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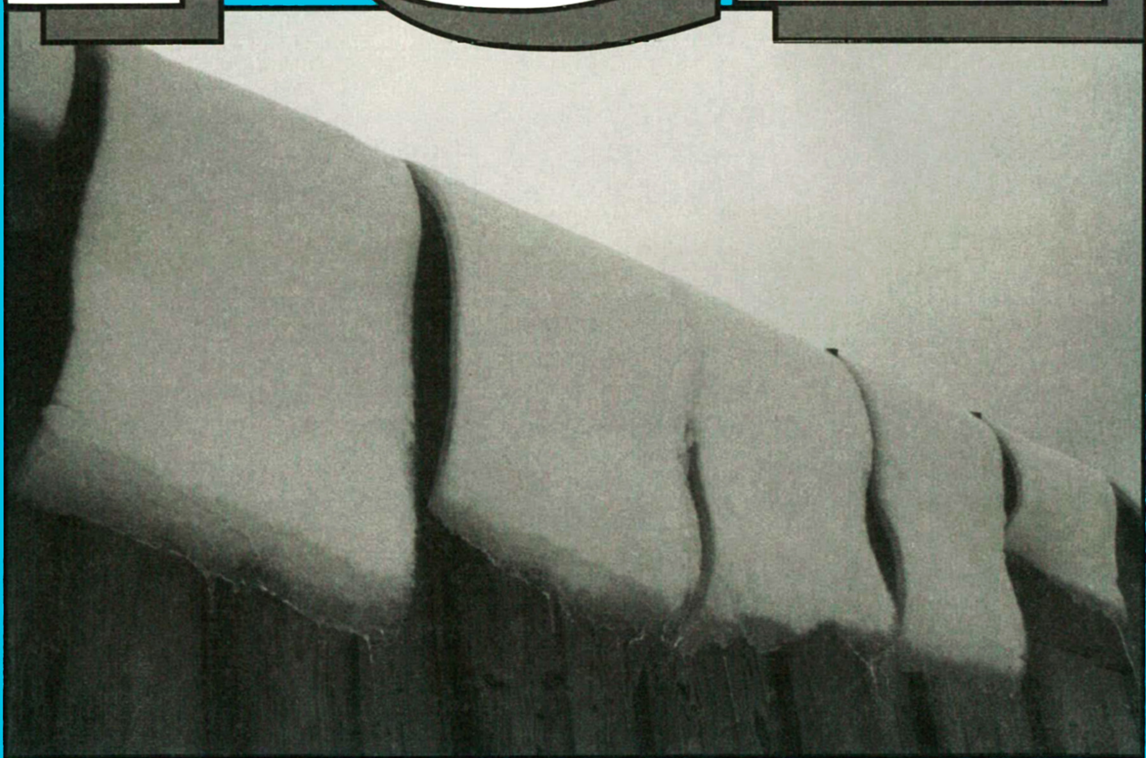

NEWS BULLETIN OF THE INTERNATIONAL GLACIOLOGICAL SOCIETY

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CONTENTS

COVER PICTURE:"Snow towels", showing the tensile strength of snow and the underlying ice layer when the creep and glide process is slow enough that internal deformation can take place. Roof of building near Rudolfshütte of the Austrian Alpine Club, Hohe Tauern, Austrian Alps, September 2001. (Photograph by Heinz Slupetzky)

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

RECENT WORK

SWITZERLAND

(For abbreviations used see page 20)

GLACIERS AND ICE SHEETS

The new Swiss glacier inventory (SGI 2000)
(F. Paul, A. Kääb, M. Maisch, T. Kellenberger, W. Haeberli, Geog/UZI)
Within the SGI 2000 the following methods have been developed: automatic glacier classification from Landsat Thematic Mapper (TM) data; GIS-based extraction of individual glaciers with a glacier basin vector layer; and computation of 3-D glacier parameters (like slope, aspect, 2:1 ELA, etc.), by fusion with a digital elevation model (DEM). These methods were applied to Landsat TM imagery from 1984–99 to derive the new SGI 2000 and obtain glacier-change trends. The accuracy of TM-derived glacier outlines is evaluated by comparison with manually digitized outlines from higher-resolution satellite data (e.g. SPOT and IRS-1C pan bands). Processing is in a fully digital work flow, including graphical output of glacier parameters and their changes. The work flow, with all programs, is provided to the Global Land Ice Measurements from Space (GLIMS) project for worldwide application.

fpaul@geo.unizh.ch

Firn-temperature and energy-balance investigations, European Alps
(S. Suter, VAW; M. Hoelzle, Geog/UZI)
A study on the spatial occurrence. the surface energy balance and the climatic evidence of cold firn in the Monte Rosa and Mont Blanc areas was concluded in 2001. An energy-balance study at Seserjoch (Monte Rosa) showed net-radiation and turbulent-heat fluxes were the main contributors to the surface energy balance. Heat fluxes due to surface melt in summer and refreezing (of meltwater at the surface or rime accretion) must be taken into account. Near-surface firn temperatures were measured in the Mont Blanc and Monte Rosa areas. The observed thermal distribution pattern of cold firn suggested a strong influence of solar radiation and turbulent heat exchange. Theoretical calculations, using a 1-D time-dependent thermomechanical firn-temperature model, including the effect of latent heat from surface melt, showed that the englacial thermal regime is extremely sensitive to the magnitude and duration of surface melt and that melt events perturb the pure surface-temperature signal considerably. Deeper borehole-temperature records from the Mont Blanc and Monte Rosa areas implied a surface-temperature increase of the order of 0.5–1°C for the last decade.

suter@vaw.baug.ethz.ch

Glacier monitoring from ASTER imagery
(A. Kääb, F. Paul, C. Huggel, Geog/UZI)
Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) imagery for observing global land ice has been available since 2000. It is the principal prior sensor for GLIMS. Its spectral and geometric properties include 3 bands in VNIR with 15 m resolution, 6 bands in SWIR with 30 m, 5 bands in TIR with 90 m, and a 15 m resolution NIR along-track stereo-band allowing for terrain-height measurements. Various algorithms have been developed for ASTER data processing. Their benefits for glacier studies have been evaluated by accuracy assessments and application studies at test sites in the European Alps, New Zealand Alps and Himalaya: ASTER-DEMs for high-mountain environments are compared to ones derived from high-resolution aerial photogrammetry. Multispectral glacier classification from ASTER data is compared to glacier mapping from other high-resolution air- and space-borne sensors. The potential of repeated ASTER imagery for ice-velocity measurements is demonstrated and evaluated using field measurements. Combination of above techniques represents a powerful tool for assessing glacier-related hazards (e.g. glacier-lake outbursts and ice avalanches).

kaeaeb@geo.unizh.ch

Glacier response to surface perturbation; Vatnajökull, Iceland
(G. Aðalgeirsdóttir, VAW; G.H. Gudmundsson, BAS; H. Björnsson, SI)
In the course of a tremendous jökulhlaup following the subglacial eruption in Vatnajökull in October 1996, a depression in the surface of the ice cap was created by ice melting from the walls of a subglacial tunnel. Initially it was about 6 km long, 800 m wide and 100 m deep. The canyon represents a significant perturbation in the geometry of the ice cap where the total ice thickness is 200–400 m. Detailed maps of surface elevation and bed topography had been made prior to this event so it was possible to study the influence of it on the local velocity and stress fields. Repeated measurements of flow velocity and elevation changes near the canyon were made over a period of about 2 years. The importance of horizontal stress gradients at the spatial scale of this canyon is demonstrated by calculating the transient evolution of an idealized surface depression using both analytical zeroth- and first-order theories, as well as the shallow-ice approximation (SIA) and a finite-element model incorporating all the terms of the momentum equations. The transient evolution of the canyon is calculated with the 2-D time-dependent finite-element

model with flow parameters that are tuned to an optimal agreement with measured flow velocities. The model reproduces observed changes in the geometry over 15 months reasonably well. Changes in both velocities and geometry are considerably better reproduced with this full system model compared to an alternative model based on the SIA.

gudfinna@vaw.baug.ethz.ch

Modelling Vatnajökull, Iceland

(G. Aðalgeirsdóttir, VAW; G.H. Gudmundsson, BAS; H. Björnsson, SI)

The project aims at defining and testing 2-D and 3-D stationary and time-dependent flow models to describe Vatnajökull: general dynamics; flowlines; location of ice divides; velocity distribution; shape, thickness and extent; nearness of the ice cap to an equilibrium state for the present mass balance distribution; sensitivity to changes in mass balance; and response to climatic variations. The model is isothermal and is based on the zeroth-order SIA. Geometrical input data are based on results from radio-echo sounding surveys. Observed surface velocity is used to determine the flow parameters (the parameters A and n of Glen's flow law) and amount of basal sliding. A non-linear regression model describing the present mass-balance distribution is coupled with the flow model. The model is constrained with a 9 year record of measured mass balance at about 40 locations on the ice cap. Model computations indicate the ice cap is extremely sensitive to small changes in the height of the ELA, which presents changes in the overall mass balance. There appears to be no stable steady state possible for this configuration. Preliminary experiments with additional periodic surges in the flow regime of the ice cap indicate that surges may act like a stabilizing mechanism.

gudfinna@vaw.baug.ethz.ch

Flow modelling of firn-covered cold glaciers

(H. Blatter, IACS; M. Funk, A. Schwerzmann, VAW)

Cold, high altitude mountain glaciers represent an important archive of the regional climate history. This project, in cooperation with H. Gäggeler and M. Schwikowski (UBern and PSI), investigates flow properties of compressible cold firn in high accumulation areas of glaciers. A novel caliper-inclinometer is used for logging boreholes on Piz Zupo, Swiss Alps. In situ measurements will be carried out immediately after drilling and repeated after several months to years. Surface ice velocities and strain rates will be measured and the glacier bed sounded by radar to obtain the information necessary for numerical flow modelling of the Piz Zupo area. Numerical modelling of the flow, densification and stress fields of high-altitude firn layers of substantial thickness are also planned. The research supports dating and interpretation of physical properties of firn and ice cores, and the ice-core borehole and logging data permit validation of the flow properties of firn and the boundary conditions for flow modelling.

blatter@geo.umnw.ethz.ch

Measurement and modelling of internal ice deformation of Unteraargletscher, Switzerland

(H.G. Gudmundsson, BAS; J. Helbing, M. Funk, VAW)

The total forward motion of glaciers can be divided into internal ice deformation and basal motion. An understanding of both modes of motion is crucial to our ability to model the flow behaviour of glaciers. Internal ice deformation is described with a flow law relating strain rate to stress. The basal motion comprises basal sliding and bed deformation and is usually described in flow models using a sliding law relating basal motion and basal shear stress. Recent improvements in flow modelling and field observation techniques make it feasible to use in situ measurements of ice deformation, combined with stress solutions based on advanced flow models, to study the flow law of ice. The goal is to use inverse modelling of measurements of internal ice deformation and surface velocities to test hypotheses for the flow law of temperate ice, and to validate theoretical concepts about glacier flow.

The deformation of boreholes will be measured with an inclinometer, the diffusion of prominent surface undulations surveyed with GPS equipment, and temporal variations in surface velocity with an automatic theodolite.

helbing@vaw.baug.ethz.ch; ghg@bas.ac.uk

Bed-deformation experiment, Engabreen, Norway

(U.H. Fischer, VAW; N.R. Iverson, Geol&AS/ISU; T.S. Hooyer, WGS; D. Cohen, Geol&Geophys/YU; M. Jackson, NVE; J. Kohler, NPI)

A detailed study of sediment deformation processes is being carried out beneath Engabreen via the Svartisen Subglacial Laboratory, beneath 230 m of temperate ice. One of the strengths of this approach is that many interpretive limitations caused by uncertainties inherent in similarly motivated borehole investigations are eliminated. A trough (~2 m x 1.5 m x 0.4 m deep) was blasted in the rock bed and filled with sediment. Instruments were placed in the sediment to record shear deformation, dilation and contraction, total normal stress and pore-water pressure. Pore pressure was manipulated by feeding water to the base of the sediment with a high-pressure pump. After irregular deformation during closure of ice on the sediment, shear deformation and volume change stopped, and total normal stress became constant at 2.1 MPa. Pump tests conducted subsequently induced pore-water pressures >70% of the total normal stress and resulted in shear deformation over most of the sediment thickness with attendant dilation. Ice separated from the sediment when effective pressure was lowest, and shear deformation stopped. Velocity profiles averaged over the duration of pump tests indicate that rates of shear strain increase upward toward the glacier bed.

ufischer@vaw.baug.ethz.ch

Ice-bed coupling of sediment-based glaciers

(U.H. Fischer, M. Rousselot, VAW)

The dynamics of glaciers overlying soft beds depends to some extent on the rheological and hydraulic properties of the substrate. A large-scale laboratory apparatus (rotary-ploughing device) is being designed and constructed to investigate how mechanical and hydrological conditions of a deformable sediment control the coupling at the ice/bed interface and the resulting distribution of motion at the base of soft-bedded glaciers. Specifically, ploughing experiments will be carried out by dragging instrumented objects through sediment under realistic subglacial conditions. Simultaneous measurements of the drag on these objects and the pore-water pressure in the sediment can then be used to test the hypothesis that excess pore pressures in sediment down-glacier from ploughing clasts weaken the ice/bed interface. This effect may cause rapidly sliding glaciers on sediment to decouple from their beds.

ufischer@vaw.baug.ethz.ch

3-D pattern of stress and velocity, Haut Glacier d'Arolla, Switzerland

(U.H. Fischer, VAW; D. Mair, EAS/UAlb; I. Willis, Geog/UCam; B. Hubbard, CG/UWalesA; P. Nienow, GTS/UGlas; H. Blatter, IACS)

An integrated fieldwork and modelling strategy is being used to study how basal conditions affect the 3-D distribution of stress and velocity within the ablation area of Haut Glacier d'Arolla. From May 1998–August 1999, spatial and temporal variations in basal water pressure, sediment thickness, texture and strength, surface motion, internal ice deformation, basal sliding and subglacial sediment deformation were monitored. There were distinct patterns of surface, internal and basal motion that varied between spring, summer, and fall/winter, reflecting patterns of basal water pressure and sediment characteristics. These, in turn, are influenced by the proximity to subglacial drainage axes. In particular in spring, when the glacier speeds up from ~2 cm d^{-1} to >10 cm d^{-1} over short periods of a few days, the zone of maximum surface velocity shifts from the centre of the glacier towards the major drainage axes where water-pressure fluctuations are greatest. Furthermore, the relative importance of basal motion to surface motion increases during these "spring events". The field data have been used to drive and test a 3-D glacier-flow model. The model can reproduce the spring, summer, fall/winter, and annual patterns and magnitudes of movement very accurately.

ufischer@vaw.baug.ethz.ch

Transfer of water through a moulin/R-channel system, Unteraargletscher, Switzerland

(T. Schuler, U.H. Fischer, VAW)

To characterize water flow through a subglacial channel of Unteraargletscher, a series of tracer tests were undertaken over a number of discharge cycles during the 2000 ablation season. Dye injections into a moulin were repeated every few hours and were accompanied by simultaneous measurements of discharge of supraglacial meltwater draining into the moulin and bulk runoff in the proglacial stream. Records of dye concentration reveal a diurnal variability in terms of flow velocity and dispersivity. Pronounced velocity-discharge and velocity-dispersion hystereses reflect changes in the drainage configuration. A time-dependent model of subglacial water flow is used to interpret the observed variations in flow velocity. Two mechanisms were identified which contribute to the observed velocity-discharge hysteresis: The ability of a Röthlisberger channel to adjust its size to the hydraulic conditions affects the pressure gradient and therefore the flow velocity. In addition, depending on the pressure in the channel, water input from the surface is retarded in the moulin system. A two-component model of subglacial plumbing is proposed to interpret the tracer experiments. The velocity-dispersion hysteresis is analyzed independently using a commercial fluid-dynamics code and results support the two-component model.

schuler@vaw.baug.ethz.ch

Stability of steep glaciers

(A. Pralong, M. Funk, VAW)

Prediction of the break-off time of unstable ice masses is important if settlements or other installations (roads, railway, etc.) exist within the potential hazard zones of a glacier. Until now predictions of the failure time of hanging glaciers has been based on an empirical formula proposed by Röthlisberger and Flotron. A theoretical validation of the formula was performed by Iken with a numerical flow model. The goal of this project is a better physical understanding of the failure processes leading to the break-off. A continuum damage-mechanics model will be coupled to a glacier-flow model to compute the progressive fracture of ice and to simulate this failure processes. To determine the parameters of the numerical model, field measurements have been performed on two hanging glaciers in the Bernese Alps (Mönch and Eiger). Boreholes were drilled to determine the depth of the ice and thermistors installed into these holes to measure the ice temperature. Stakes with reflectors were installed on unstable ice masses and their position measured up to break-off with a theodolite-laser distometer. Acceleration curves are derived from these measurements and will be compared to the results of the numerical model.

pralong@vaw.baug.ethz.ch

Web-based training on glacier- and permafrost related hazards

(S. Oswald, A. Kääb, W. Haeberli, Geog/UZI)

Within the Swiss Virtual Campus project "Dealing with Natural Hazards" (led by the Centre of Competence on Natural Hazards) the Geog/UZI prepares e-learning modules on glacier- and permafrost-related hazards, suitable monitoring techniques and risk-management strategies. The treated hazards include ice avalanches, glacier floods, glacier-length changes, periglacial-debris flows, periglacial-slope instabilities and combined events. The e-course focusing on the graduate/doctoral student level, and continued education for experts, is in English.

soswald@geo.unizh.ch; www.cenat.ch

Monitoring and modelling of rock-slope instabilities from recently deglaciated slopes

(A. Kääb, Geog/UZI)

The relief of valley flanks related to glacier retreat can destabilize rock slopes so rock slides occur. Such rock slides endanger mountain infrastructure and can trigger other hazards such as river damming. Selected active rock-slide areas in the Swiss Alps (Aletsch, Findelen) are monitored by terrestrial surveying and high-precision digital photogrammetry. Geometry changes and surface-velocity fields, in the order of centimetres to decimetres per year, are obtained. The kinematic boundary condition at the surface, the bedding-plane and other parameters characterizing slope instabilities are modelled. Repeated terrestrial surveying is applied to detect speed variations and potential acceleration of a slide.

kaeaeb@geo.unizh.ch

Remote sensing and GIS for early recognition of glacier- and permafrost-related hazards

(C. Huggel, A. Kääb, F. Paul, N. Salzmann, W. Haeberli, Geog/UZI)

This project is working with an approach structured in (1) detection, (2) evaluation and (3) modelling of glacier hazards. Remote-sensing data is used as the main input to (1). Algorithms taking advantage of multispectral, high-resolution data are applied for detecting glaciers and glacier lakes. Digital terrain modeling, and classification and fusion of panchromatic and multispectral satellite imagery is performed in (2) to evaluate the hazard potential of possible hazard sources detected in (1). The locations found in (1) and (2) are used as input to (3). The models developed in (3) simulate the processes of lake outbursts and ice avalanches based on hydrological flow modelling and empirical values for average trajectory slopes. A probability related function allows the model to indicate areas with lower and higher risk to be affected by catastrophic events. Applications of the models to recent ice avalanches and lake outbursts show satisfactory correspondence with observations of respective catastrophic events.

chuggel@geo.unizh.ch

Historical data for analyses of glacier floods and ice avalanches, Swiss Alps

(C. Huggel, A. Kääb, W. Haeberli, Geog/UZI)

During historical times glacier catastrophes, such as outbursts from glacial lakes and ice avalanches, repeatedly caused major damage in the Swiss Alps. Due to the high variety of the processes involved, risks from such events in glacierized areas must be estimated from the empirical knowledge base of historical information: a prerequisite for any corresponding hazard assessment. All available data on historical glacier catastrophes are being compiled, since any such inventory is lacking. Data were collected from chronicles, the annals of the Swiss Alpine Club, historical experts and other sources from the 16th–20th centuries. The data are analyzed in terms of maximum outburst or break-off volume, maximum flood discharge, runout distance and area affected, damage and protective measures. The historical sources are far from homogeneous thus hindering the extraction of complete information on every event. All parameters are examined to refine and adapt existing empirical models. In addition, the database is linked to a GIS to analyze the spatial variability of, and the areas affected by, the events. The data represent a basis for remote-sensing and GIS-based modelling of glacier-hazard potentials in the Swiss Alps.

chuggel@geo.unizh.ch

Analysis of glacier inventories 1850/1973/2000

(M. Maisch, F. Paul, Geog/UZI; R. Weingartner, UBern)

The main results of the NRP 31 project on "Glaciers of the Swiss Alps" (published in 2000) and the first data of the new Swiss Glacier Inventory (SGI 2000) are summarized, as special parts of the "Hydrological Atlas of Switzerland" (project leader: R. Weingartner). One of the two planned atlas sheets will be a statistical analysis of the approx. 2000 glaciers of the Swiss Alps, their glaciological characteristics (i.e. glacier types, categories of shrinking behaviour) and their spatial distribution (i.e. ELA trend surfaces). A second series of maps and diagrams will illustrate the scale and dynamics of glacier recession since the mid-19th century with respect to areal and volumetric changes. The new SGI 2000 results, based on satellite imagery, will display the most recent trends in glacier behaviour.

maisch@geo.unizh.ch

Glacier hazards at Monte Rosa and Ghiacciao del Belvedere, Macugnaga, Italian Alps

(W. Haeberli, A. Kääb, C. Huggel, F. Paul, Geog/UZI; with Centro Nazionale delle Ricerche (Torino) and Regione Piemonte)

After an outburst of the ice-dammed Lago delle Locce in 1979, flood-protection work and a general analysis of hazards from glaciers were carried out in the area between Macugnaga and Monte Rosa, Valle Anzasca, Italian Alps. Extraordinary developments are now taking place at Ghiacciaio del Belvedere. A surge-type flow acceleration started in the lower parts of the Monte-Rosa east face during summer 2000, leading to strong crevassing and deformation of Ghiacciaio del Belvedere, with extreme bulging of its orographic right margin. High water pressure and accelerated movement lasted into winter 2001/2002: ice is now overriding the LIA moraine in places. In addition, an active detachment zone for rock-falls and debris flows has developed recently on the east face of Monte Rosa; somewhat more south of the area of accelerated glacier movement. The growing hazard potential to the local infrastructure is serious. Investigations to assess the hazards are now underway.

haeberli@geo.unizh.ch

Geoinformation on glaciers and permafrost as a planning tool in the Upper Engadin, eastern Swiss Alps

(C. Rothenbühler, AE; W. Haeberli, Geog/UZI; F. Keller, AE; with Universität Trier)

Glacier and permafrost changes, related to fast and accelerating climate change, not only induce irritations in the human perception of high-mountain landscapes and their recreational value but may also be accompanied by development of long-term disequilibria and ecosystem instability, related to various components of the water cycle, to slope processes, soil formation and living conditions. This multidisciplinary project involves close collaboration between research, consulting and management experts on high mountains, landscape and tourism and political authorities; it aims to design and develop a spatio-temporal information system on past, present and potential future glacier and permafrost conditions as a strategic instrument for analysis, for long-term planning and for decision making in the strongly developed tourist region of the Upper Engadin. Emphasis is on easy access to available information (databases, case-studies, analyses), systematic observation of key indicators, use of advanced remote-sensing techniques, application of robust GIS-based numerical models and visualization of potential scenarios.

haeberli@geo.unizh.ch

SNOW AND AVALANCHES

Definition and characterization of potential avalanche release areas

(M. Maggioni, U. Gruber, SLF)

Swiss avalanche-hazard map zones are defined by the frequency and the impact pressure of a potential avalanche event. It is crucial to be able to estimate the release frequency and release extent for a specific avalanche track accurately. A detailed analysis of avalanche-release-area topographies is being performed to establish general rules relating topographic parameters to avalanche frequency. In the region of Davos, where an almost complete database of avalanche events over the last 50 years exists, all avalanche release areas have been analyzed with respect to topographic characteristics. First, relevant topographic parameters are used to define potential release areas automatically. Second, every potential release area is characterized by smaller-scale geomorphological parameters. Finally, these geomorphological parameters are analyzed with respect to the avalanche frequencies observed in the different potential release areas.

maggioni@slf.ch

Fracture mechanics of snow and fracture propagation in avalanche release

(J. Schweizer, SLF; H.O.K. Kirchner, ISM/UParisS; G. Michot, LPM)

Brittle-fracture propagation after initial fracture formation is one of the key processes leading to dry-snow-slab avalanche release, but is poorly investigated due to the extremely difficult experimental conditions. Based on interfacial-fracture mechanics we suppose that the contrast in the elastic moduli and in thickness of two adjacent layers determines the interface-fracture energy and accordingly fracture propagation. The stress-intensity factors (or toughness) in tension and shear have been determined for snow types typically found in slabs. The values for K_{Ic} and K_{IIc} are about the same, of the order of 250 Pa m$^{1/2}$. With its extraordinary low values of fracture toughness, snow is one of the most brittle materials known to man.

schweizer@slf.ch

Temperature dependence of elastic-shear modulus of snow

(J. Schweizer, SLF)

Temperature is often considered as one of the most decisive factors in avalanche formation, but its effect on snow stability is partly controversial. The stiffness (or initial tangent modulus) seems to be the most sensitive mechanical prophet of snow. To determine the temperature dependence of the effective elastic-shear modulus of snow, dynamic torsional-shear experiments at a frequency of 1 Hz were performed with a stress-controlled rheometer. Results indicate that snow is a rheologically simple material. The elastic modulus was found to decrease with increasing temperature following an Arrhenius relation below –6°C and much stronger at higher temperatures. The modulus proved to be highly temperature sensitive in the range of interest for snow-stability evaluation. This highly non-linear behaviour has a strong effect on avalanche formation.

schweizer@slf.ch

Simulation of snowdrift and snow deposition in steep terrain

(M. Lehning, N. Raderschall, J. Doorschot, W. Ammann, SLF)

Snow transport by wind is a major factor influencing avalanche danger and the local microclimate. A snowdrift model has been developed that combines an atmospheric model analysis of the high-resolution wind field over steep topography, a novel formulation for snowdrift, and a snow-cover model distinguishing saltation and suspension. For the wind field, the mesoscale atmospheric prediction model ARP has been adapted to steep terrain and is used with a lateral resolution of 25 m. Critical components are a novel physical model for snow saltation and coupling between the snow cover, the drifting and blowing snow and the wind field. The formulation of the coupling functions is of major importance. The model system is applied to predict snow loading on avalanche slopes. Major characteristics of snow redistribution are captured by the model. In steep terrain, saltation appears to contribute less to snow redistribution than previously assumed.

lehning@slf.ch

Snowdrift and surface-energy balance in steep Alpine terrain

(C. Fierz and M. Lehning, W. Ammann, SLF)

The energy- and mass-exchange processes at the Earth's surface are of major significance for many research fields such as meteorology, climatology, hydrology and agriculture. However, many energy- and mass-balance studies over snow-covered surfaces either deal with surface properties, neglecting processes in the snow cover, or are only adequate for flat and homogeneous terrain. A model of the full and complex interaction between the atmosphere and a snow-covered surface, valid for steep terrain and small scales (few meters), is missing. We propose creating a model for the snow/atmosphere interaction in complex terrain, considering snowdrift (including saltation and suspension), snow-cover development, radiation (including multiple scattering from nearby slopes) and turbulent fluxes of heat and moisture.

fierz@slf.ch

Snow/vegetation interaction with adapted SNOWPACK model

(I. Meirold-Mautner, M. Lehning, P. Bartelt, V. Stöckli, W. Ammann, SLF)

Photoperiodism (recognition of seasons) and photosynthesis play a particular role for vegetation under the snow cover. This study will develop a model to simulate the behaviour of plants under snow covers. The snow-cover model, SNOWPACK, is a basis for development of a physically based snow/vegetation model. Preliminary studies show that moderate temperatures and the availability of solar radiation are critical for all relevant plant processes. To simulate them realistically, a spectrally resolved treatment of radiation flux is incorporated into SNOWPACK. Mie calculations for each homogeneous snow layer, in combination with the d-Eddington approximation, lead to spectrally detailed information of solar-radiation penetration into the snow-pack. Radiation absorption measurements serve as a verification of the modelling results.

meirold@slf.ch

SNOWPACK modelling of snow-cover stability

(S.A. Sokratov, M. Lehning, SLF)

The SNOWPACK model is applied to Alpine sites where detailed snow-pit observations are conducted continuously. Despite remaining discrepancies in quantitative snow-structure parameters, a general agreement was found between snow layering predicted by the model and that observed. Failure positions from snow-cover stability tests are considered as possible sources of avalanche appearance. Particular attention is paid to a detailed analysis of the processes responsible for the observed and the modelled snow structure specific to the corresponding depths. From the correlation analysis suggestions for a quantitative stability assessment, using SNOWPACK, are made. The strength of layers and interfaces is formulated as a function of the snow-microstructure parameters.

lehning@slf.ch

Cold, two-phase wind tunnel with natural snow particles

(M. Lehning, H. Simon, T. Exner, J.-D. Rüedi, W. Ammann, SLF)

Snow-cover and snowdrift research and modelling are impeded by difficulties in conducting experiments under controlled conditions with natural snow. To allow such experiments, a two-phase wind tunnel has been moved from the EPFL to Davos. Additional specific and state-of-the-art equipment has been installed including turbulence sensors (hot wires, Prandtl tubes), image-analysis systems and snowdrift sensors. The new facility will allow studies of the interaction between the natural snow cover and atmosphere under controlled conditions. The following scientific questions are being addressed: erodability of natural snow, evaluation of snowdrift models, exchange of energy and momentum, mechanical properties of windblown snow and test of wind-drift sensors.

lehning@slf.ch

3D-reconstruction of snow

(M. Schneebeli, G. Krüsi, SLF)

Snow, being a highly elusive material, is difficult to measure. Snow samples cast in dimethylphtalate can be conserved for several month to years. In addition, the frozen casting liquid makes it possible to slice the sample on a microtome. During the past years, this technique has been perfected in several ways. A new illumination system has been developed to achieve a homogeneous and highly diffuse illumination, including a digital camera for image acquisition and a semi-automatic control for the microcontroller-operated microtome. Now, up to 250 high-contrast images of snow samples (area 1–20 cm^2) can be acquired per hour. The subsequent reconstruction process is based on our own software development, including image segmentation and 3-D visualization. The method is invaluable because transportation of fragile snow samples (<300 kg/m^3) is impossible, but casting at the site is relatively easy.

schneebeli@slf.ch

Quantitative interpretation of snow profiles in the near-infrared spectrum

(M. Schneebeli, SLF; M. Matzl, HUB)

The reflectivity of snow depends, in the near infrared spectrum, on the grain- and bond size. We calibrated the reflectivity of different snow types and developed an algorithm to segment images taken in the near-infrared by layers. This method provides a new way of classifying layers and closing the gap in recognition of spatial variability at 3–100 cm, which is difficult to assess by cast samples and by high-resolution penetrometry.

schneebeli@slf.ch

Avalanche and snow climatology of Switzerland

(M. Schneebeli, M. Laternser, SLF)

Avalanche activity depends strongly on snowfall trends and snow depth. Long-term changes (>40 years) in natural avalanche activity, snow depth and new snow have been analyzed. A new method, taking in account the probability of snowfall size and spatial autocorrelation of the stations, has been developed to determine the spatial extent of snowfall events and to model probability maps of the different snow-measuring networks in Switzerland. Snow depth in Switzerland has been classified into optimally separated regions, thus allowing an objective optimization of the current network for long-term observation of snow depth. These analyses are essential to understanding the development of snow cover in Switzerland, relevant to risk assessment, tourism and hydrology. The results show that the past 10 years are significantly below the average of the instrumented period (1930–2000).

schneebeli@slf.ch

Development of high-resolution snow penetrometer (SnowMicroPen)

(M. Schneebeli, SLF; J.B. Johnson, CRREL/AK)

An instrument to measure snow mechanical properties and snow texture rapidly and with high spatial resolution is being developed. The temperature drift of the force sensor has been reduced by a factor of 20, and the entire electronics is now based on a microprocessor-based solution, thus reducing the weight and significantly increasing the ease of use. The instrument has been used at SLF (since 1998), at CRREL, Alaska (since 2001), by the US National Avalanche Service (since 2001) and at the SASE, India (from 2002). With SnowMicroPen, the mechanical properties of low-density snow during metamorphism, the spatial variability of weak layers and snow roads, can now be measured for the first time. Future developments are to improve the signal interpretation, to develop a critical-layer detection software and to reduce the overall weight and price eventually.

schneebeli@slf.ch

New cable sensor for continuous monitoring of snow water profile

(M. Stähli, M. Schneebeli, WSL/SLF)

A new cable sensor for measuring the density and water-equivalent profile of a snowpack has been developed at the Research Centre Karlsruhe, Germany. The unshielded flat-band cable (length 30–40 m) measures the dielectric constant of the snow pack in two different measuring frequency ranges at a spatial scale comparable to high-resolution remote sensing. A field test of the snow cable-sensor is running at Weissfluhjoch (2600 m a.s.l.) where an extensive set of snow cover and meteorological data is available. The measurements will be used for validating existing numerical snowpack models to improve snowmelt runoff predictions.

manfred.staehli@wsl.ch

Textural and mechanical variability of mountain snowpacks

(C. Pielmeier, M. Schneebeli, SLF)

It has not been possible so far to [illegible] and quantify spatial variability of snow packs with high resolution. We have used SnowMicroPen to measure at high spatial resolution (10–50 cm horizontal gridsize) the variability of the snowpack. The signal is discriminated between a hardness and texture component, and the emerging pattern is visualized in 2- and 3-D and used to calculate spatial statistics. In addition we use cast snow samples to measure sub-cm variation and profile photographs to measure the horizontal variability between the penetrometer measurements. The anisotropic snowpack is then simulated using a new algorithm developed by Vanmarcke and compared to real snowpacks.

pielmeier@slf.ch

Structural properties of weak layers

(M. Schneebeli, J. Schweizer SLF)

The initial fracture of a snow slab is initiated in a weak discontinuity parallel to the slope. To understand the processes and simulate the fracture, detailed knowledge of the microstructure of such layers is necessary. The goal is to measure and describe the microstructure of typical weak layers and interfaces of layers of dry-snow avalanches. The entire spectrum of layers causing slabs will be documented, such that a statistically relevant dataset is available. Stable interfaces will also be sampled. The structure will be reconstructed using a semi-automated microtome and reconstructed digitally. Microstructural and mechanical parameters will then be calculated (elastic modulus, shear modulus of the interface, tensor of texture) and geometric parameters (connectivity, length and diameter of bonds). This is an essential base to improve our understanding of avalanche formation. The data will serve to parameterize 2- and 3-D models of avalanche formation and improve the recognition of critical layers.

schneebeli@slf.ch

X-ray micro-computer tomography for 3D-visualization and analysis of snow structure

(M. Schneebeli, SLF)

To investigate temporal changes of snow structure and circumvent the well-known large spatial variability, we need a method for undisturbed 3-D visualization. The micro-CT 80 has several advantages: a large sample diameter of up to 80 mm, high spatial resolution (up to 2000 pixel, resolution about 100 mm), possibility of subsampling larger samples with higher effective resolution and the possibility of running it in a cold-room. First experiments are looking at the dynamics of grain formation and dissolution at high temperature gradients and equitemperature sintering with different grain-size. For these, a micro-temperature-gradient chamber has been developed to control snow metamorphism. Tests to determine the dynamic bond formation of snow on ice are performed at intervals of 2 hours. A non-destructive high-frequency-compression instrument is in development to measure the elastic modulus of the snow samples directly and compare it to the micro-structural elastic modulus.

schneebeli@slf.ch

Climate impacts on winter tourism, Swiss Alps

(H. Elsasser, R. Bürki, Geog/UZI)

The future of Swiss Alpine winter tourism must be reassessed in view of global climate change to determine possible strategies for overall development of mountain regions. At present, 85% of all Swiss ski areas still have sufficient snow cover. A 300 m rise of the snowline, however, would reduce this to about 63%. As a consequence, skiers would expect more artificial snow, go on winter holidays less often, and concentrate on ski areas at higher altitudes. Climate change will be used to justify increased use of artificial snow and advances into areas above 3000 m, raising a variety of new problems, both economic and ecological. Climate change may increase economic pressure in terms of capital concentration and division into "winners" and "losers". Although global climate change will certainly have an impact on tourism, it is not the only factor that influences tourism.

elsasser@geo.unizh.ch

Avalanche flow in forests

(P. Bartelt, L. Lorenzato, U. Gruber, V. Stöckli, SLF)

During the 1999 extreme avalanche winter, flowing- and powder-snow avalanches often destroyed large forested areas. Avalanche deposits contained large amounts of fractured-tree material. Overturned trees were clearly visible along the avalanche tracks. In this project, nine forests damaged in winter 1999 were used to validate a theoretical model describing the fracture, entrainment and overturning of forested stands. Friction coefficients for flowing-snow avalanche models, based on standard forest classes, were derived based on parameters such as tree type, tree spacing, tree height and root strength for a specific forest. The research is ongoing, since the number of study cases must be increased to increase the reliability of the derived friction parameters.

bartelt@slf.ch; gruber@slf.ch

High-frequency avalanches: release-area characteristics and runout distances

(U. Gruber, S. Sardemann, SLF)

This study was motivated by the permafrost researchers' hypothesis that permafrost occurrence is more likely in areas usually covered by avalanche deposits; with a retarded snow-free state. Previously this phenomenon was modelled by a simple average slope rule that was imprecise. Known release areas of high-frequency avalanches were characterized using topographic characteristics (i.e. slope, distance to the next ridge, size, curvature and aspect). Then the 2-D numerical Voellmy–Salm model was calibrated to the high-frequency avalanche runout distances. A procedure was developed to determine the release areas of frequent avalanches automatically and to calculate their runout distances over large regions. The method will be transferred and applied to permafrost regions in the Swiss Alps. The modelled deposition areas will be compared both to permafrost measurements here and to the old simple-average-slope method.

gruber@slf.ch

IFKIS: avalanche warning system and organization in Switzerland

(M. Bründl, M. Steiniger, U. Stöckli, J. Rhyner, W. Ammann, SLF)

The 1999 avalanche winter revealed deficiencies in crisis management of avalanche threats at local, regional and intercantonal levels and showed considerable regional differences. Responding to these deficiencies, the IFKIS (Intercantonal Early Warning and Crisis Information System) project was started. The first goal is a unified education concept for avalanche-security officials responsible for villages, roads and ski resorts. The second is the development of an internet-based information system for avalanche forecasters, safety services and decision makers. Rapid exchange of information between different security services and decision makers is crucial for efficient crisis management; for this, internet-based, content-management systems are used. A first test application is running with an external partner in the region of Davos/Klosters.

bruendl@slf.ch

Avalanche rescue beacon testing

(J. Schweizer, G. Krüsi, SLF)

The performance and most efficient handling of avalanche rescue beacons is very important for successful rescue in cases of avalanche burial. Avalanche beacons must follow the ETS 300718 international standard, but the advent of beacons with digitized output for searchers has caused much uncertainty among the users – mainly back-country skiers. It has also made comparison more difficult, so new testing methods must be developed. We follow technical developments closely, consult the public and represent it in the standardizing committee of the European Telecommunication Standards Institute (ETSI) that has recently issued a new standard. Since 1999, we have designed and performed or co-ordinated three major tests of avalanche-rescue-beacon performance. We focused on key characteristics, such as search time and range, the latter determining the search strategy (search-strip width).

schweizer@slf.ch

Effect of spatial variability of mechanical snowpack properties on avalanche formation

(J. Schweizer, K. Kronholm, C. Pielmeier, M. Schneebeli, SLF)

No conclusive field measurements of spatial variability are available. The scale of the spatial variability of the mechanical properties of the snow cover is thought to depend on processes that act on the snow cover, but the scales associated with the variability are not well known. The relation between snowpack stability and spatial variability is not known, although it is thought that poor stability implies a high number of triggering points (i.e. spatial variability should be low). It is unclear whether spatial variability should increase with increasing stability. We aim to establish a conclusive set of measurements on the variability of the snow cover and on the scale of variability and then relate them to avalanche activity. *schweizer@slf.ch*

Verifying snowpack stability and avalanche danger

(J. Schweizer, M. Lehning, J. Rhyner, T. Wiesinger, SLF)

Verification of snowpack stability and avalanche danger is difficult compared with verifying weather forecasts, because the stability of the snowpack cannot be observed or measured easily. Furthermore, avalanche release is in part a haphazard affair, due to spatial variability, and is a stochastic process depending on the scale of observation. However, verification is a prerequisite for development, application and improvement of avalanche forecasting. To verify snowpack stability and avalanche danger, the following steps are planned: improved recording of avalanches in the test area of Davos, more specific definitions and descriptions of snowpack stability states and corresponding danger levels, collection of detailed snowpack data for model development and verification by field measurements at different scales, verification of the regional snowpack stability by field measurements and development of a recording scheme for the avalanche warning service to document forecast decisions.

schweizer@slf.ch

Dynamics of mixed-flowing/powder-snow avalanches

(B. Turnbull P. Bartelt, SLF)

The events of winter 1999 clearly demonstrated the need for a simple model to consider the danger of mixed-flowing/powder-snow avalanches in avalanche-hazard mapping and defence strategies. As a result, a four component 1-D model, based on the AVAL-1D numerical model, is being developed. It solves depth-averaged mass and momentum balances for each component: the incumbent snow cover; the dense-flowing avalanche; the powder cloud and a turbulent wake. The dynamics of the avalanche are strongly dependent on the mass exchanges between the components and entrainment of the surrounding air. Work will continue with validating and calibrating the model using experimental data and field observations.

turnbull@slf.ch

AVAL-1D: an avalanche dynamics program for practice

(M. Christen, P. Bartelt, U. Gruber, SLF)

AVAL-1D is a 1-D avalanche-dynamics program that predicts runout distances, flow velocities and impact pressures of both flowing or powder-snow avalanches. Complex terrain is realistically, accurately and easily specified using digital maps. Well-calibrated depth-average continuum models are used to track the motion of avalanches from initiation to runout. AVAL-1D has two computational modules: FL-1D (flowing avalanches) and SL-1D (powder-snow avalanches), both programmed in C. These modules solve the governing equations of mass, energy and momentum balance using up-winded finite-difference schemes. The user-friendly graphical interface is programmed in Interactive Data Language. Flow velocities, heights and dynamic pressures can be visualized along the entire avalanche track. XY-Plots of calculated data at user-selected points are possible. AVAL-1D is an easy-to-use, stable and well-calibrated simulation tool for snow avalanche professionals, used in eight countries around the world.

aval1d@slf.ch

Entrainment and deposition processes in flowing avalanches

(B. Sovilla, P. Bartelt, SLF)

In practical avalanche-dynamics calculations, the entrainment of the snow cover and mass deposition along the avalanche path are not considered. Observations show, however, that part of the snow cover will usually be eroded, sometimes down to the ground and, at the same time, local or continuous deposits will be distributed along the path. Both field and laboratory experiments are used to investigate mass-entrainment and deposition processes in flowing avalanches. The work involves: (1) defining the measurement techniques and devices to capture mass changes in flowing avalanches; (2) performing entrainment and deposition tests at the Vallée de la Sionne test site, in the laboratory and at different sites; (3) developing a theory of mass entrainment and deposition; and (4) developing numerical models and practical calculation methods to treat mass entrainment and deposition.

sovilla@slf.ch

Mass transport in drifting snow in high Alpine environments

(J. Doorschot, M. Lehning, N. Raderschall, A. Vrouwe, SLF)

Wind transport of snow has a major impact on the avalanche hazard and on ecology and hydrology in mountainous environments. Saltation is the wind transport of granular material that takes place close to the ground, where particles follow ballistic trajectories. A numerical model has been developed which computes the mass flux in saltation on the basis of particle trajectories and conservation of momentum. Model results, as well as theoretical arguments, indicate that for snow, contrary to sand, aerodynamic entrainment, as opposed to rebound, is the main process that sets particles in motion. The model results were validated with field measurements of mass transport in snow saltation. Measurements of the threshold friction velocity for snowdrift were also made; the results demonstrate that threshold conditions strongly depend on snow characteristics, and that short-term fluctuations of the turbulent shear stress need to be taken into account in the numerical mass-flux simulations.

lehning@slf.ch

Statistical inference for avalanche events

(B. Brabec, V. Chavez, SLF)

A statistical methodology has been developed and implemented to (1) draw maps of estimated return levels and point-wise bootstrap confidence intervals, (2) respond to other questions of interest such as choosing the number of days over which new snowfalls might be aggregated, and (3) allow other analyses which consider, for example, monthly rather than yearly maxima. Our statistical technology combines the point process/generalized Pareto model for exceedances with smoothing methods to give a flexible exploratory approach to changes in extreme snowpacks. The results will be implemented in a tool for practitioners at SLF.

jrhyner@slf.ch

Rule-based and process-oriented forecasting models

(B. Brabec, M. Gassner, M. Lehning, T. Stucki, SLF)

A new rule-based and process-oriented avalanche forecasting model will be developed for winter 2004/5. The model will integrate data from automatic stations, snowpack-model calculations and the experience of avalanche forecasters expressed by probalistic rules. Some rules will be generated from data and snowpack-model simulations. The performance of the model will be superior to the existing NXD-REG approach.

lehning@slf.ch

Snow–ski interaction during carved turns

(P. Federolf, M. Fauve, A. Lüthi, H. Rhyner, W.J. Ammann, SLF)

Skiing enjoys a popularity on which not only the skiing industry but also tourism and other service industries are economically dependent. However, even though the basic kinematics of skiing are well known, many other aspects of skiing remain controversial or unknown. This project focuses on interactions between the ski and snow during carved turns. The processes are influenced both by material characteristics of the ski–binding–boot system and the snow properties, such as its deformation characteristics. The results will be applied to a finite-element simulation which should help in the design of new skiing equipment.

rhyner@slf.ch

Ski pistes with artificial and natural snow: temperature and snowmelt

(C. Rixen, V. Stoeckli, SLF)

We measured snow depth and density of ski-piste snow and its effects on ground temperature and snowmelt as part of a project on environmental impacts of artificial snow. Pistes with and without artificial snow (10 each) and adjacent control plots were analyzed. On those with natural snow, the thin and compacted snow cover led to severe seasonal soil frost. On pistes with artificial snow, soil frost occurred less frequently because of increased insulation due to greater snow depth. The time of snowmelt was delayed by more than 2 weeks because of the greater snow mass. Average winter ground temperatures under a continuous snow cover decreased by approximately 1°C on both piste types compared with control plots. The results suggest that the heat balance of Alpine soils is changed for both piste types, either by extensive heat loss or by delayed snowmelt.

rixen@slf.ch

Ski pistes with artificial and natural snow: vegetation reactions

(S. Wipf, C. Rixen, V. Stoeckli, SLF)

Artificial snow is applied in many ski resorts so the impacts on vegetation are being considered. In 12 Alpine ski resorts, we recorded the vegetation composition of ski pistes with artificial or natural snow and compared it to that of undisturbed sites. Snow-cover characteristics were also investigated. Artificial snowing increased snow depth which prevented soil frost but led to late snowmelt, while under pistes with natural snow, extensive soil frosts occurred. The longer (2–16 years) artificial snow had been applied, the more abundant were species specialized on Alpine sites with a deep and long-lasting snow cover (snowbeds). Wind-edge species, naturally occurring on wind-swept ridges, showed the opposite reaction. This suggests that vegetation composition reacts fast to changing snow conditions, giving further input to current climate-change discussions.

wipf@slf.ch

Effects of natural hazards on tourism: 1999 Swiss avalanche winter

(C. Nöthiger, SLF)

"Indirect" effects of natural hazards consist mainly of economic losses. The indirect costs of the 1999 Swiss avalanche winter to the tourist industry were mostly from closure of access roads, decommissioning of several cable cars and ski lifts, the bad weather conditions and probably press coverage as well. Day-trippers stayed away primarily in February 1999, overnight guests in March 1999 as well, and to a degree even in February 2000. The total losses for the tourist industry added up to approximately SF330 million; almost entirely for the companies immediately affected. Improvement in public relations may be the most important measure to cope with indirect costs of natural hazards in the future.

noethiger@slf.ch

Influence of snow cover on ibexes, Bernese Oberland

(M. Oetliker, V. Stöckli, SLF)

Places of residence, mobility and behaviour of ibexes (*Capra i. ibex L.*) are being correlated with snow-cover characteristics and weather conditions, using GPS telemetry, visual observations, detailed snow-cover investigations and evaluation of snow and weather data from automatic stations (IMIS and ENET). As a result, the winter habitats favoured by ibexes will be better characterized. This should help optimize tourist needs, the needs of the wildlife, as well as planning of habitats for new ibex colonies. The study will provide guidelines for authorities in their decision-making. The project can be followed almost in real time through the web page www.steinbock.ch.

oetliker@slf.ch

FROZEN GROUND

Swiss permafrost monitoring (PERMOS)

(D. Vonder Mühll, Geog/UZI/UBas; R. Delaloye, Geog/UFrib; W. Haeberli, M. Hoelzle, Geog/UZI; B. Krummenacher, SLF)

The Permafrost Monitoring Network Switzerland (PERMOS) has been initiated by the Swiss Coordinating Group Permafrost and the Glaciology Commission within the Swiss Academy of Sciences (GK/SAS). PERMOS is in a pilot phase from 2001–03. It complements the traditional GK/SAS glacier-monitoring network with a further component of the cryosphere. It documents long-term permafrost modifications in the Swiss Alps with regard to ongoing and potential future warming trends. The thermal state is systematically observed and aerial photos taken for later photogrammetric analyses of the permafrost environment. Three parts are observed: (1) temperatures in permafrost boreholes and sometimes horizontal/vertical deformation; (2) temperatures at the base of the snow cover (BTS), soil temperature and qualitative development of the snow cover (duration, thickness);

(3) aerial photographs (black-and-white and infrared) for photogrammetric analyses of rock glaciers and documenting geomorphological, hydrological and biological modifications in permafrost areas. Monitoring is conducted by Canton Valais, GGUB, GGUF, Geog/UZI, IGT, Geog/ULaus, SFISAR and VAW.

daniel.vondermuehll@unibas.ch

Unstable Alpine permafrost: a natural hazard

(L.U. Arenson, S.M. Springman, IGT; H.R. Maurer, M. Musil, Geophys/ETH-Z; D. Vonder Mühll, Geog/UZI/UBas)

Geophysical investigations at Muragl rock glacier, Upper Engadin, showed the frozen body can be determined quite accurately with careful data processing and borehole-log calibration. Borehole-to-borehole investigations reveal information about the subsurface between two holes so spatial permafrost distributions can be determined. Nearby, in the Murtèl-Corvatsch rock glacier, unfrozen water and high air-void ratios were found within the frozen body. The rock-glacier hydrology seems to be much more complex than originally expected and, since water influences the thermal regime, it has to be considered for further thermal and stability analyses. TDR cables were installed for the first time in permafrost to gain more detailed information on temporary and vertically distributed deformations within this rock glacier. Monitoring of deformation and temperatures in the instrumented boreholes is ongoing and will be included in the PERMOS.

lukas.arenson@ethz.ch

Weathering-rind measurements and relative-age dating of rock-glacier surfaces

(M. Laustela, M. Egli, R. Frauenfelder, W. Haeberli, Geog/UZI)

The development of the rock-debris weathering rind of several rock glaciers on granite and gneiss in the Swiss Alps has been investigated. The weathering mapping has been compared to other absolute and relative methods of rock-glacier surface dating such as radiocarbon dating, Schmidt-hammer measurements and photogrammetric determinations of flow trajectories. Rock-weathering rinds found were usually much thinner than those observed on sandstones (e.g. in New Zealand). A close relationship was found between the thickness of weathering rinds and the Schmidt-hammer method, which itself correlates with absolute-age-determination methods. Mapping of rind thickness is more difficult on rock glaciers with complex morphologies (i.e. confluences, divergences or overriding individual lobes).

megli@geo.unizh.ch

Monitoring mountain permafrost and glacier changes by digital photogrammetry

(A. Kääb, Geog/UZI; T. Eiken, UOslo)

Digital analysis of repeated aerial photography permits automatic measurement of DEMs, thickness changes over time and surface displacements, with high resolution and accuracy. These new techniques are applied to rock glaciers and glaciers. Due to optimal optical contrast, best results are obtained for blocky surfaces. Results include dense velocity fields of debris-covered glaciers and a number of rock glaciers in Switzerland and on Svalbard. Modelling of such data provides valuable insights into the dynamics and strain regime, the development of surface topography, the mass-balance distribution, velocity variations with time and age of the deforming bodies.

kaeaeb@geo.unizh.ch

Monitoring and modelling spatio-temporal variations of mountain permafrost creep

(A. Kääb, R. Frauenfelder, Geog/UZI)

Little is known about the spatio-temporal variations of rock-glacier creep. This is crucial for understanding the evolution, present-day conditions and sensitivity to climate forcing of the frozen debris. Repeated terrestrial surveys and image analysis are performed to monitor velocity changes with high temporal resolution on selected rock glaciers. Results point to a large range of variability. Rock glaciers creeping at almost constant rates over the observation period, as well as those with drastic seasonal speed variations are found. Measurements are compared to a numerical model simulating the effect of temperature variations with depth on the resulting speed of a creeping ice body.

kaeaeb@geo.unizh.ch

Talik formation and geothermal anomaly, Murtel/Corvatsch, eastern Swiss Alps

(W. Haeberli, Geog/UZI; Th. Kohl, Geophys/ETH-Z; D. Vonder Mühll, Geog/UZI/UBas)

The Murtèl/Corvatsch permafrost borehole was drilled in 1987 and has been monitored ever since. Mean annual temperature at the permafrost table is around –2.5°C with a rising tendency. Permafrost conditions at the site are assumed to have existed throughout the entire Holocene. At 55 m deep, temperatures are affected by seasonal water flow in a thin layer (talik) at the debris/edrock interface. A characteristic geothermal anomaly is observed with stable negative ground temperatures above and below the seasonally unfrozen zone. The shape of the temperature profile, together with a sensitivity analysis using a 2D-heat conduction calculation, indicates permafrost extends at least 25 m below the talik. Unusual high temperature gradients in the talik are the result of a several-meter-large fluid zone in summer which delimits the talik at the base. Such channelling already provides steady-state situations after 25 years.

haeberli@geo.unizh.ch

Time-dependent temperature evolution in high-mountain permafrost

(Th. Kohl, Geophys/ETH-Z; D. Vonder Mühll, Geog/UZI/UBas, W. Haeberli, Geog/UZI)

The observed thermal data from various boreholes that have been drilled into high-mountain peaks allow a direct assessment of the external energy supply to the subsurface. Quantification of the past climatic history in these areas is only possible when accounting for 3-D topography from DTM data, surface temperature variation with altitude and slope orientation and various thermal transport mechanisms in the layers beneath the permafrost zone. The ground-surface temperature distribution, being strongly sensitive to the shallow (~100 m deep) subsurface temperature field, should be assessed by additional measurements. A cost-optimized strategy is developed to locate those points which are most sensitive and which provide the most useful data. These theoretical investigations use a sophisticated numerical procedure with complex 3-D finite-element meshes.

kohl@ig.erdw.ethz.ch

Effect of frozen soil on ground-water recharge in Alpine areas

(D. Bayard, EPFL; M. Stähli, WSL)

The effect of soil freezing on ground-water recharge in Alpine areas, where water demand for ski resorts or hydropower may be considerable, is being determined. Detailed process studies of infiltration into frozen and unfrozen soil are carried out at Grächen/Hannigalp (2100 m a.s.l.) and Gd-St-Bernard pass (2450 m a.s.l.), in southern Switzerland. In winter 2000/01, the soil at both sites was unfrozen below deep snowpacks, but in winter 2001/02 a deep soil frost formed at both sites, allowing direct comparison between frozen and unfrozen conditions. Water-balance measurements (surface and subsurface runoff, deep percolation) are carried out on 10 m^2 plots. Dye-tracer experiments reveal the infiltration pattern into frozen and unfrozen soil during snowmelt. The field experiments are analyzed with numerical models to simulate the infiltration dynamics and areal ground-water recharge.

daniel.bayard@epfl.ch

Flow modelling of rock glaciers

(G. J.-M. C. Leysinger Vieli, VAW; G. H. Gudmundsson, BAS)

All known active rock glaciers in the Alps are far from equilibrium state in the sense that the material velocity at the snout is similar to the rate-of-advance of the rock glacier. This is a fundamentally different situation from Alpine glaciers where ablation and material velocities at the snout are of similar orders of magnitude. One implication of this difference is that the rock-glacier depth–age structure can be expected to depend crucially on details of the flow field near the snout, whereas the snout is passive for glaciers and ice sheet. The snout flow-field cannot be calculated correctly with zeroth-order models. For this purpose, a full-system numerical model has been developed describing the advance and retreat of glaciers and rock glaciers. The model follows the transient evolution of the surface in detail using a mixed Lagrange–Euler formulation. Model–model comparison is used to estimate the importance of horizontal stress transmission on the rate-of-advance.

leysin@vaw.baug.ethz.ch; ghg@bas.ac.uk

Snow cover/permafrost interaction

(M. Luetschg, P. Bartelt, M. Lehning, SLF; W. Haeberli, Geog/UZI; V. Stoeckli, SLF)

Permafrost temperatures are strongly affected by topographic, atmospheric and soil-specific factors such as mean annual air temperature, solar radiation and soil grain-size. In these interrelationships, the snow cover plays a principle role due to its high albedo and insulation. The processes between the snow cover and underlying ground are being described numerically to obtain an integral understanding of the internal relationships. With a soil-coupled version of the SNOWPACK model, the focus is on the following problems: (1) the interactive correlation between snow-cover characteristics (thickness, density, period) and permafrost; (2) the effect of latent- and lateral-heat transport processes in different soil types (coarse blocky, fine grained); and (3) the biophysical conditions at the snow-cover/permafrost interface. Field and laboratory measurements are used to verify model results.

luetschg@slf.ch

Low-altitude frozen ground and forest dynamics

(M. Phillips, V. Stöckli, SLF; M. Freppaz, UTurin; R. Delaloye, Geog/UFrib; E. Reynard, Geog/ULaus)

Several low-altitude sites in Switzerland have very cold ground temperatures or permafrost. Two locations, Creux du Van, Neuchâtel and Brüeltobel, Appenzell (~1250 m a.s.l.), are investigated to determine the interactions between cold-ground temperatures and vegetation cover. Both sites are on scree slopes at the foot of high limestone cliffs and are densely covered in vegetation. The plants are of high-altitude type and the growth of spruce (*Picea abies* L. Karst) is highly reduced. Soil temperature, chemical composition and nutrient turnover are measured and vegetation relevés and dendroecological analysis of perennial plant and tree growth are performed. The results are expected to provide information on stunted-tree growth and may allow reconstruction of past permafrost dynamics by analysis of tree-ring growth.

phillips@slf.ch

Stability of snow-supporting structures on steep slopes in Alpine permafrost

(M. Phillips, S. Margreth, W.J. Ammann, SLF)

The performance of three types of snow-supporting structures (snow bridges, snow nets and the newly developed hanging bridge) is monitored at Pontresina Schafberg, Arolla Mt. Dolin and Randa Wisse Schijen (~3000 m a.s.l.) in the Swiss Alps. The sites are in steep permafrost terrain and are all characterized by a very unstable scree cover. Slope movements are measured using inclinometer pipes and the position of each foundation is surveyed yearly. Ground temperatures are monitored in boreholes to 20 m depth and snow distribution is registered using an automatic camera at one site and observations at the others. Down-slope movements of the structures are particularly pronounced (e.g. up to 10 cm a^{-1}) when the winter snow load is important. Sectors of the slopes which are not equipped with structures are warmer (as snow melt is not delayed in Spring) and are subject to more deformation.

phillips@slf.ch

Mountain permafrost in peripheral areas, western Switzerland

(R. Delaloye, M. Monbaron, A. Turatti, Geog/UFrib; C. Lambiel, E. Reynard, Geog/ULaus)
Peripheral areas of permafrost distribution lie on the edges of normal permafrost: at the lower limit of permafrost distribution, recently deglaciated proglacial margins, rock-face bases with little solar radiation, etc. The first objective is to delimit the permafrost bodies. Classical prospection methods (d.c. resistivity techniques, BTS) are used, but need to be adapted to these particular sites as interpretation of results is not obvious. A second aim is to characterize conditions for the existence of permafrost in these areas and how it might react to climate warming.
reynald.delaloye@unifr.ch; christophe.lambiel@rect.unil.ch

Glacier/permafrost relationships, western Swiss Alps

(R. Delaloye, Geog/UFrib; E. Reynard, C. Lambiel, Geog/ULaus; L. Marescot, R. Monnet, L. Baron, Geophys/ULaus)
Glacier/permafrost relationships are being studied in recently deglaciated forefields. Ground-surface temperature measurements and various geoelectrical methods (d.c. resistivity soundings, resistivity mapping and 2-D electrical resistivity tomography) are combined. Areas with low- and high-resistivity ice and unfrozen areas are mapped, and thermal and morphological degradation by the Little Ice Age advance is noted. Historical reconstruction of glacier/permafrost relationships is also carried out.

reynald.delaloye@unifr.ch;
emmanuel.reynard@igul.unil.ch

Thermal regime and processes in cold scree slopes

(R. Delaloye, Geog/UFrib; E. Reynard, C. Lambiel Geog/ULaus; L. Marescot, R. Monnet, L. Baron, Geophys/ULaus; M. Phillips, V. Stöckli, SLF; M. Freppaz, UTurin)
The thermal regime and processes of a cold scree slope at Creux du Van, Jura, western Switzerland (1200 m a.s.l.) are investigated by various thermal and meteorological measurements. Geoelectrical methods are also used to map the ground-ice distribution and its character. Thermal and geophysical results are combined with soil-chemistry and dendroecological analyses to characterize the ground thermal regime and ecological condition relationships and eventually reconstruct the thermal and vegetation dynamics of the talus slope.

reynald.delaloye@unifr.ch

Glacier/permafrost relationships, Posets Range, central Pyrenees, Spain

(R. Delaloye, Geog/UFrib; R. Lugon, IUKB; C. Lambiel, E. Reynard, Geog/ULaus; E. Serrano, Univ. Valladolid)
Glacier/permafrost relationships are being studied in the forefields of two small glaciers in the central Pyrenees. Continuous ground-surface temperature measurements and geoelectrical prospecting (d.c. resistivity soundings and resistivity mapping) are combined. There is evidence of high-resistivity ice and most accumulations of loose material in the forefields of both glaciers are interpreted as push-moraines from glacier advances in the Little Ice Age.

reynald.delaloye@unifr.ch

Permafrost characteristics in sedimentary terrains and natural hazards in Arolla and Mont Gelé areas, central Valais

(C. Lambiel, Geog/ULaus)
To identify hazardous slopes in danger from permafrost degradation, one must know if the slopes are frozen, how much ice is in the ground, and the thickness of the active layer, etc. To get this information, the Mont Gelé and Arolla test sites, with various aspects, landforms, lithology, etc., have been selected. Various permafrost-prospection methods are used to obtain maximum information on the permafrost structure and its extent. The large-scale model obtained will be applied to potentially dangerous Alpine valleys.

christophe.lambiel@rect.unil.ch

Rock-glaciers and related terrain parameters, eastern Swiss Alps

(R. Frauenfelder , W. Haeberli, M. Hoelzle, Geog/UZI; B. Schneider, UBas)
A GIS-based model of rock-glacier distribution has been developed, applying the basic processes involved. An empirical sample of approx. 90 active rock glaciers in the eastern Swiss Alps was analyzed statistically, for terrain parameters (like rock-wall extents, geology, etc.) and their relation to rock-glacier parameters (like rock-glacier size, slope, etc.). First results indicate a relation exists between rock-wall extent and rock-glacier size, but is complex and involves factors like cliff-recession rates (as a function of geology, temperature, jointing, etc.) and subsequent talus-input variations. These factors seem to play a key role in defining rock-glacier bodies. The results imply that the relation between slope angle and rock-glacier size follows a negative ratio, and that a constant-thickness approach (probably thermally caused?) may be more appropriate than the widely applied concept of perfect plasticity (constant basal shear stresses).

rfelder@geo.unizh.ch

Permafrost distribution in cold-mountain areas from advanced remote sensing

(S. Gruber, M. Hoelzle, D. Schlaepfer, K. Itten, W. Haeberli, Geog/UZI)
An airborne imaging-spectrometer campaign at the Corvatsch high-mountain site, southern Switzerland, is planned for 2002 to derive precise spatial data fields on

albedo and emissivity. A well-calibrated sensor, having a high radiometric resolution together with reliable geometric and atmospheric–topographic correction procedures, is expected to produce output with high relative and absolute accuracy. Albedo and emissivity of geological surfaces in rugged topography is a vital factor in physically based energy-balance models. The derived data will be incorporated into the PERMEBAL model, simulating ground surface temperatures and permafrost distribution at 10 m grids.

stgruber@geo.unizh.ch

Surface temperatures in steep rock faces

(S. Gruber, M. Peter, M. Hoelzle, I. Woodhatch, W. Haeberli, Geog/UZI)

As part of a new measurement strategy to improve understanding and modelling of surface temperatures in steep cold-mountain rock faces, 24 data loggers were placed at sites beween 2000 and 4500 m a.s.l. Knowledge of the spatial distribution of cold rock faces and development of a reliable parameterization is vital for 2-D and 3-D ground-temperature models and for retrieval of climate signals from permafrost boreholes. The absence of snow cover on steep rock faces, combined with a "clean" coupling of the surface and subsurface by heat conduction, is an opportunity for calibration and verification of surface energy-balance models. Planning considerations are: sampling strategy and site selection based on a ground-temperature model; logistics (safety, efficiency); local placement of data loggers; and logger design.

stgruber@geo.unizh.ch

Ice caves in the Jura

(M. Luetscher, P.-Y. Jeannin, SISKA; W. Haeberli Geog/UZI; M. Beniston, Geog/UFrib)

Low-elevation ice caves, special features of perennially frozen ground, have been recognized and described for a long time. To better understand this phenomenon the SISKA, in collaboration with geography departments from Zürich and Fribourg, began a detailed study, in April 2001, based on the physics of heat transfer and air flow in these caves. Initially, Monlési ice cave, Boveresse/NE, the largest in the Jura, was described in detail. Ice formation seems to be controlled by water infiltration, air circulation and trapping of external cold air. Snow accumulation plays a secondary role in this process.

marc.luetscher@isska.ch

ICE CORES

Crest- and cornice-type low-altitude ice archives

(R. Frauenfelder, W. Haeberli, A. Kääb, Geog/UZI; S. Wagner)

Perennial snowbanks and glacierets constitute virtually unexplored low-altitude ice archives of potentially important information on Holocene climate variability. Investigations were initiated on several such patches and on a crest-type miniature ice cap at Piz Murtèl, Swiss Alps, to: (1) describe their glaciological characteristics (thickness, temperature, structure, flow, age, ice accumulation); and (2) analyze information contained within the ice (isotopes, impurities, organic matter, etc.) for climatic interpretations. Shallow-core drilling, borehole-temperature measurements, radio-echo sounding, temperature data logging, visual observation, geodetic surveying and finite-element modelling of basic 2-D configurations were carried out on the Piz Murtèl ice cap.

rfelder@geo.unizh.ch

Perennial ice patches

(R. Frauenfelder, A. Kaeaeb, W. Haeberli, Geog/UZI)

The potential of perennial ice patches as palaeoclimatic archives is being investigated, starting from the assumption that they contain old ice and have to exhibit a pronounced dynamic and thermal stability. Four categories of factors supporting such stability leads to the conclusion that (a) the microtopographic situation, (b) the (small) size, (c) ground thermal conditions, especially permafrost, and (d) the dirt and debris content, are mainly responsible for the degree of ice-patch longevity. Clearly, the existence of permafrost supports (or even enables) the perennial persistence of snow/ice patches. Systematic analysis of inventoried perennial ice patches shows that many which had survived, probably since the beginning of the last century, vanished in the 1990s.

rfelder@geo.unizh.ch

Ice-core studies, Belukha Glacier, Siberian Altai

(S. Olivier, UBern, PSI; M. Schwikowski, B. Rufibach, PSI; H.W. Gäggeler, P. Ginot, UBern, PSI; M. Lüthi, VAW; T. Papina, S. Eyrik, IWEP)

The Altai range is close to major sources of air pollution in eastern Kazakhstan and southern Siberia (heavy-metal mining, metallurgy) and to the Semipalatinsk nuclear-test site (atmospheric radionuclides). To reconstruct air-pollution levels in the Altai, a 140 m ice core was drilled on Belukha glacier (49°48′26.3″ N, 86°34′42.8″ E, 4062 m a.s.l.) in June–July 2001. It is on a saddle between the two summits of Belukha, the highest mountain in the Altai (4506 m a.s.l.). This site was selected following an exploratory study in 2000. The drilling nearly reached bedrock, as indicated by glacier-thickness measurements. The 900 kg of collected ice were sent frozen to Switzerland for glaciochemical analyses.

margit.schwikowski@psi.ch

Firn-core records, Gorra Blanca, Patagonia

(M. Schwikowski, PSI; G. Casassa, CECS, UMag; A. Rivera, UChile, CECS)

Hielo Patagónico Sur (HPS) is the largest body of ice in the Southern Hemisphere outside Antarctica. Ice-core records from HPS would provide an opportunity to investigate changes in the position and strength of the westerly airflow through time. However, few investigations have been carried out there due to the extremely difficult nature of fieldwork in this region, where strong winds and precipitation prevail. In addition, melting due to relatively warm temperatures largely influences the glaciochemical records. To investigate the suitability of different HPS sites as palaeoclimate archives, three shallow firn cores were drilled at Gorra Blanca during the fourth expedition of the Icefields Science Initiative, organized by CECS. The aim was to find higher-elevation glacier sites less influenced by meltwater formation and percolation.

margit.schwikowski@psi.ch

Glaciochemical records from Andean glaciers

(M. Schwikowski, PSI; P. Ginot, St. Knüsel, H.W. Gäggeler, UBern, PSI; U. Schotterer, UBern; with B. Francou, LGGE; P. Ribstein, IRD-F)
Ice-core records from Cerro Tapado, Chile (30°08′ S, 69°55′ W; 5536 m a.s.l.), from Illimani, Bolivia (16°39′ S, 67°47′ W; 6432 m a.s.l.), and from Chimborazo, Ecuador (1°30′ S, 78°50′ W; 6230 m a.s.l.), have been studied to reconstruct short-term climate variability, probably related to ENSO. A strong effect of sublimation on the glaciochemical record was observed, especially in the dry climate at Cerro Tapado. Enrichment of chloride could be used to reconstruct the amount of sublimation. For Chimborazo, a secondary effect observed was an ash layer deposited on the glacier from the eruption of two nearby volcanoes, which, due to meltwater percolation, caused a significant perturbation in the concentration records of ionic species. This indicates how vulnerable such unique archives are, and how urgent is the task of recovering palaeoenvironmental information from glaciers shrinking rapidly due to global warming.

margit.schwikowski@psi.ch

SNOW/ICE CLIMATOLOGY AND HYDROLOGY

Impact of climate change on Alpine glaciers

(C. Schneeberger, H. Blatter, IACS)
To project the evolution of a glacier, three advanced numerical models are used, (1) an Atmosphere–Ocean General Circulation Model (AO–GCM) to simulate climatic conditions corresponding to some greenhouse scenario, (2) a model to compute the surface mass balance on a glacier based on climatic input, and (3) an ice-flow model to predict the evolution of the glacier surface for a given mass-balance scenario. The climate scenarios are computed with GCM's in time-slice experiments with 10 year T106 high-resolution control runs for the present climate and a high-resolution 10 year time-slice in the mid-21st century for 2×CO_2. The time-slice runs use boundary conditions provided by transient runs with lower resolution AO–GCM's, based on the IPCC scenario IS92a. This scenario predicts a doubling of atmospheric CO_2 concentration in 2050 with respect to the pre-industrial value. To compute the present glacier mass balance, the present-day observed climate was used. A "downscaling" procedure of the GCM result for a representative gridpoint, to the local situation on the glacier, for 2050 was defined by adding the modelled climate change between today and 2050 to the present-day observed climate. This procedure is applied to a sample of glaciers, selected on the basis of availability of comprehensive glaciological data.

schnee@geo.umnw.ethz.ch

Cosmogenic radionuclides in polar ice

(J. Beer, EAWAG; M. Suter, IPP)
This project aims to establish detailed continuous records of ^{10}Be and ^{36}Cl for the GRIP ice core from Summit, Greenland. Based on these records the following scientific questions will be addressed: reconstruction of solar variability over the past 100,000 years; role of solar variability in climate forcing; changes in the carbon system and, in particular, changes in global deep-water formation; reconstruction of the geomagnetic field intensity; improvements in dating ice; improvements in analytical techniques.

beer@eawag.ch; suter@particle.phys.ethz.ch

Thermodynamic sea-ice model

(H. Huwald, H. Blatter, IACS; L.-B. Trembaly, LDEO)
A multi-layer thermodynamic snow–sea-ice model was developed and tested against observational data from the Surface Heat Balance of the Arctic Ocean (SHEBA) experiment. The model uses a coordinate transformation which maps the thickness of the snow and ice slabs onto unity intervals and thus enables flexible relayering of the snow and ice layers while conserving energy. It considers heat conduction in a snow and ice layer, absorption of solar radiation, brine formation, and atmospheric and oceanic heat fluxes at the boundaries. The model is run for one year (September 1997–September 1998) using observed downward radiation and air temperature, humidity and wind speed for computing turbulent heat fluxes as forcing fields. This model validation is done as part of the ongoing Sea Ice Model Intercomparison Project (SIMIP2). The results point at problems associated with the high horizontal variability of snow and ice thickness and identify which observations are required for a precise model validation.

huwald@geo.umnw.ethz.ch

Dry-snow zone climate, Greenland ice sheet

(A. Ohmura, IACS)
The objectives are: (1) investigations of the energy balance on the dry snow zone; (2) structure of the stable boundary layer and turbulence in extremely stable stratification; (3) gathering experiences to build a permanent environment observatory at Summit, Greenland; and (4) mechanism of blowing snow. The project started in 2000 and continues. The first over-wintering measurement took place in winter 2001/2002. Turbulent fluxes and profiles of atmospheric characteristics are investigated on a 50 m meteorological tower,

supported with a wind profiler and regular and intensive radio sounding of the atmosphere. Radiation is measured with the BSRN instrumentations, supplemented with observations of radiation and heat transfer in the snow cover. A particular goal is parameterization of a stable boundary layer and description of turbulent fluxes under such a condition, as well as the interaction of the sensible heat flux between turbulence and radiation. The 50 m tower is used to determine divergences of sensible heat flux and short- and longwave irradiances.

ohmura@geo.umnw.ethz.ch

AMUNDSEN: a tool to interpolate, simulate and visualize variable fields in Alpine terrain

(U. Strasser, IHW)

Mountain regions are characterized by a large intrinsic variability of natural processes in both space and time. AMUNDSEN (Alpine MUltiscale Numerical Simulation ENgine) is a new software tool to derive time series of spatially variable fields applying a wide range of interpolation and parameterization procedures. Its potential applications cover simulation of physical processes in glaciology, hydrology, climatology and other Alpine research fields. Basic considerations include platform independence, raster- and vector-data capability, full representation of temporal and spatial variability, a simple interface to plug in existing models and real-time visualization of the computed fields. The program is free and can be applied or extended. It is coded in IDL, which enables very efficient coding of vector and array manipulations and offers many visualization possibilities. IDL runs on UNIX/LINUX, Windows and Macintosh and can call external FORTRAN or C routines. The present functionality of AMUNDSEN covers a range of interpolation routines for scattered measurements, computation of topographic parameters from a DTM, parameterization of snow albedo and visualization of fields. See http://www.arolla.ethz.ch/Amundsen.html.

strasser@ihw.baug.ethz.ch

Role of snow and glaciers in Alpine hydrology

(M. Verbunt, K. Jasper, J. Gurtz, H. Lang, M. Zappa, IACS; P.Warmerdam, EnvS/UWag)

A temperature-index approach, including incoming solar radiation, was used as a submodel in the gridded-hydrological-catchment model WaSiM-ETH to simulate the melt rate of glacierized areas. Meltwater and rainfall are transformed into glacier discharge using linear-reservoir approaches. The complex model was applied to three high-Alpine river catchments, with different glacierized areas, to simulate discharges of the whole catchments. The catchment are: (a) Massa river (Wallis-Aletschgletscher) to the Blatten gauge (195 km^2, 65.9% glacierized); (b) Rhone basin (central Switzerland, mainly Rhonegletscher) to the Gletsch gauge (39 km^2, 52% glacierized); and (c) Dischma river (landscape of Davos, Scalettagletscher) to the Kriegsmatte gauge (43.3 km^2, 2.1% glacierized). Gridded datasets of elevation, soil type, and land use were used, as well as meteorological data from the MeteoSwiss network. These data were spatially and temporally interpolated and modified according to exposition, slope and topographic shading. Continuous-discharge simulations for the catchment areas were performed for 1981–2000 and compared with hourly discharge observations at the catchment outlets at a spatial resolution of 100 m and temporal resolution of 1 hour. The pronounced diurnal and seasonal fluctuations in discharge, typical for glacierized catchments, were simulated in good agreement with observations. The mean monthly water-balance elements (precipitation, evapotranspiration, runoff and its components including glacier runoff and snowmelt) for the catchments are estimated. The altitudinal dependence of the elements are compared.

gurtz@geo.umnw.ethz.ch

Spatially-distributed snowmelt modelling

(M. Zappa, J. Gurtz, IACS; F. Pos, P. Warmerdam, EnvS/UWag; U. Strasser, IHW)

To explore the choice of temperature-index- or energy-balance-based approaches for computing snowmelt, three temperature-index-based and an energy-balance-based snowmelt model have been investigated in detail. The snow models have been integrated in the spatially distributed hydrological model PREVAH. The study analyzed hydrological simulations of the Dischmabach catchment (43.3 km^2, 1668–3146 m a.s.l.) for 1982–2000. All four snowmelt approaches allowed a good simulation of the discharge regime and of the seasonal course of the snow cover. The highest efficiency was obtained with a radiation-based temperature-index approach. A simplified energy-balance approach, combined with the positive degree-day method, showed a performance very similar to the classical positive degree-day approach. The physically based energy-balance ESCIMO snow model gave high performance variability from year-to-year. The simulation analyses confirmed the importance of the snowmelt module for sound spatially distributed modelling of the hydrological cycle in an Alpine region. The module can be simple, due to the high relevance of surface air temperature for computing the seasonal course of the snow cover. The dependence of the seasonal water balance on altitude was also investigated. The quality of the spatially distributed reproduction of periods with positive and negative water balance (snow accumulation and melt) is crucial for the correct simulation of the runoff hydrograph. The runoff maximum in the Dischmabach catchment is caused by superposition of the main snowmelt season and the period of maximum rainfall at 2100–2800 m a.s.l.

zappa@geo.umnw.ethz.ch

Nutrient release from melting snow

(P. Waldner, M. Schneebeli, M. Stähli, W.J. Ammann, SLF/ WSL; M. Schwikowski, PSI; H. Flühler, ITO-ETH-Z)

In Alpine regions, the ionic content of precipitation stored in the winter snow cover is a relevant source of nutrients for the vegetation. The nutrient release of a subalpine, pronouncedly layered, field snowpack was measured with 32 basin samplers (0.4 x 0.7 m^2). Base melt, surface-melt percolation and a saturated lateral water flow in basal layers contributed to a heterogeneous release. In the case of nitrate, grain-scale ion redistribution during metamorphism did not dominate the release due to moderate temperatures and concentrations near solubility in ice. In cold-room experiments, the flow behaviour of meltwater was investigated by sieving snow types into a rectangular acrylic glass bin. Dye tracing showed boundaries between micro-structurally different snow layers that represent capillary barriers, at which percolation accumulates and preferential flow fingers emerge.

peter.waldner@wsl.ch

Spatial distribution of the snow cover in a sub-Alpine semi-forested landscape

(M. Stähli, P. Weissberg, Ch. Hegg, WSL)
An improved knowledge of the spatial snow-cover distribution in sub-Alpine areas having a complex topography and a highly heterogeneous forest structure is necessary for hydrological purposes. The snow-cover distribution of the Alptal sub-Alpine catchment (1000–1600 m a.s.l.) is being investigated using long-term snow-course measurements at about 15 locations, aerial photographs taken during several snowmelt seasons, Landsat TM images, as well as physically based and multiple-regression models. The snow models will be used in an operational runoff-forecasting system.

manfred.staehli@wsl.ch

GLACIAL GEOLOGY/ PALAEOGLACIOLOGY

Shear parameters of Alpine basal tills for palaeo-glacial reconstruction and engineering geology

(S. Bleuler, C. Schlüchter, UBern)
Basal tills are a widespread facies within the palaeo-extension of Ice Age glaciers. Palaeoglacial reconstructions still lack input data on the physical and mechanical properties of the former glaciers. With detailed mapping of the LGM glaciers both in the inner Alpine valleys and in the Alpine foreland, and with an extensive testing program of shear parameters of basal tills, we envisage realistic dynamic modelling of the maximum extension of valley glaciers during OIS 2. Our shear tests include conventional ring shear with long shearing paths and triaxial shear under w_{opt}-conditions on samples of valley long-axis transects. We also include samples (if possible) from basal areas of actual glaciers, because the increasing cohesive strength in certain samples being investigated as a function of lithological parameters is of special interest.

bleuler@geo.unibe.ch

Holocene glacier variations, Swiss Alps

(A. Hormes, C. Schlüchter, UBern)
Spectacular specimens of wood and compressed fossil peat have been released during the past 6 years by a number of Alpine glaciers, indicating they have been much smaller in the past than at present. Radiocarbon dating points to a repetition of such events over the past 10 kyr. Additional dating and palaeoecological studies on these fossil wood and peat samples will explain Holocene Alpine glacier oscillations.

anne@duskwalker.net

Northern and Southern Hemisphere Last Glacial Maximum ice extent

(F. Preusser, C. Schlüchter, UBern; P. Oberholzer, ETH-Z)
The Last Glacial Maximum ice extent and its timing in Chile, New Zealand, interior North America and the European Alps is being studied by a consortium of scientists from New Zealand, Chile, U.S.A., Norway, China and Switzerland. Detailed mapping and lithological logging of key sections is the basis for radiocarbon, OSL and surface-exposure dating of outwash sediments, moraines and ice-contact features. Special emphasis is given to the study (and dating) of the geological features related to the Younger Dryas cold reversal.

schluechter@geo.unibe.ch

Last Glacial Maximum ice cap in western Alps

(M.A. Kelly, C. Schlüchter, UBern; Peter W. Kubik, PSI)
The surface configuration of the Last Maximum Alpine ice cap is reconstructed based on detailed mapping of glacial erosional features, which indicate the former ice-surface elevation and flow directions within the western inner-Alpine region. The ice-surface reconstruction for the western Alps, combined with previous works from the western and central Alps, provides the most accurate representation of the Last Maximum ice surface in the Swiss Alps and indicates that the ice cap was influenced by both the underlying surface topography and a dominant southerly circulation. A major question is the age of this ice cap in the inner-Alpine region. Surface-exposure dating of mapped erosional features is applied to determine an age of deglaciation from the maximum ice surface.

kelly@geo.unibe.ch

Digital model and ice-flow analysis of the Würmian Rhein-Glacier (maximum extent)

(C. Benz, W. Haeberli, O. Keller, R. Weibel, Geog/UZI; with UOslo)
A first complete digital registration, modelling and analysis of the Würmian Rhein Glacier during its maximum extent has been done with a geographical information system (GIS). Existing data in analogue form (maps of reconstructed ice margins, ice surfaces or ground surfaces with/without Holocene sediments) is compiled from various sources. The information is then digitally registered, using the GIS ArcInfo and an intermediate resolution DTM. Existing algorithms and models for estimating surface-boundary conditions are tested with the 3-D model of the Würmian Rhein Glacier. First results confirm that flow under conditions of small driving stresses in the flat piedmont lobe was slow.

chbenz@geo.unizh.ch

Reconstruction of glacier fluctuations and dendrochronological investigation, Swiss Alps

(H. Holzhauser, Geog/UZI; with UBern)

Palaeosols and fossil woods have been dated in an attempt to reconstruct, without gaps, the amplitude of Holocene fluctuations of various Alpine glaciers in the Valaisian and Bernese Alps (Rhone-, Grosser Aletsch-, Gorner- and Lower Grindelwaldgletscher). Special attention is paid to minimum glacial extensions during the Holocene. At present, the last 3200 years have been reconstructed. With the aid of dendrochronological investigations of larches from the upper Alpine timberline and from glacier forefields, it is hoped to construct a long, absolute, dendro-standard curve. This curve can be used as an aid to absolute dating of fossil woods and as an indicator of past short- and long-term climate changes. By this work, the standard curve is now extended from 140 BC to AD 1999. With this and historical documents, it is possible to reconstruct the advances of the Gornergletscher within the 14th and 19th centuries in great detail. The advances of Grosser Aletschgletscher during the "Göschener cold period II" (about AD 100–600) and in the 16/17th centuries can be reconstructed with dendrochronologically dated wood. The results concerning the last 700 years (Late Middle Ages and modern times) can be combined with documentary sources and historical pictorial records. Special attention is paid to the "Medieval Climatic Optimum" (about AD 800–1300) and the Little Ice Age (about AD 1300–1850).

holzi@geo.unizh.ch

Application of exposure dating to the chronology of glacial and periglacial landforms, Grisons region

(M. Maisch, D. Brandova, W. Haeberli, Geog/UZI; J. Beer, AWAG)

The project combines exposure dating by measuring in-situ cosmogenic isotopes (^{10}Be and ^{26}Al) with the conventional radiocarbon method. A new sample-preparation facility for exposure dating has been established at Geog/UZI. Using samples from glacially and periglacially induced landforms, such as morainic ridges, transfluence passes, scoured bedrock and fossil rock glaciers, the project can refine present knowledge, especially of events and glacier stages older than the Younger Dryas period (Gschnitz-, Clavadel- and Daun-stadial). The results of exposure datings will be cross-checked with conventional radiocarbon samples taken simultaneously at peat bogs close to the exposure-dating sites. AMS measurements of the samples will be done in close collaboration with ETH Hönggerberg (M. Suter, P. Kubik, S. Ivy-Ochs).

maisch@geo.unizh.ch

Glacial geomorphology and glacier reconstruction in Late-glacial landscapes of the Upper Engadin

(M. Maisch, A. Kääb, W. Haeberli, Geog/UZI; H. Blatter, IACS)

In the Upper Engadin (Grisons, eastern Swiss Alps) a GIS-based, multilayered geomorphological mapping project is being completed. The database will serve as a tool to describe the present distribution of glacial and periglacial landforms (forefield areas, rock glaciers) as well as to reconstruct former glacier extents (i.e. Younger Dryas moraines) and to model their palaeoglaciological and palaeoclimatological characteristics.

maisch@geo.unizh.ch

Absolute and relative-age dating of rock-glacier surfaces in Alpine permafrost

(W. Haeberli, D. Brandova, S. Castelli, M. Egli, R. Frauenfelder, A. Kääb, M. Maisch, Geog/UZI; with University of Bonn)

Rock-glacier surfaces reflect debris accumulations produced, deposited and deformed during historical and Holocene times. Dating such surfaces can best be achieved by using a combination of absolute and relative-age determination methods. The potential of radiocarbon dating, optically stimulated luminescence, cosmogenic-exposure dating, lichenometry, Schmidt-hammer measurements, weathering-rind mapping and photogrammetric determinations of flow velocities/trajectories are being explored. Relict "rock-glacierized" features, abundant in many mountain ranges and most probably formed during Late-glacial cold-dry periods, can in principle be dated by cosmogenic (exposure) dating. However a number of difficult problems with this method need to be overcome in the future.

haeberli@geo.unizh.ch

Rutor Glacier during mid-Holocene: glacier contraction, palaeoclimate and vegetation history

(C. A. Burga, Geog/UZI; G. Orombelli, UMilB)

New material from a fresh section of the Alpine peat bog sediments, formerly covered by Rutor Glacier (2510 m a.s.l.), Aosta Valley, Italy, has been sampled. A detailed sediment profile of the new peat-bog section, 20 additional radiocarbon dates and a second series of pollen analyses were made. Rutor Glacier was revisited in summer 1998 and showed considerable shrinking. New samples were taken from the same site. The second series of pollen analyses confirm the palynostratigraphic results of the first series published by Burga (1991, 1993, 1994 and 1995).

burga@geo.unizh.ch

Compiled by Marcia Phillips and Walter J. Ammann

ABBREVIATIONS USED

AE	Academia Engiadina, Samedan, Switzerland
AS	Atmospheric Sciences
BAS	British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET, U.K.
CECS	Centro de Estudios Científicos, Valdivia, Chile
CG	Centre for Glaciology, Institute of Geography and Earth Sciences, UWalesA
CRREL/AK	Cold Regions Res. & Engineering Lab., Alaska Projects Office, Fort Wainwright, AK 99703-0170, U.S.A.
EAS	Earth and Atmospheric Sciences
EAWAG	Swiss Federal Institute of Science and Technology, CH-8600 Dübendorf, Switzerland
EnvS	Environmental Sciences
EPFL	École Polytechnique Fédérale de Lausanne, CH-1015 Lausanne, Switzerland
ETH-Z	Eidgenössische Technische Hochschule, CH-8057 Zürich, Switzerland
Geog	Geography
Geol	Geology/Geological Sciences
Geophys	Geophysics
GTS	Department of Geography and Topographic Science
HUB	Humboldt Universität, D-10099 Berlin, Germany
IACS	Institute for Atmospheric and Climate Science, ETH-Z
IGT	Geotechnical Institute, ETH-Hönggerberg, CH-8093 Zürich, Switzerland
IHW	Institute of Hydromechanics and Water Resources Management, ETHZ
IPP	Institute for Particle Physics, ETHZ
IRD-F	Institut de Recherche pour le Développement, Montpellier, France
ISM	Institut de Sciences des Matériaux
ISU	Iowa State University, Ames, IA 50011-3210, U.S.A.
IUKB	Institut Universitaire Kurt Bösch, Sion, Switzerland
IWEP	Institute for Water and Environmental Problems, Barnaul, Russia
LDEO	Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY 10964, U.S.A.
LGGE	Laboratoire de Glaciologie et Géophysique de l'Environnement, F-38402 Saint-Martin-d'Hères Cedex, France
LPM	Laboratoire de Physique des Matériaux, École des Mines, Nancy, France
NPI	Norwegian Polar Institute, Polarmiljøsenteret, N-9296 Tromsø, Norway
NVE	Norwegian Water Resources and Energy Administration, P.O. Box 5091 Majorstua, N-0301 Oslo, Norway
PSI	Paul Scherrer Institute, CH-5232 Villigen, Switzerland
SI	Science Institute, UIce
SISKA	Swiss Institute for Speleology and Karst Studies, La Chaux-de-Fonds, Switzerland
SLF	Swiss Federal Institute for Snow and Avalanche Research, CH-7260 Davos Dorf, Switzerland
UAlb	Univ. of Alberta, Edmonton, Alberta T6G 2E3, Canada
UBas	University of Basel, CH-4051Basel, Switzerland
UBern	University of Bern, CH-3012 Bern, Switzerland
UCam	University of Cambridge, Cambridge CB2 3EN, England, U.K.
Uch	Universidad de Chile, Santiago, Chile
UFrib	University of Fribourg, Switzerland
UGlas	University of Glasgow, Glasgow G12 8QQ, Scotland, U.K.
UIce	Univ. of Iceland, Dunhaga 5, IS-107 Reykjavík
ULaus	University of Lausanne, CH-1015 Lausanne, Switzerland
UMag	Universidad de Magallanes, 01855 Punta Arenas, Chile
UMilB	Università di Milano-Bicocca, I-20126 Milano, Italy
UOslo	University of Oslo, N-0316 Oslo, Norway
UParisS	Université Paris-Sud, Orsay, France
UTurin	Università di Torino, I-10124 Torino, Italy
UWag	University Wageningen, Wageningen, The Netherlands
UWalesA	University of Wales, Aberystwyth, Ceredigion, Dyfed SY23 3DB, Wales, U.K.
UZI	University of Zürich-Irchel, CH-8057 Zürich, Switzerland
VAW	Laboratory of Hydraulics, Hydrology and Glaciology, ETH-Z, CH-8092 Zürich, Switzerland
WGS	Wisconsin Geological Survey
WSL	Eidgenössische Forschungsanstalt für Wald, Schnee und Landschaft, CH-8903 Birmensdorf, Switzerland
YU	Yale University, New Haven, CT 06520-8109, U.S.A.

IGS STAFF CHANGES

In April of this year, Joan Keating retired. She had worked part time for the IGS since 1999, setting papers for the *Journal* and *Annals*. We welcome Ann Leeding who has taken her place and now works part time for us on Tuesdays and Thursdays.

JOHN GLEN PRIZE

At the 2001 Annual General Meeting of the British Branch of the International Glaciological Society, a prize for the best student presentations (both oral and poster) made at its Annual Meetings was introduced. The prize is to be called the John Glen Prize in recognition of John's continued enthusiastic support of the IGS British Branch. It was awarded by John himself at the 2001 meeting at the British Antarctic Survey, Cambridge. The award for best oral presentation went to Robert Bingham, University of Glasgow, for his talk on "Seasonal evolution of the drainage system with a high-Arctic polythermal valley glacier, as revealed by dye-tracing studies". The award for best poster went to Zoe Robinson, Keele University, for her presentation entitled "Proglacial ground-water response to multi-magnitude atmospheric/volcanic events".

Tony Payne (A.J.Payne@bristol.ac.uk)

INTERNATIONAL SYMPOSIUM ON SNOW AND AVALANCHES

Davos, Switzerland, 2–6 June 2003

CO-SPONSORED BY

Swiss Federal Institute for Snow and Avalanche Research (SLF, Davos)

FIRST CIRCULAR

The International Glaciological Society will hold an International Symposium on Snow and Avalanches in 2003. The symposium will be held at the congress centre, Davos, Switzerland with registration on 1 June, and sessions from 2–6 June.

THEME

The properties of snow in mountain and polar regions and the processes taking place within the snow cover are critical factors in the interpretation of climate and remote sensing signals and in our ability to model the movement of snow. In most mountain regions, avalanches pose a significant threat to human life and property. Improved scientific knowledge of mountain snow and avalanche dynamics opens up new and powerful prospects for reductions in this threat.

This Symposium will focus on those aspects of snow science related to understanding the snow cover, its properties and movement.

TOPICS

The suggested topics include:

- snow properties (mechanical, physical, electro-magnetic, chemical)
- modelling snow and ice
- snow cover (distribution, evolution, variability, climate change)
- snow cover monitoring and modelling
- snow drifting, blowing snow
- snow-cover ecology (interaction with flora and fauna)
- artificial snow
- snow and winter sports
- snow-cover hydrology
- avalanches (formation, process, snow-cover stability, modelling, monitoring, experiments)
- avalanche risk management

SESSIONS

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

PUBLICATION
Selected papers from the symposium will be published by the Society in the *Annals of Glaciology*. All papers (including poster papers) 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. A full range of hotel accommodation will be available.

FURTHER INFORMATION
If you wish to attend the symposium, please return the attached form as soon as possible to the IGS office. The Second Circular will give information about accommodation, the general programme, and preparation of abstracts and final papers. 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
S. Ommanney (Secretary General, International Glaciological Society)

CHIEF SCIENTIFIC EDITOR
P. Föhn (Chief Senior Scientist, SLF, Davos)

LOCAL ARRANGEMENTS COMMITTEE
Walter Ammann (Chairman)

INTERNATIONAL SYMPOSIUM ON SNOW AND AVALANCHES

Davos, Switzerland, 2–6 June 2003

Family Name: ____________________

First Name(s): ____________________

Address: ____________________

____

____

Tel: __________ Fax: __________

E-mail: ____________________

I hope to participate in the Symposium ☐

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 ☐

ANNALS OF GLACIOLOGY, VOLUME 34

The following papers from the Fourth International Symposium on Remote Sensing in Glaciology held in College Park, Maryland, U.S.A., 4–8 June 2001, have been accepted for publication in *Annals of Glaciology* Vol. 34, edited by J.-G. Winther and R. Solberg:

A P Ahlstrøm, C E Bøggild, J J Mohr, N Reeh, E L Christensen, O B Olesen and K Keller
Mapping of a hydrological ice-sheet drainage basin on the West Greenland ice-sheet margin from ERS-1/-2 SAR interferometry, ice-radar measurement and modelling

L M Andreassen, H Elvehøy and B Kjøllmoen
Using aerial photography to study glacier changes in Norway

M Aniya, R Naruse and S Yamaguchi
Utilization of 6 x 6 cm format vertical aerial photographs for repetitive mapping of surface morphology and measurement of flow velocities of a small glacier in a remote area: Glaciar Soler, Hielo Patagónico Norte, Chile

R L Armstrong and M J Brodzik
Hemispheric-scale comparison and evaluation of passive-microwave snow algorithms

P Bardel, A G Fountain, D K Hall and R Kwok
Synthetic aperture radar detection of the snowline on Commonwealth and Howard Glaciers, Taylor Valley, Antarctica

R Bindschadler, T Scambos, H Rott, P Skvarca and P Vornberger
Ice dolines on Larsen Ice Shelf, Antarctica

W M Calvin, M Milman and H H Kieffer
Reflectance of Antarctica from 3 to 5 µm: discrimination of surface snow and cloud properties

G Casassa, K Smith, A Rivera, J Araos, M Schnirch and C Schneider
Inventory of glaciers in isla Riesco, Patagonia, Chile, based on aerial photography and satellite imagery

F G L Cawkwell and J L Bamber
The impact of cloud cover on the net radiation budget of the Greenland ice sheet

J C Comiso
Correlation and trend studies of the sea-ice cover and surface temperatures in the Arctic

S B Das, R B Alley, D B Reusch and C A Shuman
Temperature variability at Siple Dome, West Antarctica, derived from ECMWF re-analyses, SSM/I and SMMR brightness temperatures and AWS records

C Derksen, A Walker, E LeDrew and B Goodison
Time-series analysis of passive-microwave-derived central North American snow water equivalent imagery

C S M Doake, H F J Corr and A Jenkins
Polarization of radio waves transmitted through Antarctic ice shelves

O Eisen, U Nixdorf, F Wilhelms and H Miller
Electromagnetic wave speed in polar ice: validation of the common-midpoint technique with high-resolution dielectric-profiling and γ-density measurements

E Ermolin, H de Angelis and P Skvarca
Mapping of permafrost on Vega Island, Antarctic Peninsula, using satellite images and aerial photography

M A Fahnestock, W Abdalati and C A Shuman
Long melt seasons on ice shelves of the Antarctic Peninsula: an analysis using satellite-based microwave emission measurements

S Filin and B Csathó
Improvement of elevation accuracy for mass-balance monitoring using in-flight laser calibration

M Frezzotti, S Gandolfi, F La Marca and S Urbini
Snow dunes and glazed surfaces in Antarctica: new field and remote-sensing data

M Frezzotti and M Polizzi
50 years of ice-front changes between the Adélie and Banzare Coasts, East Antarctica

H A Fricker, N W Young, I Allison and R Coleman
Iceberg calving from the Amery Ice Shelf, East Antarctica

S Fujita, H Maeno, T Furukawa and K Matsuoka
Scattering of VHF radio waves from within the top 700 m of the Antarctic ice sheet and its relation to the depositional environment: a case-study along the Syowa–Mizuho–Dome Fuji traverse

L Gray, N Short, R Bindschadler, I Joughin, L Padman, P Vornberger and A Khananian
RADARSAT interferometry for Antarctic grounding-zone mapping

R O Green, J Dozier, D Roberts and T Painter
Spectral snow-reflectance models for grain-size and liquid-water fraction in melting snow for the solar-reflected spectrum

S Gudmundsson, M T Gudmundsson, H Björnsson, F Sigmundsson, H Rott and J M Carstensen
Three-dimensional glacier surface motion maps at the Gjálp eruption site, Iceland, inferred from combining InSAR and other ice-displacement data

D K Hall, R E J Kelly, G A Riggs, A T C Chang and J L Foster
Assessment of the relative accuracy of hemispheric-scale snow-cover maps

K C Jezek
RADARSAT-1 Antarctic Mapping Project: change-detection and surface velocity campaign

I Joughin
Ice-sheet velocity mapping: a combined interferometric and speckle-tracking approach

A Kääb, F Paul, M Maisch, M Hoelzle and W Haeberli
The new remote-sensing-derived Swiss glacier inventory: II. First results

E Kärkäs, H B Granberg, K Kanto, K Rasmus, C Lavoie and M Leppäranta
Physical properties of the seasonal snow cover in Dronning Maud Land, East Antarctica

R E J Kelly
Estimation of the ELA on Hardangerjøkulen, Norway during the 1995/96 winter season using repeat-pass SAR coherence

A G Klein and J Stroeve
Development and validation of a snow albedo algorithm for the MODIS instrument

M König, J Wadham, J-G Winther, J Kohler and A M Nuttall
Detection of superimposed ice on the glaciers Kongsvegen and midre Lovénbreen, Svalbard, using SAR satellite imagery

R Kwok
Arctic sea-ice area and volume production: 1996/97 versus 1997/98

Li Jun and H J Zwally
Modeled seasonal variations of firn density induced by steady-state surface air-temperature cycle

Li Xin, T Koike and Cheng Guodong
Retrieval of snow reflectance from Landsat data in rugged terrain

T Markus, D J Cavalieri and A Ivanoff
The potential of using Landsat 7 ETM+ for the classification of sea-ice surface conditions during summer

K Matsuoka, H Maeno, S Uratsuka, S Fujita, T Furukawa and O Watanabe
A ground-based, multi-frequency ice-penetrating radar system

T Matsuoka, S Uratsuka, M Satake, A Nadai, T Umehara, H Maeno, H Wakabayashi, F Nishio and Y Fukamachi
Deriving sea-ice thickness and ice types in the Sea of Okhotsk using dual-frequency airborne SAR (Pi-SAR) data

N M Mognard and E G Josberger
Northern Great Plains 1996/97 seasonal evolution of snowpack parameters from satellite passive-microwave measurements

T Murray, T Strozzi, A Luckman, H Pritchard and H Jiskoot
Ice dynamics during a surge of Sortebræ, East Greenland

L Padman, H A Fricker, R Coleman, S Howard and L Erofeeva
A new tide model for the Antarctic ice shelves and seas

C L Parkinson
Trends in the length of the Southern Ocean sea-ice season, 1979–99

C L Parkinson and D J Cavalieri
A 21 year record of Arctic sea-ice extents and their regional, seasonal and monthly variability and trends

F Paul, A Kääb, M Maisch, T Kellenberger and W Haeberli
The new remote-sensing-derived Swiss glacier inventory. I. Methods

F C Pivot, C Kergomard and C R Duguay
Use of passive-microwave data to monitor spatial and temporal variations of snow cover at tree line, near Churchill, Manitoba, Canada

J M Ramage and B L Isacks
Determination of melt-onset and refreeze timing on southeast Alaskan icefields using SSM/I diurnal amplitude variations

F Rau and M Braun
The regional distribution of the dry-snow zone on the Antarctic Peninsula north of 70° S

E Rignot
Mass balance of East Antarctic glaciers and ice shelves from satellite data

E Rignot, D G Vaughan, M Schmeltz, T Dupont and D MacAyeal
Acceleration of Pine Island and Thwaites Glaciers, West Antarctica

A Rivera, C Acuña, G Casassa and F Bown
Use of remotely-sensed and field data to estimate the contribution of Chilean glaciers to eustatic sea-level rise

H Rott, W Rack, P Skvarca and H de Angelis
Northern Larsen Ice Shelf, Antarctica: further retreat after collapse

T A Scambos and T Haran
An image-enhanced DEM of the Greenland ice sheet

M Schmeltz, E Rignot and D MacAyeal
Tidal flexure along ice-sheet margins: comparison of InSAR with an elastic-plate model

C A Shuman and J C Comiso
In situ and satellite surface temperature records in Antarctica

P Skvarca, H de Angelis, R Naruse, C R Warren and M Aniya
Calving rates in fresh water: new data from southern Patagonia

B E Smith, N E Lord and C R Bentley
Crevasse ages on the northern margin of Ice Stream C, West Antarctica

M Stähli, J Schaper and A Papritz
Towards a snow-depth distribution model in a heterogeneous subalpine forest using a Landsat TM image and an aerial photograph

S Surdyk
Low microwave brightness temperatures in central Antarctica: observed features and implications

N Takeuchi
Optical characteristics of cryoconite (surface dust) on glaciers: the relationship between light absorbency and the property of organic matter contained in the cryoconite

T Tanikawa, T Aoki and F Nishio
Remote sensing of snow grain-size and impurities from Airborne Multispectral Scanner data using a snow bidirectional reflectance distribution function model

S W Vogel
Usage of high-resolution Landsat 7 band 8 for single-band snow-cover classification

A E Walker and A Silis
Snow-cover variations over the Mackenzie River basin, Canada, derived from SSM/I passive-microwave satellite data

W L Wang, H J Zwally, W Abdalati and S Luo
Modeling of ice flow and internal layers along a flowline through Swiss Camp, West Greenland

X Wang and J R Key
Aggregate-area radiative flux biases

R L Wessels, J S Kargel and H H Kieffer
ASTER measurement of supraglacial lakes in the Mount Everest region of the Himalaya

N W Young and G Hyland
Velocity and strain rates derived from InSAR analysis over the Amery Ice Shelf, East Antarctica

H J Zwally, M A Beckley, A C Brenner and M B Giovinetto
Motion of major ice-shelf fronts in Antarctica from slant-range analysis of radar altimeter data, 1978–98

JOURNAL OF GLACIOLOGY

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

M Arck and D Scherer
A physically based method for correcting temperature data measured by naturally ventilated sensors over snow

D I Benn, S Wiseman and K A Hands
Growth and drainage of supraglacial lakes on the debris-mantled Ngozumpa Glacier, Khumbu Himal, Nepal

D H Elsberg, W D Harrison, K A Echelmeyer and R M Krimmel
Quantifying the effects of climate and surface change on glacier mass balance

D P Hansen and L A Wilen
Performance and applications of an automated *c*-axis ice-fabric analyzer

J T Harper, N F Humphrey and M C Greenwood
Basal conditions and glacier motion during the winter/spring transition, Worthington Glacier, Alaska, U.S.A

W D Harrison, D H Elsberg, K A Echelmeyer and R M Krimmel
On the characterization of glacier response by a single time-scale

G Holdsworth and H R Krouse
Altitudinal variation of the stable isotopes of snow in regions of high relief

D M Holland
Computing marine-ice thickness at an ice-shelf base

B Hubbard
Direct measurement of basal motion at a hard-bedded, temperate glacier: Glacier de Transfleuron, Switzerland

H Jiskoot, A K Pedersen and T Murray
Multi-model photogrammetric analysis of the 1990s surge of Sortebræ, East Greenland

A V Kulkarni and I M Bahuguna
Correspondence. Glacial retreat in the Baspa basin, Himalaya, monitored with satellite stereo data

L Lliboutry
Overthrusts due to easy-slip/poor-slip transitions at the bed: the mathematical singularity with non-linear isotropic viscosity

L Lliboutry
Velocities, strain rates, stresses, crevassing and faulting on Glacier de Saint-Sorlin, French Alps, 1957–76

L Lliboutry
Extension of Glacier de Saint-Sorlin, French Alps, and equilibrium-line altitude during the Little Ice Age

N A Nereson and E D Waddington
Isochrones and isotherms beneath migrating ice divides

V Nijampurkar, K Rao, M Sarin and J Gergan
Isotopic study on Dokriani Bamak glacier, central Himalaya: implications for climatic changes and ice dynamics

S F Price, R A Bindschadler, C L Hulbe and D D Blankenship
Force balance along an inland tributary and onset to Ice Stream D, West Antarctica

G H Roe
Modeling precipitation over ice sheets: an assessment using Greenland

E Schlosser, N van Lipzig and H Oerter
Temporal variability of accumulation at Neumayer station, Antarctica, from stake array measurements and a regional atmospheric model

M Sharp, M Skidmore and P Nienow
Seasonal and spatial variations in the chemistry of a High Arctic supraglacial snow cover

L H Smedsrud
A model for entrainment of sediment into sea ice by aggregation between frazil-ice crystals and sediment grains

M K Spencer, R B Alley and T T Creyts
Preliminary firn-densification model with 38-site dataset

I E Tabacco, C Bianchi, A Zirizzotti, E Zuccheretti, A Forieri and A Della Vedova
Airborne radar survey above Vostok region, east-central Antarctica: ice thickness and Lake Vostok geometry

O Torinesi, A Letréguilly and F Valla
A century reconstruction of the mass balance of Glacier de Sarennes, French Alps

E D Waddington, J F Bolzan and R B Alley
Potential for stratigraphic folding near ice-sheet centers

Yi Chaolu and Cui Zhijiu
Subglacial deformation: evidence from microfabric studies of particles and voids in till from the upper Ürümqi river valley, Tien Shan, China

RECENT MEETINGS (of other organizations)

MIDWEST GLACIOLOGY MEETING

Northern Illinois University, DeKalb, Illinois, March 2001

In March of 2001, a geographically and professionally diverse group gathered at Northern Illinois University in DeKalb for the annual Midwest Glaciology Meeting. The two days of presentations were interesting and the discussions were lively. "Thin ice on the edge" would serve well as the meeting's motto, including floating, deflating, and palaeo forms. North America's Laurentide Ice Sheet (LIS) was featured in presentations regarding mechanisms and rates of till-sheet deposition along its warm, wet southern edge and in new reconstructions of cold, small-gradient outlet glaciers in the eastern Canadian Arctic. Thin, clay-rich till ramps on the upstream sides of escarpments on Door Peninsula, between two southern lobes of the LIS, were a novel, though unresolved, mystery. Till voyeurs had yet more cause for joy, thanks to stunning borehole videos of basal ice on Ice Stream C, West Antarctica. Alternating debris-rich and debris-poor layers rise many meters from the base of this now-stagnant ice stream. On the topside, cracks in glacier ice were of considerable interest. Crevasses were found to have negligible effects on the surface measurement of ice-stream deformation, were the subject of improvements to crack initiation theory, and were caught in the act of propagation on the floating terminus of Pine Island Glacier, thanks to multi-sensor imaging of Antarctica. Other insights into the evolution of floating ice derived from GPS/AWS instrumentation of an Antarctic iceberg and high resolution imaging of dolines on the Larsen Ice Shelf. The fates of diatoms were presented as a proxy for total shear history of tills, while the rise and fall of foraminiferal assemblages along the Western Antarctic Peninsula indicated a transition to an ENSO-like cycle in the region at the onset of the southern hemisphere climatic optimum. MGM Millennium, NIU's second turn at hosting the event, was declared by all to have been another success.

Christina Hulbe (chulbe@pdx.edu)

6th ALPINE GLACIOLOGY MEETING

VAW, Zürich, Switzerland, 21–22 February 2002

The 6th annual Alpine Glaciology Meeting (AGM) was held at the Laboratory of Hydraulics, Hydrology and Glaciology (VAW) of the Swiss Federal Institute of Technology (ETH) in Zürich on 21–22 February 2002. With 55 participants from as far from the Alps as the Netherlands attending the meeting, and study areas spanning the globe from northern Europe to central Asia to South America and many points in between, it becomes more evident that the meeting was named only for the location in which it occurs. It was good to see that graduate students were strongly represented. The 33 oral and 4 poster presentations over the two days covered a variety of topics reflecting the width of glaciology: glacier mass balance, energy balance, glacier hydrology, subglacial processes, glacier–climate interaction, ice-core studies, glacier dynamics, remote sensing, glacier hazards. The discussions during the sessions and breaks and over dinner were very fruitful and, again, manifested the importance of exchanging research ideas between participating glaciologists. In keeping with the informal tradition of AGM, no abstracts or papers were submitted and no proceedings will be published.

The 7th annual meeting is planned for late February 2003, and will be hosted by the Laboratoire de Glaciologie et Géophysique de l'Environnement in Grenoble, France.

Urs H. Fischer (ufischer@vaw.baug.ethz.ch)

FUTURE MEETINGS (of other organizations)

SYMPOSIUM ON MASS BALANCE OF ANDEAN GLACIERS

Valdivia, Chile, 12–13 March 2003

A Symposium on Mass Balance of Andean Glaciers will be hosted at Centro de Estudios Científicos in Valdivia, Chile, 12–13 March 2003. The Symposium is being organized by the Working Group on Andean Glaciers of the International Commission of Snow and Ice (http://geowww.uibk.ac.at/research/icsi/), with the goal of presenting advances and current understanding related to mass balance and glacier changes of Andean glaciers of South America. The official language will be English.

The following topics related to mass balance of Andean glaciers are to be addressed in the Symposium:

1) Mass balance measurement techniques;
2) Mass balance monitoring programmes;
3) Recent glacier variations and their relation with climate;
4) Glacio-hydrological studies and the relation with glacier mass balance.

We invite you to submit an abstract. Using the submitted abstracts as a guide, and based upon schedule constraints, the scientific committee will decide whether to accept an oral or poster presentation. Authors of accepted presentations will be invited to submit a paper. The proceedings of the Symposium are planned to be published in an international, peer-reviewed journal.

Immediately after the Symposium, a 1-day workshop on Friday 14 March is proposed for planning a mass balance network for Andean glaciers. All attendees to the Symposium will be welcome to this Workshop.

Valdivia is an attractive city of 130,000 inhabitants, surrounded by navigable rivers that connect with the Pacific Ocean, with good air and ground connections to Santiago. The city is located in the lake district of Chile, where active volcanoes and mountain glaciers coexist with abundant vegetation on the lower reaches. March marks the end of the summer season, with warm temperatures and occasional rain.

A 2-day post-symposium tour (15–16 March) will visit a glacier-covered volcano in the Chilean lake district.

Format for abstracts
Each submitted abstract is to be not more than 250 words. Please ensure your abstract contains the following information: **Title of abstract - author(s) - address - facsimile - email - preferred status** (oral presentation, poster, either). Font style is to be 12 pitch Times New Roman. Abstracts are to be received by the symposium convenor by e-mail as a Microsoft Word file attachment, before 1 October 2002.

Convenor and Head of the Working Group on Andean Glaciers of ICSI:
Gino Casassa, Centro de Estudios Científicos (CECS), Valdivia, Chile, Tel [56](63)234-540; Fax [56](63) 234-517; gcasassa@cecs.cl

Co-Convenors:
Andrés Rivera, Deputy Head, Working Group on Andean Glaciers, CECS, Valdivia and University of Chile, Santiago, Chile. Currently at Bristol University, U.K., Tel [44](117)928-8300; Fax [44](117)928-7878; andres.rivera@bris.ac.uk

Georg Kaser, Institut für Geographie, Universität Innsruck, Innrain 52, A-6020 Innsbruck, Austria, Tel [43](512)507-5407; Fax [43](512)507-2895; georg.kaser@uibk.ac.at

Pierre Ribstein. Maison des Sciences de l'Eau. IRD, BP 64501, 34394 Montpellier cedex 5, France. Tel [33](4)67-14-90-35; Fax [33](4)67-14-90-71; ribstein@msem.univ-montp2.fr

Christoph Schneider, Institut für Physische Geographie, Universität Freiburg, Werderring 4, D-79085 Freiburg, Germany, Tel [49](761)203-3548; Fax [49](761)203-3596; christoph.schneider@ipg.uni-freiburg.de

LABORATORY STUDIES OF THE FLOW OF ICE WORKSHOP

École Nationale de Ski et d'Alpinisme (ENSA), Chamonix Mont-Blanc, France, 31 August 2002

Objective
To establish guidelines for further laboratory study of ice flow, including the relationship between ice flow and crystal structure and other physical properties, particularly as it relates to the flow of the polar ice masses.

Who should attend
Experimentalists (those doing ice-deformation tests); theorists (those interpreting the results); modellers (those using the results); any others who are interested.

Questions to be answered
What do we know already? What don't we know? What is important to find out? What experiments need to be carried out? What range of stress pattern, temperature, stress, strain, strain rate, impurity content, crystal size, initial fabric, etc. needs to be covered? Deformation apparatus design – what needs to be developed? ?????

Format
Informal presentations where all participants discuss current laboratory work and share ideas openly. White board session to identify important points. Writing session to prepare draft paper (for publication) detailing recommendations for future work

Registration and information
There will be a 20 Euro registration fee (payable on 31 August) to cover hire of the venue, morning tea and lunch. If you are interested in attending, please contact
Jo Jacka (jo.jacka@aad.gov.au)
Armelle Philip (philip@lgge.obs.ujf-grenoble.fr)

FASTDRILL 2002 WORKSHOP

Interdisciplinary Polar Research Based on Fast Ice-Sheet Drilling
University of California, Santa Cruz, U.S.A., 3–6 October 2002

The workshop will have two primary objectives: (1) to provide an integrative forum for representatives of different scientific disciplines who are interested in a fast and mobile ice-sheet drilling system in order to address scientific problems, and (2) to identify relevant technological needs specific to each of the represented disciplines. Participation of scientists and engineers interested in polar biology, geology, geophysics, glaciology, paleoclimatology, ice-drilling technology, and other related disciplines is encouraged.

The final workshop report will include presentation abstracts as well as a summary of workshop discussions and recommendations. This report will be submitted to the NSF Office of Polar Programs and distributed to participants and other interested individuals. Limited funds are available to support workshop attendance.

RATIONALE

The scientific community, interested in sampling polar ice sheets and their substrata, has been growing and now incorporates biologists, geologists, and glaciologists. This multidisciplinary interest is opening new research frontiers. Significantly advancing our scientific understanding along many of these frontiers will require targeted sampling strategies and the acquisition of data from arrays of deep access holes on multiple spatial scales ranging from local to continent-wide. Recent advances in drilling technology may allow the development of a mobile drilling system capable of rapidly drilling arrays of boreholes through the 3–4 km thick polar ice sheets. Scientific applications that would be possible with a fast-access drilling system include, but would not be restricted to: sampling of subglacial geology, both glacially-related strata and bedrock; investigation of basal conditions and their control on ice sliding; geothermal heat-flow measurements; providing access to subglacial lakes; detection of life in deep ice through sampling and borehole logging; site selection for deep ice cores; logging climate proxies with geophysical instruments; borehole paleothermometry; and ice rheology studies.

GOALS

The specific goals for the proposed workshop are to: (1) provide a forum for discussions between scientists representative of the four major disciplines interested in research requiring ice-drilling capabilities (biology, geology, glaciology, paleoclimatology) and experts in ice drilling, conventional drilling technology, and downhole sampling systems; (2) formulate and present to NSF the participants' recommendations for future directions in polar research based on rapid-access drilling capabilities. This will include future targets for drilling and sampling that would maximize the interdisciplinary scientific payoff; (3) formulate and present to NSF the participants' recommendations regarding the near-future developments in drilling and sampling technology that are needed to meet the identified scientific goals; (4) identify and put in place formal/informal mechanisms, which are needed to provide crossdisciplinary coordination and to promote interdisciplinary collaboration in drilling-based polar research (e.g., listservers, web pages, working groups, regular workshops, practical steps to be taken to submit an interdisciplinary proposal for a near-future drilling and coring project).

ORGANIZING COMMITTEE

G.D. Clow (clow@usgs.gov),
D.H. Elliot (elliot.1@osu.edu),
R.D. Powell (ross@geol.niu.edu),
J.C. Priscu (jpriscu@montana.edu),
S. Tulaczyk (tulaczyk@es.ucsc.edu)

Full version of this announcement can be found at:
http://www.es.ucsc.edu/~tulaczyk/fastdrill.htm

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2002

21–28 August 2002
EU glacier training course, Obergurgl, Austria
J.C. Moore, Arctic Centre, Univ. Lapland, P.O. Box 122, FIN-96101 Rovaniemi, Finland (Tel [358](16) 341-2757; Fax [358](16)341-2777; jmoore@urova.fi; http://www.urova.fi/home/hkunta/jmoore/glacioeurolab4/oberannounce.htm)

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

31 August 2002
Workshop on Laboratory Studies of the Flow of Ice, Chamonix Mont-Blanc, France
A. Philip, Laboratoire de Glaciologie et Géophysique de l'Environnement, Domaine Universitaire, 54 rue Molière, BP 96, F-38402 Saint-Martin-d'Hères Cedex, France (Fax [33]476-82-42-01; philip@lgge.obs.ujf-grenoble.fr)

4–5 September 2002
* IGS British Branch Meeting, Department of Geography, University of Glasgow, Scotland, UK
P.W. Nienow, Department of Geographic and Topographic Science, University of Glasgow, Glasgow G12 8QQ, Scotland, UK (Tel [44](141)330-3634; Fax [44] (141)330-4894; igs2002@geog.gla.ac.uk; http://www.geog.gla.ac.uk/igs2002)

10–21 September 2002
Summer School on Ice Sheets and Glaciers in the Climate System, Karthaus, northern Italy
J. Oerlemans, Inst. of Marine and Atmospheric Research, University of Utrecht, Princetonplein 5, P.O. Box 80.005, NL-3508 TA Utrecht, The Netherlands (Tel [31](30)253-3275; Fax [31](30)254-3163; j.oerlemans@phys.uu.nl)

29 September–4 October 2002
International Snow Science Workshop 2002, Penticton, British Columbia, Canada
J. Bennetto, Chair, ISSW 2002, Box 38037, 794 Fort Street, Victoria, British Columbia V8W 3N2, Canada (Tel [1](250)387-7523; Fax [1](250)356-8143; chair@issworkshop.org; www.ISSWorkshop.org)

3–6 October 2002
Fastdrill 2002 Workshop, Interdisciplinary Polar Research Based on Fast Ice-Sheet Drilling, University of California, Santa Cruz, California, USA
S. Tulaczyk, Dept. of Earth Sciences,University of California, Santa Cruz, CA 95064, USA (Tel [1](831)459-5207; Fax [1](831)459-3074; tulaczyk@es.ucsc.edu; http://www.es.ucsc.edu/~tulaczyk/fastdrill.htm)

7–9 November 2002
* IGS Nordic Branch Meeting, Oslo, Norway
G. Lappegard, Dept. Geography, Univ. Oslo, P.O. Box 1042, Blindern, N-0316 Oslo, Norway (Tel [47]22-85-58-12; Fax [47]22-85-72-30; gaute.lappegard@ geografi.uio.no; http://www.geografi.uio.no/forskning/igs/)

2–6 December 2002
16th IAHR International Symposium on Ice, Dunedin, New Zealand
P.J. Langhorne, Dept. Physics, Univ. Otago, P.O. Box 56, Dunedin, New Zealand (Tel [64](3)479-7749; Fax [64](3)479-0964; nzice@physics.otago.ac.nz; http://www physics.otago.ac.nz/~nzice/)

16–17 December 2002
International Workshop on Snow Hydrology in Mediterranean Regions, Beirut, Lebanon
H.G. Jones, INRS-Eau, Université du Québec, 2700 rue Einstein, C.P. 7500, Sainte-Foy, Québec G1V 4C7, Canada (Tel [1](418)654-2533; Fax [1](418)654-2562; gerry_jones@inrs-eau.uquec.ca)

2003

13–14 January 2003
Conference on Cryospheric Systems, Geological Society, Burlington House, London, UK
C. Harris, Dept. Earth Sciences, Univ. Wales, P.O. Box 914, Cardiff CF1 3YE, UK (Tel [44](29)2087-4336; Fax [44](29)2087-4326; harrisc@cardiff.ac.uk)

14 February 2003
Röthlisberger Symposium, Milestones in Physical Glaciology: From the Pioneers to a Modern Science, Auditorium Maximum, ETH Zürich, Switzerland
M. Funk, Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie (VAW), ETH-Zentrum, Gloriastrasse 37/39, CH-8092 Zürich, Switzerland (Tel [41](1)632-4132; Fax [41](1)632-1192; funk@vaw.baug.ethz.ch)

12–13 March 2003
Symposium on Mass Balance of Andean Glaciers, Centro de Estudios Científicos, Valdivia, Chile
G. Casassa, Centro de Estudios Científicos (CECS), Valdivia, Chile (Tel [56](63)234-540; Fax [56](63)234517; gcasassa@cecs.cl)

12–16 May 2003
Seventh Conference on Polar Meteorology and Oceanography and Joint Symposium on High-Latitude Climate Variations, Hyannis, Massachusetts, USA
J. Francis, Inst. of Marine and Coastal Sciences, Rutgers Univ., Highlands NJ 07732, USA (Tel [1](732)708-1217; Fax [1](732)872-1586; francis@imcs.rutgers.edu; http://www.ametsoc.org/AMS)

25–30 May 2003
ISOPE-2003, 13th Annual International Offshore and Polar Engineering Conference, Honolulu, Hawaii, USA
ISOPE-2003 TPC, P.O. Box 189, Cupertino, CA 95015-0189, USA (Tel [1](408)980-1784; Fax: [1](408)980-1787; meetings@isope.org; http://ww.isope.org)

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

30 June – 11 July 2003
XXIII General Assembly of the International Union of Geodesy and Geophysics, Sapporo, Japan (http://www.jamstec.go.jp/jamstec-e/iugg/html/frist.htm)

Remote Sensing of the Cryosphere (JSH01; 7–8 July). R.L. Armstrong, CIRES/NSIDC, Univ. Colorado, Campus Box 449, Boulder, CO 80309, USA (Tel [1](303)492-1828; Fax [1](303)492-2468; rlax@kryos.colorado.edu)

Snow Processes: Representation in Atmospheric and Hydrological Models (JWH01; 9–10 July). J.W. Pomeroy, Centre for Glaciology, Inst. of Geography and Earth Sciences, Univ. Wales, Aberystwyth, Ceredigion SY23 3DB, Wales, UK (Tel [44](1970)622-781; Fax [44](1970)622-659; john.pomeroy@aber.ac.uk)

Cryosphere–Climate Interactions (JSM10; 2 days) S.P. O'Farrell, CSIRO Div. of Atmos. Res., Private Bag No.1, Aspendale, Victoria 3195, Australia (Tel [61](3)9239-4573; Fax [61](3)9239-4444; siobhan.ofarrell@dar.csiro.au)

Global Sea Level Rise, Global Climate Change and Polar Ice Sheet Stability (JSM11; 2 days) A. Cazenave, GRGS, CNES, 18 avenue Edouard Belin, F-31055 Toulouse Cedex, France (Tel [33]561-33-29-22; Fax [33]561-25-32-05; anny.cazenave@cnes.fr)

Nakaya–Magono Celebration on the Growth of Ice Crystals and Snow (JSM15; ½ day) R. List, Dept. of Physics, Univ. Toronto, 60 St. George Street, Toronto, Ontario M5S 1A7, Canada (Tel [1](416)978 2982; Fax [1](416)978-8905; list@atmosp.physics.utoronto.ca)

Role of Atmospheric Processes in Mass Balance Exchange in the Polar Regions (JSM16: 1 day) R. Bintanja, Inst. for Marine and Atmospheric Research, Utrecht University, Princetonplein 5, NL-3584 CC Utrecht, The Netherlands (Tel [31](30)253-32-59; Fax [31](30)254-31-63; r.bintanja@phys.uu.nl)

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

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

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

2004

23–27 August 2004
** International Symposium on Arctic Glaciology, Geilo, Norway
Secretary General, IGS, Lensfield Road, Cambridge CB2 1ER, UK (www.spri.cam.ac.uk/igs/home.htm)

2005

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

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

NEW MEMBERS

Guy Adema, Denali National Park, P.O. Box 9, Denali Park, Alaska, AK 99755, U.S.A. (Tel [1](907)683-6356; Fax [1](907)683-9634; guy_adema@nps.gov)

Todd Albert, CIRES/CSES, University of Colorado, Campus Box 216, Boulder, Colorado, CO 80309-0216, U.S.A. (Tel [1](303)492-6881; Fax [1](303)492-1149; todd.albert@colorado.edu)

Helena Alexanderson, Department of Quaternary Geology, Lund University, Sölvegatan 13, S-223 63 Lund, Sweden (Tel [46](46)222-7881; Fax [46](46)222-4419; helena.alexanderson@geol.lu.se)

David J. Barclay, Department of Geology, State University of New York at Cortland, P.O. Box 2000, Cortland, New York, NY 13045, U.S.A. (Tel [1](607)753-2921; Fax [1](607)753-2927; barclayd@cortland.edu)

Marion Bougamont, Department of Earth Sciences, University of California — Santa Cruz, Earth & Marine Sciences Bldg., A208, 1156 High Street, Santa Cruz, California, CA 95064, U.S.A. (Tel [1](831)459-2838; Fax [1](831)459-3074; marion@es.ucsc.edu)

Jonathan L. Carrivick, School of Earth Science & Geography, Keele University, Keele ST5 5BG, England, U.K. (Tel [44](1782)583-620; Fax [44](1782)715-261; j.l.carrivick@esci.keele.ac.uk)

David Chandler, Centre for Glaciology, Institute of Geography and Earth Sciences, University of Wales, Aberystwyth, Ceredigion SY23 3DB, Wales, U.K. (Tel [44](1970)621-859; Fax [44](1970)622-659; dmc01@aber.ac.uk)

Poul Christoffersen, Department of Civil Engineering, Technical University of Denmark, Center for Arctic Technology, Building 204, DK-2800 Lyngby, Denmark (Tel [45]45-25-21-68; pc@byg.dtu.dk)

Dorthe Dahl-Jensen, Department of Geophysics, The Niels Bohr Institute (NGIfAPG), University of Copenhagen, Juliane Maries Vej 30, DK-2100 Copenhagen Ø, Denmark (Tel [45]35-32-05-56; Fax [45]35-36-53-57; ddj@gfy.ku.dk)

Guglielmina Adele Diolaiuti, Dipartimento di Scienze della Terra, Universit di Milano, Via Mangiagalli 36, I-20100 Milano, Italy (Tel [39](02)50-31-55-14; Fax [39](02)70-63-82-61; guglielmina.diolaiuti@unimi.it)

David C. Finnegan, U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, 72 Lyme Road, Hanover, New Hampshire, NH 03755-1290, U.S.A. (Tel [1](603)646-4106; Fax [1](603)646-4644; david.finnegan@crrel.usace.army.mil)

P. Jay Fleisher, Department of Earth Sciences, State Univ. New York at Oneonta, Ravine Parkway, Oneonta, New York, NY 13820-4015, U.S.A. (Tel [1](607)436-3375; Fax [1](607)436-3547; fleishpj@oneonta.edu)

Alessandro Ghinoi, Dipartimento di Scienza della Terra, Università di Modena, Largo S. Eufemia, I-41100 Modena, Italy (Tel [390](59)205-5855; Fax [390](59)205-5887; ghinoi.alessandro@unimo.it)

Aslak Grinsted, Arctic Centre, University of Lapland, P.O. Box 122, FIN-96101 Rovaniemi, Finland (Tel [358](16)341-2748; ag@glaciology.net)

Eleanor Haresign, School of Geography and Geosciences, University of St Andrews, Irvine Building, North Street, St Andrews, Fife KY16 9AL, Scotland, U.K. (Tel [44](1334)462-811; Fax [44](1334)463-949; ech@st-and.ac.uk)

Joel T. Harper, Department of Geology and Geophysics, University of Wyoming, P.O. Box 3006, Laramie, Wyoming, WY 82071-3006, U.S.A. (Tel [1](307)766-6752; Fax [1](307)766-6679; joelh@uwyo.edu)

Jakob Helbing, Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie (VAW), ETH-Zentrum, Gloriastrasse 37/39, CH-8092 Zürich, Switzerland (Tel [41](1)632-4122; Fax [41](1)632-1192; helbing@vaw.baug.ethz.ch)

Catherine Hooper, School of Geography, University of Leeds, Leeds LS2 9JT, England, U.K. (Tel [44](113)233-6638; Fax [44](113)233-3308; pgcrh@geography.leeds.ac.uk)

Marzena Kaczmarska, Polar Environmental Centre, Norwegian Polar Institute, N-9296 Tromsø, Norway (Tel [47](77)75-05-38; Fax [47](77)75-05-01; marzena@npolar.no)

Eric Yves Larour, Jet Propulsion Laboratory, California Institute of Technology, Mail Stop 300-235, 4800 Oak Grove Drive, Pasadena, California, CA 91109-8099, U.S.A. (Tel [1](818)354-1640; Fax [1](818)393-3077; eric.larour@jpl.nasa.gov)

James Lehrer, 1334 Sierra Alta Way, Los Angeles, California, CA 90069, U.S.A. (Hom [1](310)276-9288; Fax [1](310)276-2901; lehrer50@MSN.com)

Martin Lüthi, Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie (VAW), ETH-Zentrum, Gloriastrasse 37/39, CH-8092 Zürich, Switzerland (Tel [41](1)632-4140; Fax [41](1)632-1192; luthi@vaw.baug.ethz.ch)

Bryan G. Mark, Department of Geography & Topographic Science, University of Glasgow, Glasgow G12 8QQ, Scotland, U.K. (Tel [44](141)330-2287; Fax [44](141)330-4894; bmark@geog.gla.ac.uk)

Megan Mellsop, P.O. Box 4, Franz Josef Glacier, 7952, New Zealand (Tel [64](3)752-0763; Fax [64](3)752-0102; walks@franzjosefglacier.com)

Shad O'Neel, University NAVSTAR Consortium (UNAVCO), 3340 Mitchell Lane, Boulder, Colorado, CO 80301, U.S.A. (Tel [1](303)497-8041; shad@unavco.ucar.edu)

Byron R. Parizek, 2000 North Oak Lane, State College, Pennsylvania, PA 16803, U.S.A. (Tel [1](814)865-6720; Fax [1](814)863-7823; parizek@essc.psu.edu)

Ralph Patterson, Northwest Weathernet INL, P.O. Box 1313, Issaquah, Washington, WA 98027-0052, U.S.A. (Tel [1](425)644-8468; Fax [1](425)644-1939; ralphpatterson@yahoo.com)

Nicholas P. Pelham, Department of Geography, University of Salford, Peel Building, Salford Crescent, Salford M5 4WT, England, U.K. (Tel [44](161)295-3136; Fax [44](161)295-5015; n.p.pelham@pgr.salford.ac.uk)

Karen Guldbaek Schmidt, Center for Planetary Science, The Niels Bohr Institute (NGIfAPG), University of Copenhagen, Juliane Maries Vej 30, DK-2100 Copenhagen Ø, Denmark (Tel [45]35-32-05-19; Fax [45]35-36-53-57; kgs@gfy.ku.dk)

Konosuke Sugiura, 3173-25 Showa-machi, Kanazawa-ku, Yokohama 236-0001, Japan (Tel [81](45)778-5648; Fax [81](45)778-5706; sugiura@jamstec.go.jp)

Lev Tarasoff, Department of Physics, University of Toronto, 60 St. Georges Street, Toronto, Ontario M5S 1A7, Canada (Tel [1](519)821-3555; Fax [1](416)978-8905; lev@atmosp.physics.utoronto.ca)

Slawek Tulaczyk, Department of Earth Sciences, University of California — Santa Cruz, Earth & Marine Sciences Bldg., A208, Santa Cruz, California, CA 95064, U.S.A. (Tel [1](831)459-5207; Fax [1](831)459-3074; tulaczyk@es.ucsc.edu)

Catharine Ward, CLIWOC Project, National Maritime Museum, The SW Basement, Greenwich, London SE10 9NF, England, U.K. (Tel [44](208)312-6722; Fax [44](208)312-6508; cward@nmm.ac.uk)

Andrew P. Wright, Room 3.39, The Hawthorns, 14 Woodland Road, Clifton, Bristol BS8 1UQ, U.K. (Tel [44](117)928-8300; a.p.wright@bristol.ac.uk)

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ICE

Editor: C.S.L. Ommanney (Secretary General)

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All enquiries about the International Glaciological Society should be addressed to:
Secretary General, International Glaciological Society, Scott Polar Research Institute,
Lensfield Road, Cambridge CB2 1ER, England
Tel: +44 (1223) 355974 Fax: +44 (1223) 336543
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