly at Little America V on the Ross Ice Shelf. Little was known at this time of the characteristics and behaviour of large ice shelves. Heap went to Antarctica for the 1962–63 season, where he joined a University of Michigan traverse led by W. Hoffman that re-measured stakes set out along the 400 mile (750 km) Dawson Trail between Ross Island and Roosevelt Island. He was working with fellow glaciologists W.J. (Bill) Campbell and Art Rundle. Heap and Rundle published their work, combining earlier seasons' data (surveyed by Charles Swithinbank), a total of some 2000 stake measurements, deducing an annual accumulation on the northern part of the Ross Ice Shelf between 1960 and 1962 of 14.4 g cm^{-2}, noting that this could be lower than the climatic average by as much as 10–30%. Their value is close to the presently accepted figure.

The second project was with the Great Lakes Research Division of the University to study of the growth of ice on Lake Michigan (funded by NSF and the RAND Corporation), a natural extension of his sea ice work. In these pre-satellite remote sensing days the collection of observations involved a variety of platforms – ferries and other vessels, aircraft and shoreline observations. He organised a group of volunteers to make observations around the shores of the lake in the 1962–63 winter, an airborne campaign and observations by ship.

Heap returned to the UK in 1964, enticed by his earlier mentor, Brian Birley Roberts, to a position at the Foreign and Commonwealth Office. This transition led Heap away from glaciology for good but into the intriguing political world of the recently established Antarctic Treaty, of which Roberts was one of the primary architects. His new boss, didactic, challenging and irascible, with exacting standards, had spotted Heap during his sojourn at the SPRI as a research student and enthused him with his vision that the scientific value of Antarctica and its vulnerable natural systems should be buffered from international conflicts and machinations of the cold war. Heap took over as Head of the FCO Polar Regions section when Roberts retired in 1975. Besides his central concerns with Antarctica, the growing interest in the Arctic led Heap to establish a position to advise on the UK's northern interests and took a keen interest himself, attending conferences and seminars.

He sustained his early interest in glaciology through the Society. He had been encouraged to take on the role of Honorary Treasurer by his close SPRI associate Hilda Richardson and was a regular attender at Annual General Meetings. His services to the Society were recognised by the award of the Richardson Medal in 1999.

On retirement from the FCO, Heap was made CMG and returned to academia as director of the SPRI – coming full circle – a post he held until 1997. To meet the growing international demand for polar information and expertise, Heap worked to secure additional finances from the University of Cambridge to expand the Institute. As none were forthcoming he set to work to raise them himself. Through a successful campaign the magnificent west wing and its 'Shackleton Memorial Library' was constructed, which has enabled the SPRI to remain at the forefront of polar research.

Heap also fostered the need to preserve the heritage of Antarctica through conservation of the huts and artefacts of successive expeditions. He became Chairman of the UK Antarctic Heritage Trust, whose Patron, HRH The Princess Anne, took a keen interest and visited the Antarctic courtesy of the Trust's sister organisation in New Zealand. He was also Chairman of the Trans-Antarctic Association.

Heap maintained an active and intelligent interest in all matters polar to the very end, keenly fostering a younger cadre of polar scientists and diplomats in whose progress he was always enthused. Latterly he served as a Liberal Democrat District Councillor for South Cambridgeshire.

He is survived by his wife Peggy and children Tom, Sarah and Alice.

David J. Drewry

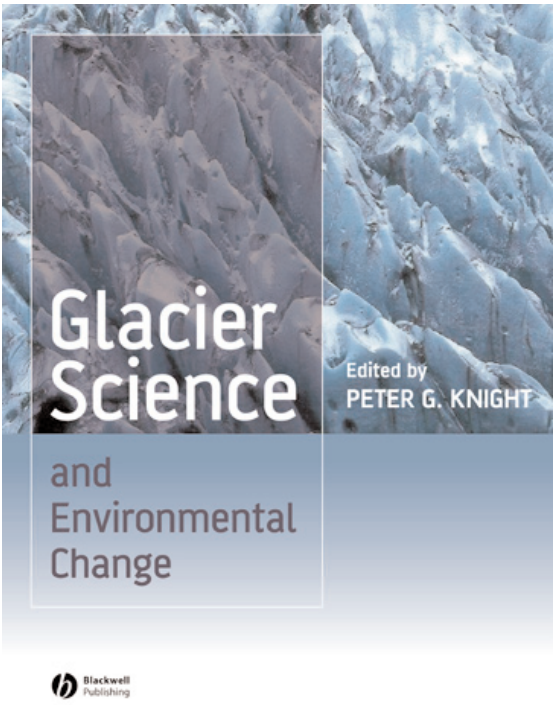
IGS members book offer

Blackwell Publishing is offering IGS members a special discount on the following books:

GLACIER SCIENCE AND ENVIRONMENTAL CHANGE

Edited by Peter Knight, Keele University
Written by the world's foremost authorities in the subject, this book is an interdisciplinary reference work examining contemporary issues in glaciology.

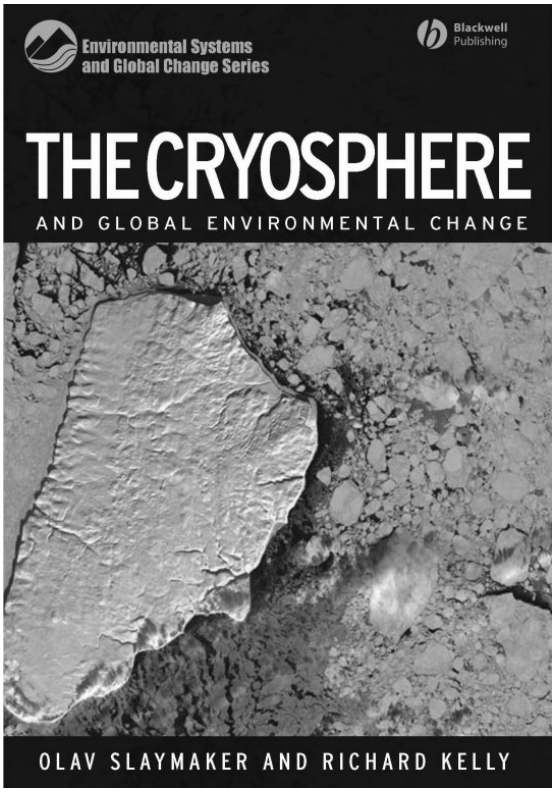
HB Aug 06 544 pages 1-405-10018-4
Normal price: £125.00 / US$249.95
Special offer price: £80.00 / US$160.00



THE CRYOSPHERE AND GLOBAL ENVIRONMENTAL CHANGE

Olav Slaymaker, University of British Columbia and Richard Kelly, University of Waterloo
The first textbook to consider all aspects of the cryosphere system in the context of global environmental change driven by human activity and climate.

PB Dec 06 280 pages 1-405-12976-X
Normal Price: £27.50 / US$64.95 Special offer price: £22.00 / US$52.00



For more information about the books please visit www.blackwellpublishing.com

To take advantage of this offer please email your request to Melanie Attridge at Melanie.Attridge@oxon.blackwellpublishing.com quoting reference IGS Offer

Materialy Glyatsiologicheskih Issledovaniy: Russian glaciological journal publishes 100th issue

Issue No. 100 of one of the oldest polar and glaciological journals in the world, *Materialy Glyatsiologicheskih Issledovaniy (MGI, Data on Glaciological Studies),* has just been released. This is a regular journal of the Soviet and Russian glaciologists. It first appeared 47 years ago, in 1961, at a time when expedient publication and discussion of the science results obtained by the Russian IGY expeditions of 1957/59 was needed. The results initially covered scientific publications dealing with Antarctica, the Arctic regions of Franz Josef Land, Novaya Zemlya, and the Polar Urals, and many mountain areas of Arctic and Pacific Siberia. *MGI* has now published articles of global interest, ranging from snow and ice physics, snow and ice hydrology and climatology, glacier flow, snow/ice avalanches, and other related subjects, to ideas on the marine ice sheets on the continental shelves of the Arctic and Antarctica.

MGI provided an instrument for publishing glaciological results of the National Academies of 15 countries making up the former Soviet Union, as well as many universities and special research centers. This required significant editorial and technical work, all handled by the Department of Glaciology of the Geography Institute of the Academy of Sciences of the USSR (now Russia). Editor in Chief all this time – around half a century – was, and still is, one person – Professor V. M. Kotlyakov.

To judge the size of the project one can note that the first 100 issues included 24 000 printed pages and more than 1000 figures and tables. All the papers now include English summaries and figure captions as well as Russian, and some are printed in English. The content of *MGI*, in addition to scientific papers, includes short communications, extended information, letters to the editor and other discussion, Russian language bibliographies, and papers given at national glaciological conferences.

MGI now is a connecting link between glaciologists and polar explorers of the 15 independent countries of the former Soviet Union or who now work in totally different venues. *MGI* is also useful reading for Western scientists to learn of the work of their Russian and FSU colleagues. Let us wish this journal further success in its work of disseminating scientific results and building science communities!

Mark F. Meier
Mark B. Dyurgerov
INSTAAR
University of Colorado at Boulder

Books received

Uli M. Huber, Harald K.M. Bugman and Mel A. Reasoner, eds. 2005. *Global Change and Mountain regions – an overview of current knowledge*, Berlin and Heidelberg, Springer Verlag. 650 pp. (ISBN-10: 1-4020-3507-1 (paperback), ISBN-10: 1-4020-3506-3, (hardback), US$ 34.95.)

Future meetings (of other organizations)

Workshop: **Glaciers in watershed and global hydrology**
Obergurgl, Austria, 27-31 August 2007
Sponsored by: International Commission on Snow and Ice Hydrology (ICSIH)
IUGG Commission for the Cryospheric Sciences (CCS)

The research/gauging station near Vernagtferner, destination of the post-workshop excursion

Conveners
Regine Hock, Stockholm
(regine.hock@natgeo.su.se)
Tomas Johannesson, Reykjavik
(tj@vedur.is)
Gwenn Flowers, Vancouver
(gflowers@sfu.ca)
Georg Kaser, Innsbruck
(Georg.Kaser@uibk.ac.at)

Homepage
http://www.ees.su.se/Obergurgl2007

Content
Glaciers significantly modify streamflow both in quantity and timing, even with low percentages of catchment ice cover. This workshop aims to bridge the gap between glaciologists and hydrologist and will focus on the

1. modelling of glaciers in runoff-models (How can glaciers be represented in runoff models? Which type of glacier melt and routing routines are necessary to capture the specific characteristics of glacial discharge? How can glaciers be included in global hydrological models?)
2. effects of climate change on glacier runoff Freesand the hydrology of glacierized catchments (How will annual, seasonal and diurnal runoff characteristics change as glaciers continue to retreat? How does the response vary in different climate regions?).
3. information content of glaciers for hydrological modelling (What kind of information can be extracted from glaciers that can aid hydrological modelling? How can glacier measurements help to constrain model parameters or provide model input?)

The workshop will address all spatial scales from small-scale catchment modelling to regional and global hydrological modelling. Contributions on any of the above topics are solicited.

Organization
The workshop will be held during 3 days including an intermediate half-day excursion. A 1–2 day excursion to Vernagtferner and the nearby research/gauging station will be offered. Publication of selected contributions in an international journal is envisaged. There is no registration fee. Abstract deadline is March 2007.

Glaciological diary

** IGS sponsored * IGS co-sponsored

2006

30 January–3 February
International Arctic Science Committee, IASC, Working Group on Arctic Glaciology
Workshop on the mass budget of Arctic glaciers and the first planning meeting of GLACIODYN (IPY)
Universitätszentrum Obergurgl, Austria
Contact Carleen Tijm-Reijmer
E–mail: c.h.tijm-reijmer@phys.uu.nl

6–10 February
GLIMS workshop
Twizel, New Zealand
Contact: Shulamit Gordon, s.gordon@antarcticanz.govt.nz AND Jeff Kargel kargel@hwr.arizona.edu

16–18 March
The 36th Annual Arctic Workshop
INSTAAR, University of Colorado Boulder, Colorado, USA
See meeting web site
E–mail: ArcticWS@colorado.edu

2–7 April 2006
European Geosciences Union meeting, cryospheric sessions
Vienna, Austria
See: http://instaar.colorado.edu/meetings/AW2006

2–7 April
European Geosciences Union meeting, cryospheric sessions
Vienna, Austria
See: http://www.cosis.net/members/meetings/programme/view.php?p_id=184 and http://meetings.copernicus.org/egu2006/

8–12 May
2nd International Workshop on Ice Caves (IWIC-II) in Slovakia
Demänovská dolina, Slovak Republic
See http://users.unimi.it/icecaves/IWIC-II

10 May
Commemorative Symposium on the EGIG project initiated by the 1956 Greenland Expedition, 'Expedition Glaciologique Internationale au Grönland'
Eidgenössische Technische Hochschule (ETH), Zurich
Contact: Prof. Dr Heinz Blatter, heinz.blatter@env.ethz.ch

14–17 May
Open Glaciology Session, Canadian Geophysical Union Annual Meeting
Banf, Alberta, Canada
Web: http://www.acs.ucalgary.ca/%7Ecguconf/
Conveners: Gwenn Flowers, gflowers@sfu.ca and Sarah Boon, boon@unbc.ca

15–16 May
Antarctic Peninsula Climate Variability: Observations, Models, and Plans for IPY Research
Hosted by the National Snow and Ice Data Center at the University of Colorado, Boulder, USA.
Web: http://nsidc.org/events/IPY_APCV
Contact: nsidc@nsidc.colorado.edu

5–9 June
Glacial Sediment Micro-Morphology Workshop
Hamilton College, Department of Geosciences, Clinto, New York, USA
Contact Danelle Parker for registration details (dparker@hamilton.edu) by 1 April 2006

7–9 June
The 63rd Eastern Snow Conference (ESC)
University of Delaware in Newark, DE, USA
See: http://www.easternsnow.org
Contact: Andrew Klein, klein@geog.tamu.edu

19–23 June
****International Symposium on Earth and Planetary Ice–Volcano Interactions.**
Reykjavík, Iceland
Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, UK
Web: http://www.igsoc.org/symposia

28–30 June
Geomorphology and Earth System Science
The British Geomorphological Research Group 2006 annual conference
Loughborough University, UK
See: http://www.lboro.ac.uk/departments/gy/gess/index.htm

5–7 July
***International workshop on Antarctic sea ice thickness**
Hobart, Australia. In conjunction with the SCAR Open Science Conference
Convenors: Dr Tony Worby (Australian Antarctic Division), email: A.Worby@utas.edu.au

Professor Steve Ackley (Clarkson University, USA), email: sackley@pol.net
See: http://www.aspect.aq/workshop2006.html

10–14 July
The 3rd Annual Meeting of the Asia Oceania Geosciences Society (AOGS 2006)
'Open Session on Glacier and Ice Sheet Research (IWG04)'
Singapore
see http://www.asiaoceania-conference.org/ > View Session Listing > Interdisciplinary Working Group (IWG) for more information about the session

12–14 July
Second SCAR (Scientific Committee on Antarctic Research) Open Science Conference on 'Antarctica in the Earth System'
Hotel Grand Chancellor, Hobart, Australia
see
http://www.scarcomnap2006.org/scarosc.php

23–28 July
International Conference on the Physics and Chemistry of Ice (PCI-2006)
Bremerhaven, Germany
Open Session on Glacier and Ice Sheet Research
see http://www.pcice2006.de

7–9 August
Asian Permafrost Conference
Lanzhou, China
see http://www.casnw.net/permafrost

21–25 August
*__International Symposium on Cryospheric Indicators of Global Climate Change__
Cambridge, UK
A joint CliC/IGS/ICSI Symposium
Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, UK
Web: http://www.igsoc.org/symposia

4–8 September
*__III International Symposium on Avalanches and Related subjects__
The contribution of theory and practice to avalanche safety
Kirovsk, Murmansk region, Russia Contact: Pavel Chernous at PChernous@apatit.com
Web: http://www.cas.kirovsk.ru/

13–14 September
*__IGS British Branch Annual Meeting 2006__
Keele University, UK
Contact the organisers at igs06@esci.keele.ac.uk
Web: http:// www.esci.keele.ac.uk/igs2006

14–22 September
9th International Symposium on High Mountain Remote Sensing Cartography (HMRSC-IX)
University of Graz, Austria Contact: Wolfgang Sulzer, wolfgang.sulzer@uni-graz.at
See: http://www.kfunigraz.ac.at/geowww/hmrsc/hmrsc_9/

15–16 September
Northwest Glaciology Meeting, 2006
Fairbanks, Alaska, USA
Contact: Martin Truffer at truffer@gi.alaska.edu
Web:http://www.northwestglaciology.org/

17–23 September
* **6th International Workshop on Ice Drilling Technology**
US Fish and Wildlife Service National Conservation Training Center, Shepherdstown, West Virginia, USA
Convenors: Joan Fitzpatrick (US Geological Survey) and Frank Wilhelms (Alfred-Wegener-Institut für Polar- und Meeresforschung, Bremerhaven)
Web: http://www.idt-workshop.unh.edu/index2.html

1–6 October
International Snow Science Workshop, ISSW 2006
Tellurite, Colorado, USA
See: http://www.ISSW.net/

2–6 October
***The Fourth International Conference on Mars Polar Science and Exploration**
Davos, Switzerland
The purpose of the conference is to assess the current state of Mars polar and climate research; discuss what might be learned from investigations of terrestrial analogs and the data returned from current and future missions; and identify the potential science objectives, platform options, and instrument suites for robotic missions to the Martian poles within the next decade
Conveners: Steve Clifford, Lunar and Planetary Institute; Walter Ammann, Swiss Federal Institute for Snow and Avalanche Research; Kathryn Fishbaugh, International Space Science Institute; David Fisher, Geological Survey of Canada; James Head III, Brown University
See:
http://www.lpi.usra.edu/meetings/polar2006

5–6 October 2006

Alpine 'Snow' Workshop
Munich, Germany
The workshop is organized by the Section Geography of the Faculty of Geosciences, University of Munich, and supported by the Berchtesgaden National Park administration (both Germany). The aim of the meeting is to bring together the snow research community for the exchange of ideas, experiences and visions. Meeting language is English
See: http://www.alpinesnowworkshop.org/

9–15 October

Water, ecosystems and sustainable development in arid and semi-arid zones
Urumqi, China
Organized by Ecole Pratique des Hautes Etudes (EPHE, France), Xinjiang University (China) and University of Tehran Contact: +33 (0)1.53.63.61.63 (Béatrice ARGANT) Watarid@ephe.sorbonne.fr
See: http://www.ephe.sorbonne.fr/watarid.htm

26–28 October 2006

***IGS Nordic Branch Annual Meeting 2006**
Polar Environmental Center, Tromsø, Norway. Contact Jack Kohler at jack.kohler@npolar.no
See: http://thor.npolar.no:8080/igs

9–12 November 2006

Open Science Conference in Beijing
Organized by The Earth System Science Partnership (ESSP)
Sessions of interest:
'Polar processes in global environmental systems', chaired by Dave Carlson, ICSU/WMO IPY and Vicky Lytle, WCRP CLIC
'Arctic environmental change: a cross-disciplinary, pan-Arctic perspective in the context of Earth system studies', chair Peter Schlosser
'Climate research to risk management', Chair Peter Lemke
See: http://www.essp.org/ESSP2006/

2007

15–16 January

Periglacial and paraglacial processes and environments, past, present and future
Geological Society, London, UK
Joint meeting between the Geological Society of London and the Quaternary Research Association
Organisers: Dr Jasper Knight (j.knight@exeter.ac.uk) and Dr Stephan Harrison (Stephan.Harrison@exeter.ac.uk), University of Exeter, UK
See: http://www.geolsoc.org.uk/template.cfm?name=Periglacial_and_Paraglacial

15–17 January 2007

Workshop on the dynamics and mass budget of Arctic glaciers
GLACIODYN (IPY) meeting
IASC Working group on Arctic Glaciology, Pontresina, Switzerland
Convenors: J. Oerlemans (IMAU, Utrecht University; (j.oerlemans@phys.uu.nl) and C.H. Reijmer (IMAU, Utrecht University; c.reijmer@phys.uu.nl)
See:
http://www.phys.uu.nl/%7Ewwwimau/research/ice_climate/iasc_wag/activities.html

21–22 May 2007

Workshop on 'Advanced concept for radar sounder'
Cambridge, UK
Contact: David Blake, British Antarctic Survey (d.blake@bas.ac.uk)
See:
http://www.antarctica.ac.uk/Meetings/2007/ACRAS2007/

17–20 June 2007

Cryogenic resources of polar regions
Salekhard City, Polar Cycle, West Siberia
Vladimir P. Melnikov Academician, Scientific Council on Earth Cryology, Russian Academy of Sciences; Yu. V. Neyolov Governor, Yamal-Nenets Autonomous District; Jerry Brown, President, International Permafrost Association
See: http://www.ikz.ru/permafrost/

2–13 July

***Union Commission for the Cryospheric Sciences (UCCS) symposium**
24th General Assembly of the International Union of Geodesy and Geophysics, titled Earth Our Changing Planet.
Perugia, Italy.
See http://www.iugg2007perugia.it/

27–31 August

Workshop: Glaciers in watershed and global hydrology
Obergurgl, Austria
Sponsored by International Commission on Snow and Ice Hydrology (ICSIH) and Commission for the Cryospheric Sciences (CCS)
Contact: Regine Hock (regine.hock@natgeo.su.se);
Tomas Johannesson, Reykjavik (tj@vedur.is);
Gwenn Flowers, Vancouver (gflowers@sfu.ca); Georg Kaser, Innsbruck (Georg.Kaser@uibk.ac.at)
See http://www.ees.su.se/Obergurgl2007

29–31 August
Polar Dynamics: Monitoring, Understanding, and Prediction
Open science conference
Geophysical Institute, University of Bergen. Allegt 70, N-5007 Bergen, Norway
See: http://www.gfi.uib.no/conference2007/info.htm
E–mail: conference2007@gfi.uib.no

3–7 September
****International Symposium on Snow Science, Moscow, Russia**
Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, UK
Web: http://www.igsoc.org/symposia

12–15 November 2007
International Symposium on Mitigative Measures against Snow Avalanches
Egilsstadir, Iceland

2008

9–13 June
****International Symposium on Radioglaciology and its Applications, Madrid, Spain**
Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, UK
See: http://www.igsoc.org/symposia

29 June–3 July
9th International Conference on Permafrost.
Celebrating the 25th Anniversary of the formation of the International Permafrost Association
University of Alaska Fairbanks, Fairbanks, Alaska, USA
See: http://www.nicop.orgn

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ICE

Editor: M.M. Magnússon (Secretary General)

This news bulletin is issued to members of the International Glaciological Society and is published three times a year. Contributions should be sent to your National Correspondent or to the Secretary General, International Glaciological Society, Scott Polar Research Institute, Lensfield Road, Cambridge CB2 1ER, England.

Annual cost for libraries, etc., and for individuals who are not members of the Society:

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