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COVER PICTURE: Weathered iceberg, December 1930 (photograph from National Institute of Oceanography, courtesy of H. F. P. Herdman).

Recent work

SWEDEN

For abbreviations, see end of this report

ALPINE GLACIERS

Glaciers as indicators of climate change

(Per Holmlund, NGSU)

The regional representativeness of Storglaciären is studied using other glaciers. The glaciers in the mass-balance programme are usually visited twice a year, at the end of the accumulation and ablation periods: the number varies. For 1993/94 it included ten glaciers, five of which are included in a long-term mass-balance programme; Mårmaglaciären, Rabots glaciär, Riukojietna, Kårsa-glaciären and Storglaciären. The glaciers have been chosen with respect to the east–west climatic gradient in the area, in which the western glaciers are influenced by a much more maritime climate than the eastern ones.

20 glaciers are observed with respect to changes in frontal position. This programme, running since 1965, also includes photogrammetric surveys and radio-echo soundings in order to improve the time resolution. Automatic weather stations have been placed at glaciers remote from the climate stations used by SMHI.

Character and distribution of englacial drainage in a sub-polar glacier

(Per Holmlund, Veijo Pohjola and Thomas Schneider, NGSU)

Information on the distribution of englacial water channels, from ice radar, is used, with visual information from borehole video recordings of active channels and from surface observations of fossil (frozen) channels, to describe englacial drainage in Storglaciären. Studies of water movement in the firn area have been initiated to trace the origin of the drainage system.

Rheology of subglacial till

(Peter Jansson, NGSU; Roger LeB. Hooke, GGUM; Brian Hansson, GUD; Neal Iverson, GGUM; Ned Grace, GUD)

The rheology of the till layer beneath Storglaciären has been investigated by continuous measurements of shear strain rate and shear strength. These, combined with measurements of basal water pressure, sliding speed, and surface velocity will provide a framework for evaluating the importance of till deformation in the sliding process. The data permit exploration of possible constitutive relations for till deformation. Laboratory ring-shear tests are used to study deformation mechanisms. Field observations indicate an inverse relationship between sediment deformation and water pressure.

Glaciological projects at Tarfala Research Station

(Wibjörn Karlén, Per Holmlund and Håkan Grudd, NGSU)

The 49 year-long mass-balance record of Storglaciären forms the basis for glacio-climatic studies in Sweden. The stake net on the glacier is surveyed every week or every second week throughout the melt season.

Climatic data have been collected continuously here since 1965; the automatic weather station was computerised in 1989. The hydrological regime is surveyed every year using stream gauges at four sites in the valley to establish a hydrological balance for Storglaciären. The station is also used for student courses and small conferences. Results and general information about the station are published in the annual report available through NGSU.

Basal ice beneath Engabreen

(Peter Jansson and Veijo Pohjola, NGSU; Jack Kohler, NVE)

Studies of basal ice and processes relating to the regelation mechanism started under Engabreen in February 1994. Short, 1–1.7 m of ice cores taken from the basal ice underneath 200 m ice are being analyzed for hydrogen- and oxygen-isotope composition, cation concentration, sediment content and ice crystallography. The cores were taken from the walls of tunnels melted into the ice from a bedrock tunnel underneath the glacier. This allowed detailed descriptions of the basal sequence of clean and sediment-rich ice. Preliminary results from oxygen-isotope ratios of a core subsample reveal a complex pattern. No firm conclusions can be drawn but it is evident that none of the theories described in the literature fit the data set in a simple fashion. Analysis of the remaining samples is under way.

Attempts have also been made to investigate the stress regime in the basal ice. A pilot study measured the normal pressure in the ice relative to pressure sensors during borehole closure. The records are not fully understood and further studies must be made before any conclusions can be drawn.

The basal ice under Engabreen contains a large number of englacial water pockets. Complete pockets have been sampled for analyses similar to those of the basal sequences. Water from the pockets has proved to be significantly lighter in oxygen-isotope ratio than the surrounding ice.

See also NORWAY (*ICE*, No. 106, 3rd issue 1994, p. 8)

Model study of Storglaciären

(Arjen P. Stroeven, NGSU)

Almost half a century of continuous investigations on Storglaciären have resulted in an impressive database against which to test a numerical time-dependent flow model. The model is one-dimensional, and describes the glacier geometry along a 5 km-long central flowline at 100 m intervals. The objective of the study is threefold: to investigate whether realistic longitudinal glacier profiles can be generated given physical (ice hardness, flow velocities), geometric, and mass-balance input; to simulate the historic variations of Storglaciären (retreat since its Little Ice Age maximum at 1910) and derive information concerning past climatic change in northern Sweden for comparison with other evidence (this part of the study also derives climatic constraints on Holocene maximum glacier extent in the northern Swedish mountains prior to 1910);

and, once the model is optimized, to predict the future behaviour of Storglaciären for varying climatic scenarios.

GLACIERS, DRONNING MAUD LAND, EAST ANTARCTICA

Snow stratigraphy from snow radar

(Per Holmlund and Cecilia Richardson, NGSU)
Snow layers were mapped in Dronning Maud Land during the austral summer 1993/94 using a snow radar. Soundings were performed along two traverses from the coast to 3000 m elevation and a total of 2300 km of profiles were recorded; part of the Swedish contribution to the International Trans-Antarctic Scientific Expedition (ITASE). Radar soundings from a terrain carrier used a frequency range of 800–2300 MHz. They penetrated the firn to a depth of 12.5 m; point-measurements were sampled every 5 m. The recordings show large variations in the accumulation pattern. The snow-radar data will be calibrated using snow-core data sampled during the expedition; annual layers will be separated by analyzing the oxygen-isotope ratios. At coring sites, a detailed grid of radio-echo profiles was surveyed to obtain a 3D snow-layer map.

The data set will be used for: interpolating accumulation data between coring sites and high-resolution visualization of the spatial distribution of snow; calculating an accumulation gradient from sea level up to 3000 m elevation for this part of the East Antarctic ice sheet; and verifying the geographical representativity of accumulation data from snow-core analysis. The potential of ground-based snow-radar data for calibrating satellite-based radar-altimeter data (ERS-1) will also be investigated.

Ice flow and ice depth measurements, Maudheimvidda basin

(Per Holmlund and Jens-Ove Näslund, NGSU)
For a balanced flow study in the Maudheimvidda basin, western Dronning Maud Land, measurements of ice flow and ice depth were carried out for 25 000 km^2 of the East Antarctic ice sheet. Between 1988/89 and 1993/94 ice movement at the several inlets and two outlets of the study area was surveyed by optical instruments up to 20 km and by high-precision differential GPS measurements at longer distances. For the major outlet, the Veststraumen Ice Stream, a maximum ice velocity of 200 m a^{-1} was determined. For the smaller Plogbreen Ice Stream, the maximum ice velocity is 90 m a^{-1}. During the same period, continuous ice-depth profiles were retrieved by radio-echo soundings at 60, 155 and 345 MHz, conducted from helicopter, terrain-carrier and skidoo. The mass gain of the basin, comprising ice flux into the area and its snow accumulation (from stake, radar and firn-core measurements), will be compared with the basin's ice-flux mass loss in the balanced flow calculation.

Interactions between ice sheet, climate and landscape

(Jens-Ove Näslund and Per Holmlund, NGSU)
The interactions between the East Antarctic ice sheet, climate and landscape evolution are poorly known, therefore a study of the subglacial landscape and long-term glacial history of western Dronning Maud Land was started in 1988/89. The subglacial bedrock morphology in the Heimefrontfjella and Vestfjella areas was mapped by radio-echo sounding at 60 and 155 MHz. The derived morphological data supply information on the climate at the time of landform formation and on the erosive capability of the present-day ice sheet. Subglacial cirques and glacial valleys close to nunataks indicate a warm-based, probably Alpine, glaciation occurred before the formation of the present mainly cold-based ice sheet, possibly as early as the pre-Quaternary. The origin and morphological characteristics of valley systems and mountain massifs beneath local ice divides at the inland Amundsenisen plateau and the coastal Högisen ice dome are also being studied.

Wet-based glacial erosion in the Vestfjella–Heimefrontfjella region

(Jens-Ove Näslund and Arjen Stroeven, NGSU; Mark Kurz, MCGWH)
The isotopic composition of bedrock surface layers can indicate how long the surfaces have been exposed to bombardment of cosmic rays. During the austral summer 1993/94, outcropping striated bedrock samples were collected from five nunatak peaks in the Vestfjella, Mannefallknausane and Heimefrontfjella mountains; the sites ranging in altitude from 500 to 2250 m a.s.l. and 50 to 300 m above the present ice surface. By assuming the erosion that striated the pavements removed all of the previously isotopically altered bedrock, we infer that a cosmogenic date on such a surface will yield a minimum age, at an order of magnitude scale, on wet-based glaciation. The study will test a suggested Late-Weichselian age for ice sheet overriding and erosion. It also allows construction of the first dated glacial chronology for western Dronning Maud Land.

ENGINEERING GLACIOLOGY

Ice properties and ice loads

(Lennart Fransson, Mikael Nyström, Georg Danielsson and Lars Åström, THL)
Ice loads on marine structures can be derived from actual ice conditions using a recently developed ice-fracturing model. The model has been calibrated by measurements on an instrumented structure in Luleå Harbour. The required mechanical properties (mainly strength and fracture toughness) of fresh-water ice and sea ice in the Gulf of Bothnia are measured directly in the field and on sampled ice cores. The ice is classified according to origin, density, crystal shape and size, and salinity and temperature. Large ice-core drills, in situ stress sensors and most ice-testing equipment are manufactured at the university. The project is financed by the Swedish Council for Building Research and the COLDTECH Foundation.

Stress measurement in ice with hydraulic fracturing method, Storglaciären

(Nils Outters, KTH)
The field study by the Division of Engineering Geology, KTH in July 1994 on Storglaciären, was the first attempt to measure ice-stresses with the hydraulic fracturing method. This method is usually used in rocks to evaluate the magnitudes and orientation of the horizontal principal stresses, assuming vertical stresses equal to the overburden pressure.

GLACIER HYDROLOGY

Water movement and storage in firn, Storglaciären

(Thomas Schneider, NGSU)

The hydraulic properties of the firn layer of Storglaciären were investigated. Above the firn-ice transition, at a depth of ≈22 m, an aquifer built up with a maximum thickness of ≈5 m at the end of July and at the beginning of September. The effective porosity was calculated from the density to be 0.073. The transmissivity of the firn layer was determined by pumping tests as 2.4 ± 0.5–$10^{-4}\,m^2\,s^{-1}$. With an aquifer thickness of about 4.8 m, the hydraulic conductivity of the firn aquifer was 4.9 ± 1–$10^{-5}\,m^2\,s^{-1}$. The average linear flow velocity amounted to $\approx 0.25\,m\,h^{-1}$ as the hydraulic gradient was 0.1. The percolation velocity was calculated from the time lag of maximal water input at the glacier surface and the water level peaks, and amounted to $0.25\,m\,h^{-1}$.

In areas influenced by draining crevasses, the magnitude of the water-level peaks became lower with progression of the melt season, indicating the development of the englacial drainage system through the summer. The water level in a crevassed area showed diurnal fluctuations, probably caused by diurnally produced meltwater waves which moved quickly through the englacial drainage system. Long-term fluctuations were a result of the water slowly percolating through the firn layer. The percolation velocity was lower at the beginning of the ablation season than at the end, indicating a widening of the firn pores. In addition, a decrease of percolation velocity with percolation depth was found reflecting decreasing permeability. The maximum water storage occurred about one week later than the maximum summer discharge at the glacier terminus, denoting the influence on the delay of water discharge from a glacierized drainage basin.

ICE-CORE STUDIES

Recent changes in snow accumulation, stable isotopes and atmospheric conditions, Antarctica

(Elisabeth Isaksson, NGSU)

Since 1988, a program of stake measurements and shallow firn coring (10–30 m) in western Dronning Maud Land has been detecting any changes in the spatial or temporal patterns of accumulation and stable isotopes, i.e. temperature. Shallow firn cores were collected along Bailey Ice Stream and on the Filchner Ice Shelf. Accumulation in the coastal area of Dronning Maud Land has decreased since the early 1930s while it seems to have been stable on the polar plateau during the last 150 years. The $\delta^{18}O$ record suggests warming both in the coastal and high-altitude areas. Interpretation of one high-resolution glacio-chemical record from the polar plateau (3000 m a.s.l.) covering 1865 to 1991 reveals changes in atmospheric conditions as well as teleconnections to lower latitudes. The results give some insight as to what might be learned from the deeper EPICA (European Programme for Ice Coring in Antarctica) core proposed for this area.

International Trans-Antarctic Scientific Expedition (ITASE): Snow cores

(Elisabeth Isaksson, Malin Stenberg and Wibjörn Karlén, NGSU)

The project is designed to study patterns in the spatial distribution of major impurities, stable isotopes and accumulation from the coast and inland, as well as any temporal changes during the last 50 to 200 years, using shallow firn cores. A ground-based expedition traveled between 72°39′ S, 16°39′ W and 75°3′ S, 2°3′ E in western Dronning Maud Land during the austral summer of 1993/94. 14 cores of 10–30 m were drilled from the coast up to 3000 m a.s.l. on the polar plateau. The coring sites were planned to sample as many elevations as possible. In addition to the cores, 2 m pits were dug and sampled. The analysis program includes; $\delta^{18}O$, Na^+, Mg^{2+}, $K+$, Ca^{2+}, $NH_4{}^+$, Cl^-, $SO_4{}^{2-}$, $NO_3{}^-$, and MSA. Results are not yet available.

Ice-core studies in a sub-polar glacier

(Veijo Pohjola and Elisabeth Isaksson, NGSU)

Ice cores from the front of Storglaciären were studied to reveal if glacier ice from the Medieval Warm Period, which ended with the Little Ice Age, can be traced through the physical and chemical character of the ice. An electrically heated thermal core-drill was designed and used to take five 10 m deep ice cores from the glacier front. Structural and textural variations, and the ECM (electrical conductivity measurements) signature of the ice cores, are used to describe the character of the ice. Based on these results, a more detailed sampling program including $\delta^{18}O$, major anions and cations, and ice-crystal orientation has been, and is being, performed.

MISCELLANEOUS

Modelling finite deformation of viscous bodies in channelized flow: an analogue to flow of valley glaciers

(Genene Mulugeta, HRTL; Veijo Pohjola, GIUU)

Experimental models are being used to simulate aspects of flow history and strain distribution in valley glaciers. Viscous silicone putties are used as material analogues to simulate glacier flow. The variable parameters in the experimental set-ups are channel geometry and the amount of friction around the glacial perimeter. The spatial and temporal variation of strain during flow is monitored using passive, initially orthogonal, grids as strain markers. From knowledge of the strain distribution and material rheology the stress distribution within the body can be calculated. These experiments can be used as scaled models of how the stress distribution in real glaciers changes with different geometrical and frictional configurations.

PALAEOGLACIOLOGY

Inuitian Ice Sheet records, Queen Elizabeth Islands, N.W.T., Canada

(Clas Hättestrand and Arjen P. Stroeven, NGSU; Arthur S. Dyke, GSC)

Numerous striated bedrock outcrops were discovered on Baillie-Hamilton Island, off the west coast of northern Devon Island. Four ice-flow directions were recognized by extremely well-developed rat-tails, crescentic fractures, and microscale stoss-lee features. The consistency of ice-flow directions obtained indicates that the overriding ice was not topographically deflected by the 200 m high island. A thick, wet-based, ice must have flowed obliquely across the more than 300 m deep strait surrounding Baillie-Hamilton Island, and cut these surfaces. A similar conclusion was derived from four striated bedrock outcrops on the northeast coast of North Kent Island, between Devon and Ellesmere Islands. Ice flowing from the northwest obliquely across Baillie-Hamilton and North Kent Islands could not have emanated from local ice domes covering the larger islands. Instead, these results are consistent with a hypothesized larger ice sheet covering the Queen Elizabeth Islands originating in the Norwegian Bay region, the Inuitian Ice Sheet.

Pliocene Antarctic ice-sheet behaviour and climate

(Arjen P. Stroeven, NGSU; Michael L. Prentice and Harold W. Borns, QSUM)
Two semi-consolidated glacial till patches on Mount Fleming, south Victoria Land, Antarctica, have been investigated. Similar types of semi-consolidated tills elsewhere in the Transantarctic Mountains (TAM) have been primarily interpreted as deposits of a wet-based East Antarctic ice overriding the highest summits of TAM in Late-Pliocene time. The timing of this event comes from marine diatom assemblages in some of these deposits which are inferred to originate from marine sediments deposited in basins on the Antarctic craton west of TAM during deglacial periods, basins that today are filled with East Antarctic ice. However, lithostratigraphic analyses of samples from 8 pits dug in the Mount Fleming tills indicate both deposits are lodgement tills deposited underneath ice emanating from local, Alpine, sources. If true, these results have profound implications for the age and climate of deposition, landscape evolution, and the significance of diatom occurrences in the till matrix.

REMOTE SENSING

Height of Antarctica from ERS-1 radar altimeter data

(Lars E. Sjöberg and Patric Jansson, KTH)
The radar altimeter on the ERS-1 satellite allows topographic mapping to latitude 82°S and a denser ground coverage. Earlier projects in Antarctica have mainly used traditional methods or the GPS technique for measuring the ice surface, methods that can only be applied to limited places in Antarctica. Knowledge of the topography of Antarctica is a key to modelling ice-sheet and ice-shelf dynamics, both through studies of ice-sheet slopes and of surface features related to ice flow. Long-term monitoring will permit study of the response of the ice sheets and ice shelves to climate change.

A pilot area, approximately 20 × 20 km, has been established and measured using kinematic GPS. Heights over the area will be computed both from GPS and the radar altimeter. The results will then be used to calibrate the radar-altimeter data.

SEA ICE

A coupled ice–ocean model, Baltic Sea

(Anders Omstedt and Leif Nyberg, SMHI; Matti Leppäranta, GUH)
The model is a dynamic coupled model, consisting of both a sea-ice and a storm-surge model. It was forced using wind and pressure fields from the HIRLAM system and introduced in pre-operational tests for Baltic Sea sea-ice forecasting during the winter of 1992/93. In general, the results were most promising, but further work is needed, particularly on the inclusion of thermodynamics, a closer coupling between the ice–ocean model and the HIRLAM model, and the development of an automatic method for generating initial data for the model.

SNOW AND ICE CLIMATOLOGY

Local climate in empty cirques just below the glaciation limit

(Peter Jansson and Stig Jonsson, NGSU)
The local climate is recorded by an automatic weather station in the Rassepautasj Massif, northern Sweden. This massif contains cirques with different aspects that are all located just below the regional glaciation limit. This project will use the climate data to model conditions favourable for glacier growth in these cirques. The information obtained will then be compared with established climate records to produce a synthetic record of the glacierization of the cirques. This is important for evaluating the erosive capability of small cirque glaciers when they are active. An alternative hypothesis is that the cirques may develop subglacially or at least become enlarged under an ice sheet.

Synoptic forcing of wind and temperature in a large cirque, East Antarctica

(Stig Jonsson, NGSU)
Between 18 January 1988 and 3 June 1989, an automatic weather station recorded 13 different weather parameters every 3 hours on a blue-ice area in Scharffenbergbotnen, a large cirque in central Heimefrontfjella, 300 km from the Weddell Sea coast. Annual and monthly data on air temperature, air pressure, wind speed, and wind direction have been analyzed, and comparisons made with corresponding data from the Neumayer and Halley stations. One interesting conclusion is that the mean annual air temperature at Scharffenbergbotnen (–18.7°C) is surprisingly high for its altitude (1150 m a.s.l.) compared with the two coastal stations; another is that the mean wind speed is very low (4.3 m s^{-1}). In fact, wind speed is only half of that at the Neumayer station although the monthly maximum wind speeds are 10–20 m s^{-1} higher. Weather conditions between April and September seem, at least during 1988 and 1989, to have been very unusual with a large-scale (30–40 days) and, superimposed on the large-scale, a small-scale (3–4 days) co-variation of air temperature, air pressure and wind speed. High-pressure events are on both scales connected with the formation of stagnant air inside the cirque. The pools of cool, stagnant air are blown away every 3–4 days by katabatic winds triggered by small variations in the synoptic pressure field. When this happens the air temperature increases more than 20°C and the wind direction swings from east towards southeast.

Abbreviations

GGUM: Department of Geology and Geophysics, University of Minnesota, Minneapolis, MN 55455, USA

GIUU: Institutionen för geovetenskap, Uppsala Universitet, 751 05 Uppsala (Institute of Earth Sciences)
GSC: Geological Survey of Canada, 601 Booth St., Ottawa, Ontario, K1A OE8, Canada
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KTH: Kungliga tekniska högskolan, Institutionen för Geodesi och Fotogrammetri, S-100 44 Stockholm (The Royal University of Technology)
MCGWH: Department of Marine Chemistry and Geochemistry, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, USA
NGSU: Naturgeografiska institutionen, Stockholms universitet, S-106 91 Stockholm (Department of Physical Geography, Stockholm University)
NVE: Norwegian Water Resources and Energy Administration, P.O. Box 5091, N0301 Oslo 3, Norway
QSUM: Institute for Quaternary Studies, University of Maine, Orono, ME 04469, USA
SMHI: Sveriges meteorologiska och hydrologiska institut, S-601 76 Norrköping (Swedish Meteorological and Hydrological Institute)
THL: Tekniska högskolan i Luleå, S-971 87 Luleå (Luleå University of Technology)

Submitted by P. Jansson

SWITZERLAND

For abbreviations, see end of this report

GLACIERS AND ICE SHEETS

Glacier variations in the Swiss Alps

(M. Aellen, VAW and GK/SANW; H. Bösch, M. Funk and W. Schmid, VAW)

The project on Variations in Glacier Length is sponsored by GK/SANW and that on Mass Balance and Movement of Glaciers by the VAW. The annual variations surveys, continuous since 1880, use an observation network which presently includes 121 glacier snouts. For the second project, single stakes or stake networks have been observed for 38 decades on a dozen glaciers which also belong to the variations network.

Results from the 112th to 114th surveys are as follows:

Number of glaciers	1991	1992	1993
Advancing	8	7	6
Stationary	1	5	–
Receding	100	94	73

The decreasing number of advancing glaciers and the dominance of receding ones make it obvious that the general tendency of the last 150 years has steadily continued but at clearly stronger than average rates. The advancing snouts were observed on large flat valley glaciers as a late response to the mass increase in the 1970s. In individual cases, where rather small glaciers increased in length, this was due either to particularities of glacier movement or to perennial snow deposited on a glacier's snout by avalanches.

The mass balances for the glaciers of four High-Alpine river basins gave the following results (average mass change in g cm^{-2}):

Glacier	1990/91	1991/92	1992/93	Method
Gries	–149	–93	–23	glaciological
Aletsch	–62	–67	9	hydrological
Limmern/ Plattalva	–127	–84	–37	statististical
Silvretta	–113	–78	–5	glaciological

Mass losses were reduced from very severe to moderate or slight due to increased rates of winter snow accumulation and summer precipitation. High melting rates were common in all summers, and excessively warm as well as very dry periods were characteristic temporary occurrences in all winters.

Little Ice Age glacier reconstruction and future perspectives

(M. Maisch, B. Denneler and A. Wipf, GIUZ)

An inventory of the 1850 glacier advance is being established for all glaciers in the Swiss Alps. To analyze the Little Ice Age (LIA) and glaciological changes since its end, nearly 2000 glacier bodies have been reconstructed. Losses in area and volume as well as changes of the ELA were measured and interpreted with respect to geography, topography and regional climate. The datasets are being used to estimate the possible magnitude of future ice retreat due to global warming. The first results show that the present glaciers, mainly the small ones, will shrink very quickly due to a significant acceleration in ablation.

Parameterization of glacier inventory data

(M. Hoelzle and W. Haeberli, VAW)

A parameterization scheme using simple algorithms for unmeasured glaciers is being applied to glacier inventory data to estimate the basic characteristics of inventoried ice bodies and to simulate potential climate-change effects on mountain glaciers. A pilot study was carried out in the Alps using inventories compiled in the mid-1970s. Dynamic response times, derived from estimates of maximum ice depth and snout ablation, mainly depend on surface slope and have characteristic lengths of a few decades. The estimated total glacier volume in the Alps was some 130 km^3 for the mid-1970s; strongly negative mass balances caused an additional loss of about 10 to

20% of this from 1980–1990. The total loss of Alpine glacier mass since 1850 is estimated at about half its original value. An acceleration of this, with annual mass losses of around 1 m a^{-1}, could eliminate much of the existing Alpine ice volume within decades.

Secular mass balances from cumulative glacier-length changes

(W. Haeberli and M. Hoelzle, VAW)

A simple continuity model is used to derive glacier mass balances from original length, observed cumulative length change and ablation at the snout. Periods considered correspond to the dynamic response time. Tests for Rhone glacier and Hintereisferner, with secular mass balances determined by the geodetic/photogrammetric method, give excellent results. Backward calculation of length changes for 11 other Alpine glaciers using a mean annual mass balance of 0.25 m w.e. a^{-1} since the end of the LIA around 1850 AD, gives considerable scatter but satisfactory overall results compared to long-term observations.

Glacier fluctuations in China and Switzerland

(Y. Ding, VAW and Academia Sinica; W. Haeberli, VAW)

To investigate large-scale patterns of glacier and climate evolution, length variation and mass-balance data of glaciers in China and the Swiss Alps are compared. Variations in front position are being analyzed for different classes of glacier length. Length changes for glaciers shorter than 10 km appear to be quite comparable in both countries, with decelerating retreat since the 1960s leading to a transient glacier advance around 1980. A recent acceleration tendency towards more negative balances is common to both regions.

Airborne laser-profiling on Alpine glaciers

(A. Geiger and M. Cocard, IGP)

A laser-altimetry system, in conjunction with a precise DGPS system and an inertial platform, in an aircraft of the Cadastral Directorate, has achieved accuracy for terrain-height determination in the order of 20 cm, thus allowing the detection of changes in ice thickness by repeated overflights. Tests over the Unteraar, Aletsch and Otemma glaciers were promising and showed significant height differences compared to earlier digital terrain models.

Subglacial water pressure, basal shear stress and sliding velocity of Findelengletscher

(A. Iken, H. Bösch, W. Schmid and M. Funk, VAW)

Between 1979 and 1985, Findelen glacier advanced some 200 m and subsequently retreated. Since 1985 the glacier has thinned by nearly 20 m. In 1980, 1982 and 1985 the relationship of subglacial water pressure and sliding velocity was studied. Similar measurements were carried out in 1994. Water pressure was recorded in 3 to 4 boreholes. Velocity was measured at 5 poles several times daily using a precise GPS system. In contrast to the previous years, significant velocity increases occurred only when the water pressure was exceptionally high. Changes in surface altitude are being evaluated from aerial photographs with a stereo plotter. From these data, and from the changes in strain-rate gradients, changes in basal shear stress will be inferred.

Subglacial drainage system of Gornergletscher

(A. Iken, K. Fabri, M. Funk and H. Bösch, VAW)

In 1992 and 1993 the following measurements were carried out in boreholes near the northern margin and at the centerline:

- subglacial water storage by measuring the distance between a surface marker and a magnetic ring anchored in a borehole just above the bed, and by measuring simultaneously the displacement of the surface marker. The bed slope was determined by radio-echo-sounding;
- subglacial water pressure;
- electric conductivity at the bottom of boreholes connected with the subglacial drainage system while a salt solution was poured into another borehole;
- slug tests (perturbation of height of water level).

The results indicate a gradual change of water storage related to changes in water pressure. Near the glacier margin, differences in water storage caused differences in the frequency of oscillations of water level in a borehole, triggered by the slug tests. The experiments suggest a very pervious drainage system existed at the northern margin, consisting of discrete channels or linked cavities. In contrast, the drainage near the centerline appears to have been through a sediment layer.

Glacier convergence

(H. Gudmundsson and A. Iken, VAW)

A theoretical and experimental study of the convergence of Lauteraar- and Finsteraarglaciers has been undertaken. Using simple conceptual models, the general characteristics of converging flow were elucidated and inferences drawn regarding the stress and strain regime of a glacial confluence.

The experimental work, from spring 1991 to spring 1993, consisted of radio-echo soundings, velocity measurements, determination of surface strain rates, vertical velocity variation and ice temperatures. The confluence centerline was subjected to longitudinal horizontal extension and a concomitant transversal compression, with the longitudinal extension exceeding the transversal compression. Vertical strain rates change from positive (extension) at the surface to negative (compression) in the lowest layers of the glacier.

A 2-D map-plane model and a 2-D flow-line model were developed to explain the strain-rate pattern. As a response to the change in boundary conditions at a glacier confluence, a surface depression will form at the junction point, and two super-elevated zones at the glacier margins of the two contributing tributaries facing the junction point will be created. For a fully 3-D model, flow velocities were calculated using Glen's flow law. All features of the measured flow field of the Unteraarglacier, such as the horizontal and vertical strain-rate pattern, as well as the spatial velocity variation, could be reproduced qualitatively within that model. A quantitative comparison, however, showed the presence of systematic differences between measured surface velocities and velocities determined with Glen's flow law for all values of η, where η is a flow-law parameter.

Deformations of basal ice

(H. Gudmundsson, VAW)

The characteristics of creeping flow close to bed undulations, and the form of the sliding law in the absence of friction, bed separation and regelation, have been analyzed by an analytical and numerical treatment of a non-linear medium flowing over a sinusoidal bed. Solutions based on a second-order perturbation analysis for the velocity field are derived and examined for a sinusoidal bed. Two different regions of extrusion flow may arise close to bedrock undulations, depending on the amplitude-to-wavelength ratio. Above the crest of the sine wave a region of local maximum, and within and above the trough a region of local minimum of the vertical velocity can develop, and exact criteria for the appearance and disappearance of these stationary points are given. Extrusion flow will cause a reversal of bore-hole inclination profiles close to the bedrock. This has been observed in nature but its cause is not yet fully understood. Numerical calculations were performed to extend the analytical results to the case of non-linear rheology and a strongly undulating bed. The general form of the sliding law for a sinusoidal bed for every possible roughness and η value has been found, and the effect of the ratio of glacier thickness to bedrock wavelength analyzed. Extrusion flow becomes increasingly important as the flow gets progressively more non-linear. For high roughness values a flow separation occurs, i.e. the main flow sets up a secondary flow circulation within the trough, and the ice participating in this circular motion theoretically never leaves it.

Stability of steep glaciers

(M. Lüthi and M. Funk, VAW)

Relevant parameters for the stability of steep (or hanging) glaciers are the stress field, the ice temperature and the strength of polycrystalline glacier ice, which seem to depend strongly on temperature and water content. For a hanging glacier at the Eiger (Bernese Alps, Switzerland), the bed geometry, ice temperature and flow velocities have been measured and the dynamics and ice temperatures modelled. The glacier is presently frozen to its bed at the front and is temperate in its central part. The cold part at the snout, in contact with the sub- and periglacial permafrost, is an important stabilizing factor. If a hanging glacier reaches a critical mass distribution, the initiation of feed-back mechanisms can lead to a destabilisation of the entire glacier. Global warming may be dangerous because the ice temperature of the snout will rise and may reach the melting point at the base. If the basal shear stress increases and reaches the critical strength for polycrystalline glacier ice, a destabilization may occur and dangerous ice avalanches result.

Alpine firn temperatures

(S. Suter, M. Funk and W. Haeberli, VAW)

Firn temperatures to 15 m were measured between 4000 and 4300 m a.s.l. at four sites on the upper Grenzgletscher (Monte Rosa, Swiss Alps), as well as to 120 m in a borehole drilled at 4200 m a.s.l. Firn and ice are cold throughout (except for the uppermost metres which became temperate last summer), whereby a non-definite dependence of 15 m temperatures upon altitude was found. A strong heat-flow inversion in the deep borehole at 4200 m a.s.l. might be attributed to the advection of cold ice from higher altitudes underneath warmer firn. This investigation hopes to establish the spatial distribution pattern of cold firn temperatures as a function of energy-balance parameters, such as solar radiation or mean annual air temperature. It is intended to set up a long-term monitoring programme on firn and ice temperatures in boreholes on Colle Gnifetti (4452 m a.s.l., Monte Rosa, Swiss Alps).

Glacier and permafrost photogrammetry

(A. Kääb and H. Bösch, VAW)

A photogrammetrical method for measuring displacement vectors of glacier and permafrost surfaces by simultaneously comparing aerial photographs taken at different times was developed. It is possible to detect slight changes in a flow field and allows valuable periodic measurements. Detailed analyses have been carried out for Gruben glacier in connection with the evolution of ice-dammed lakes, and for creeping permafrost at Pontresina–Schafberg related to avalanches and debris flows.

Gravimetric investigations at the confluence of Unteraar Glacier

(T. Wyss and E. Klingele, IGP; A. Kääb and H. Gudmundsson, VAW)

The Unteraar Glacier (Bernese Alps) was chosen as an area to investigate the shape and density distribution of a glacier bed by means of gravimetry, combined with evidence from other geophysical methods, because of the radio-echo sounding and seismic reflection data sets already available. In September 1993, 54 stations were surveyed within the confluence area. Processing and modelling of the profiles in the upper reaches of the tongue yielded results that agreed well with the bed model derived from radio-echo soundings. Anomalies at the dispersed gravity stations close to the confluence centre, however, showed a significant difference compared with the computed anomaly based on radio-echo sounding. This deficit can be explained by a different ice depth or by the existence of a ground moraine.

Modelling glacier/groundwater/permafrost-interactions

(C. Speck, J. Troesch and W. Haeberli, VAW)

Two existing finite-element models, calculating temperatures and hydraulic conditions interactively, were coupled to quantify the effects of freezing and thawing on groundwater flow in an aquifer beneath polythermal glaciers resting on highly permeable sedimentary beds. First model experiments for idealized Ice Age conditions in the Swiss Plateau point to strong effects on deep ground-water circulation near the snout where hydraulic gradients are steep due to the surface slope of the ice margin. Such effects could have influenced permafrost and ground temperature evolution to a large extent.

Numerical methods of glacier modelling

(H. Blatter, GGEZ)

A new algorithm proposed, by Muller (1991) at the Dept. of Mathematics, University of Geneva (Prof. G. Wanner) for calculating the 2-D velocity and stress fields, was extended to three dimensions. The algorithm includes the effects of deviatoric stress gradients in a consistent approximation in first order of the aspect ratio. Its numerical efficiency makes it applicable to an interesting range of glacier and ice-sheet models.

SNOW AND AVALANCHES

Snow monitoring and avalanche warning systems

(W. Ammann, W. Good, R. Bolognesi, O. Buser, B. Gauderon, M. Roveretto and P. Weilenmann, SFISAR)
A conceptual study involves integrating local automatic measuring stations into an overall regional and national avalanche warning system to improve the quality of the national avalanche warning bulletin and to enable publication of regional and local bulletins. SFISAR is testing available equipment, developing new sensors, defining interfaces and standards for the necessary data communication and evaluating software. Decision support software is part of the research project and will be an important tool for decision-makers.

Creeping deformation, temperature distribution and water transport in a phase-changing snowpack

(P. Bartelt and W. Ammann, SFISAR; E. Anderheggen, ISE)
The complex, nonlinear interaction between the mechanical, thermodynamic and hydraulic properties of snow is hard to predict, making avalanche forecasting difficult. Better predictions of snowpack stability can be obtained with the help of computer simulations. A 2-D (plane-strain) finite-element program is being developed to model the creeping deformation, temperature distribution and water transport in a phase-changing snowpack. The model will include a nonlinear, viscous, temperature-dependent constitutive law for snow, layer discontinuities with sliding, heat transfer with phase change and meltwater infiltration.

Dynamics of powder-snow avalanches

(F. Hermann and D. Issler, SFISAR; S. Keller, VAW)
Powder-snow avalanches are modelled in a large water tank, using fine quartz particles whose local speeds and concentrations are recorded with an ultrasonic Doppler apparatus; local dynamic pressures and turbulence levels can then be computed. A series of experiments with unchanneled track and runout are now being carried out. Meaningful laboratory modelling of powder-snow avalanches is possible only where field observations from real events are available. In addition, the velocity scale factor increases along the track as the average particle concentration diminishes.

Laboratory data are used to test a numerical model in a setting where similar physical processes take place. The model is based on the 3-D ensemble-averaged Navier–Stokes equations for the ice–air mixture, solved by the finite-volume method. Various turbulence models, such as the k-epsilon scheme, are used to achieve closure. Besides turbulence, key factors are erosion and deposition of snow in the saltation layer at the bottom of the snow cloud. The internal dynamics of this layer, as well as its mass and momentum exchanges with the snow cloud above and the dense-flow avalanche underneath, are being studied. The completed model will be used to simulate real powder-snow avalanches. These results will be very valuable in developing guidelines for avalanche zoning and for simplified numerical models.

Simulation of snowdrift

(P. Gauer, F. Hermann and D. Issler, SFISAR)
Snow drift significantly increases the release probability, size and runout distance of avalanches from lee-side slopes. This project will develop and test a numerical model that simulates the formation of cornices, the deposition of snow behind snow fences, etc. The spatial and temporal resolution will be about 1 m and 1 minute, respectively. The boundary conditions may be supplied by field measurements or a mesoscale meteorological model. The key problem is to describe the physical processes in the saltation layer, similar to the situation in powder-snow avalanches, so the theoretical framework and numerical methods will closely parallel those used in the latter. The validation is based on field measurements from Col du Lac Blanc (France) and wind-tunnel studies with glass beads by T. Castelle (EPF Lausanne).

Experimental avalanche dynamics

(F. Hermann, M. Hiller, D. Issler and B. Salm, SFISAR)
Flow speeds, flow heights and slope-perpendicular flow-speed profiles of artificially released dense-flow avalanches are measured using various types of microwave radars. A system on over-snow vehicles has been used in Val Medel, Switzerland for several years while a fixed Doppler radar system was recently installed in an avalanche track in Austria, in collaboration with the Austrian Institute for Avalanche Research, Innsbruck. Measurements from Val Medel in 1994 are being analyzed. Such data are very valuable in the development of improved models of dense-flow avalanches.

Preliminary studies on the selection and instrumentation of an avalanche test site in the Swiss Alps are being made with a view to simultaneously measuring all the parameters relevant in the dynamics of dense-flow and powder-snow avalanches. These include released mass, entrained or deposited mass, flow velocities along the track, densities, texture, flow heights and flow-velocity profiles as well as the pressures exerted on various large obstacles.

Distribution of snow-slab fracture heights

(D. Issler, SFISAR)
Fracture height, as a function of recurrence period, is critical for calculating avalanche runout distances. This project will extract a fracture-height distribution function from a large set of avalanche observations in the Davos area. The distribution function at another location can then be estimated if the local distribution of total snow-depth increase over three-day periods is known. The Davos data are not extensive enough for distinguishing different slope orientations and altitude levels at a sufficient level of statistical significance. It is also necessary, albeit very difficult, to account for snowdrift effects in the precipitation distribution function.

Numerical avalanche forecast

(R. Bolognesi, O. Buser and M. Roveretto, SFISAR)
NXD and AVALOG, two programs for computer-assisted avalanche forecast were further distributed in the Alps, the Pyrenees and Scotland. The demand for such programs is rapidly growing as security services and ski areas get the necessary hardware; therefore the two programs have been merged into NXLOG, to make use of the advantages of both. This will be tested during the winter 1994/95. The University of Edinburgh has started a project to display the results within a GIS for Scotland.

Influence of skiers on the stability of the snow cover

(J. Schweizer, Ch. Fierz and P. Bartelt, SFISAR)
To gain insight into the artificial triggering mechanism of dry slab avalanches, the influence of the skier is being studied. The forces induced on a snow cover with layers of critical strength are calculated by the finite-element method. Different cases of dynamic loading, similar to the Rutschblock procedure, are studied. In the field the forces are measured in situ with load cells. Hard layers seem to be decisive for this sort of stress propagation and hence for the stability of the snow slope.

Expert system for avalanche forecasting

(J. Schweizer and P. M. B. Föhn, SFISAR)
Two types of expert systems were developed to forecast avalanche hazard using a commercially available expert-system shell (CYBERTEK-COGENSYSTM Judgment processor). The first can be compared to a statistical model. Based on 13 weather and snow-cover parameters, the degree of hazard, the altitude and the aspect of the most dangerous slopes are given, based on similar situations. Due to the verification data, the daily a posteriori assessment of the avalanche hazard, the system could be tested over several winters in the Davos region. In 60–65% of the days the system forecasted the right degree of hazard.

The second expert system, developed on the level of physical processes, is comparable to a deterministic system. It simulates the reasoning of an experienced avalanche forecaster, needs more input parameters, especially on the snow cover, and also includes implicit rules. Due to this additional data, knowledge and experience, the performance is 70–75%.

Hybrid expert system for avalanche forecasting: ALUDES

(M. Schweizer, IUZ; P. M. B. Föhn and J. Schweizer, SFISAR)
A neural expert system was developed to assess avalanche hazards. It integrates extended symbolic computing from traditional artificial intelligence, by generating symbolic rules from subsymbolic data, with unsupervised neural networks. Based on 14 weather and snow-cover data from the Davos region, the combined diagnosis (the degree of avalanche hazard) of the neural network and of the rules is about 70% correct, compared with the verification.

Snow-cover modelling

(C. Fierz and P. Weilenmann, SFISAR)
To validate DAISY, a model for calculating temperature distribution, energy and mass flow in a seasonal snow cover, continuous temperature and settling measurements were taken in the SFISAR study plot. Model output and experimental data agree quite well. Metamorphism and percolation of water will be introduced into DAISY next and the extended model validated by in situ measurements. The long-term goal is an efficient operational snow-cover model for avalanche forecasting.

Weak layers and snowpack stability

(P. Föhn and G. Krüsi, SFISAR)
Weak layers or interfaces are a prerequisite for slab-avalanche formation. To calibrate the mechanical indices and the concurrent grain-structure data of many past field campaigns, additional measurements under controlled laboratory conditions were initiated. The shear strength is measured under controlled temperature and stress conditions and the microstructure is analyzed using close-up photos and thin sections.

Spatial variability of mechanical snow properties

(M. Schneebeli, SFISAR)
Spatial variability of mechanical snow properties plays a decisive role in slab-avalanche formation. To measure these properties, a new instrument called "rammrutsch" is used. It works like the rutschblock test but is better quantified. It is possible to measure small-scale fracture stabilities on a slope rapidly so the patterns of more-or-less stable zones should be quantifiable.

Water infiltration into snow

(M. Schneebeli, SFISAR)
The formation of wet-snow avalanches is not well understood, particularly the influence of less permeable layers and their formation. The flow paths of melting water are made visible using dye tracers and serial cuts. It is then possible to reconstruct the 3-D flow pattern and correlate it with the structural properties of the snow.

Interactions between climate, avalanches and defences

(W. Ammann, P. Föhn, M. Schneebeli, M. Laternser and S. Lentner, SFISAR)
Historical catastrophic and damaging avalanches are recorded and compared to snow and weather conditions during the past 130 years. An attempt is being made to reconstruct the influence of defence and afforestation measures on avalanche frequency for the past 100 years. Using statistical methods, the climatic effects on avalanche formation and the effects of prevention measures on avalanche releases will be quantified.

Snow-interception and snowmelt in sub-alpine forest stands

(M. Bruendl, SFISAR; D. Stadler, ITESP)
For sub-alpine spruce forests, a warmer climate may result in more wet-snow avalanches and higher flood peaks due to snowmelt in spring on frozen soils. The factors governing hydrologic processes in a spruce forest, in the snow pack and in the soil under trees are being investigated at two sub-alpine forest sites in Switzerland (1220 and 1650 m a.s.l.).

As well as climate observations, snow interception on different tree branches is observed by video cameras, flow patterns of snowmelt water in the snow cover and the soil are visualized by dye experiments, and surface runoff, subsurface flow and soil moisture are measured to estimate the effects of a possible climate change in this region.

Avalanche hazard perception and prevention strategies

(P. Schoeneich, M.-C. Busset-Henchoz, S. Dulex Putallaz, A. Herold-Revaz, R. Ledergerber and L. Bridel, IGUL)
One project studies all types of natural hazards in a region of the western Swiss Prealps (Valley of Ormonts/VD). It includes reconstructing hazard history since the mid 18th century, studying how information was transmitted to

further generations, and comparing past and present knowledge, attitudes and strategies with regard to different types of hazards. A second project concentrates on snow avalanches, comparing the attitudes and strategies of populations in different regions of Switzerland.

Mapping of avalanche hazard zones

(H. Haefner and U. Gruber, GIUZ)
Avalanche hazard zones are simulated based on a modified Salm–Voellmy model, satellite imagery and a digital elevation model. Maps showing potential avalanche hazard zones are compiled with respect to extreme events, i.e. 30 and 300 year recurrences. Regional distribution, characteristics and conditions of the forest are classified from Landsat-TM and SPOT data.

Snow mapping with ERS-1 data in the Swiss Alps

(H. Haefner, D. Nüesch, E. Meier, F. Holecz and J. Piesbergen, GIUZ)
A method, based on the radiometric and geometric correction of the ERS-1 Synthetic Aperture Radar (SAR) image data and on generating a new synthetic image by the optima-resolution approach (ORA), is used to reduce relief-induced distortions. Resulting images contain the fully interpretable parts of crossing orbits. Change detection methods are introduced to extend ORA to a multitemporal MORA concept to monitor the changing snow cover.

Deposition study of particulate air pollutants at an alpine snowfield

(M. Schwikowski, U. Baltensperger, H. W. Gäggeler [also at IAC] and D. T. Jost, PSI)
Within the Alpine snow-sampling program SNOSP of ALPTRAC, a subproject of EUROTRAC, shallow snow/firn cores 45 m deep were drilled at Jungfraujoch on 12 March 1993, 6 May 1993 and on 11–13 May 1994. The main ionic loads (NO_3^-, SO_4^{2-}, Cl^-, NH_4^+, Na^+ and C^{2+}) were determined using ion chromatography and inductively coupled plasma-ion-source–optical-emission spectrometry. The results showed that the ionic concentrations are a factor of two to three higher in spring than in winter due to an increased atmospheric stability during the winter period. An intercomparison of the deposition fluxes with those from other sites revealed that they are representative for the whole Alpine range.

Snow sampling intercomparison, Weissfluhjoch, Davos

(M. Schwikowski and U. Baltensperger, PSI; H.W. Gäggeler, PSI and IAC; cooperation with Servizio Ambiente, Milano; Servizio Idrologico, Venezia-Mestre; Institut für Meteorologie und Geophysik, Innsbruck; LGGE; Institut für Umweltphysik, Heidelberg; Institut für analytische Chemie, Wien; Institut für Meteorologie und Geophysik, Wien)
On 30 March 1993, joint snow-sampling was performed at the SFISAR site, Weissfluhjoch, Davos (2540 m a.s.l.). Here the spatial snow deposition is quite uniform and little perturbation of the snow stratigraphy occurs. Every group determined ionic concentrations over the entire snow cover using their own sampling techniques and analytical procedures. Snow densities agreed well, within 6%. Results of concentrations or total depositions agreed within 15% for the ions Cl^-, NO_3^-, SO_4^{2-}, and NH_4^+. This encouraging outcome makes it possible to determine Alpine-wide deposition patterns of atmospheric constituents by all groups participating in the SNOSP programme.

Spatial and temporal variability of snow cover in a high-Arctic catchment

(H. Leser and M. Potschin, GIB)
Nutrient and material fluxes in soil and water of terrestrial ecosystems were investigated for three years (1990–92) at Liefdefjorden (NW Spitsbergen 79°3′ N, 13° E). The snow cover plays a major storage role. Snow samples were taken at 70 points within the catchment (5 km^2). Using photogrammetry (in combination with 27 snow depth and density sites), the absolute amount of water equivalent and the spatial and temporal variability of the snow cover were quantified. The first photos were taken while the snow cover was still 100%, and depending on the melt rate, repetitions were run every 3 to 5 days.

FROZEN GROUND

Long-term monitoring of Alpine permafrost

(W. Haeberli, M. Hoelzle, F. Keller, W. Schmid, D. Vonder Mühll and S. Wagner, VAW; M. Monbaron, GGUF; K. Budmiger and B. Krummenacher, GGUB)
Efforts continue on installing and maintaining a measurement network for monitoring the long-term evolution of permafrost in the Alps. Methods applied include aerial photogrammetry of creeping permafrost within selected rock glaciers, temperature and deformation measurements in boreholes, data archiving from geophysical surface soundings and analysis of specially flown small-scale infrared photography. As a consequence of the exceptionally warm temperatures since the late-1980s, near-surface permafrost temperatures continue to rise at rates close to 1°C per decade (Murtèl borehole).

Temperature evolution in Alpine permafrost

(D. Vonder Mühll and Th. Stucki, VAW)
Temperature measurements within an active rock glacier, in the borehole Murtèl 2/1987 (Upper Engadin, Swiss Alps), show a strong warming trend of permafrost temperatures near the surface (uppermost 10 m) since 1987 (about $+0.1°C\ a^{-1}$). The data were evaluated by statistical methods. The strong relationship between the thickness and distribution of the snow layer and permafrost temperature was explored and confirmed. With increasing heat penetration the permafrost table goes down. The temperatures from the borehole are being compared with those from two other permafrost boreholes, at Pontresina Schafberg (Upper Engadin, Swiss Alps), to investigate the representativity of borehole-temperature measurements in time and space.

Permafrost cores from Murtèl rock glacier

W. Haeberli, VAW; N. Haas, BUB; B. Stauffer, KUP; collaboration with Institute of Environmental Physics, University of Heidelberg and Laboratoire de Géomorphologie, Université Libre de Bruxelles)
Deuterium and oxygen-isotope concentrations are being

analyzed for the upper, ice-rich part of the permafrost core through the active Murtèl rock glacier. Pollen analysis of a small piece of moss found in the ice at about 6 m (3 m below the permafrost table) indicates early Holocene age. AMS dating of the organic material is underway. These findings indicate the ice contained in Alpine permafrost can be thousands of years old and, in deeper layers, may even date back to late-glacial times.

Permafrost in the western Swiss Alps

(E. Reynard, M. Phillips and P. Schoeneich, IGUL)
Field observations (geomorphological mapping, location of rock glaciers), and measurements of spring-water temperatures and ground temperatures beneath the winter snow cover (BTS) are being used to reconstitute the distribution of discontinuous permafrost in the western Swiss Alps, between the Morcles and the Wildstrubel massifs. Other applications include the use of models of the potential distribution of permafrost, developed by VAW/ETHZ using the PERMAKART program, to determine the lower limit of discontinuous permafrost in all orientations in the western Swiss Alps, and to test whether the theoretical distribution of permafrost here shows patterns which are identical to or different from those of the drier eastern Swiss Alps.

Low-altitude permafrost sites

(G. Wegmann and D. Vonder Mühll, VAW)
In the Alps discontinuous permafrost usually occurs above timberline (about 2000 m a.s.l.). The distribution of mountain permafrost is predominantly influenced by the potential direct solar radiation. At very shady places sporadic permafrost islands are sometimes observed as low as 1000 m a.s.l. These localities are typically covered by coarse blocks with humid moss. The cold surface temperatures cause a growth-retardation of the vegetation, especially of spruces. Information on the occurrence of such localities are collected from forestry offices. Generally plant associations at such extreme sites correspond to those at higher-altitude belts. In the Säntis area, one site was investigated by geophysical methods (DC resistivity sounding and refraction seismics), and ground-temperature measurements taken for two years. Great thermal differences exist within short distances, especially during summer. These low-altitude permafrost sites are important for establishing the limits of pemafrost distribution and for information about the processes/factors involved.

Influence of solar radiation on Alpine permafrost

(A. Leuenberger, GGUB)
A solar radiation model was used to calculate direct, diffuse, and global radiation over a complex terrain area, taking into account slope angle, azimuth angle, and blocking by the local horizon. In the Furggentaelti, western Swiss Alps, the monthly and annual distribution of incoming short-wave radiation was calculated over a 0.4 × 0.5 km area with a mean spatial resolution of 50 m and a temporal resolution of 15 minutes. The distribution of incoming radiation was highly correlated with permafrost phenomena and with measurements of the basal temperature of the snow cover (BTS). There is an especially good correlation between the position and shape of a rock glacier and the spatial patterns of solar radiation.

Permafrost in the Bernese Alps

(M. Imhof, GGUB)
Based on topography-dependent rules of thumb, published earlier by VAW/ETHZ, a computer program (PERM) has been developed to map permafrost automatically within the IDRISI geographic information system. By applying PERM to the digital elevation model RIMINI (resolution 250 m, interpolated to 100 m), the first medium-scale map (1 : 250 000) of permafrost distribution in the Bernese Alps (western Switzerland) was produced. Verification of the model, done by comparing the map with the distribution of active rock glaciers, showed a good correspondence.

Permafrost and glacier changes in the Upper Engadin, 1850–1990–2025–2100

(M. Hoelzle, VAW)
Models are being developed to simulate changes in permafrost distribution and glacier size in mountainous areas. They exclusively consider equilibrium conditions. As a first application, it is assumed that only one parameter, mean annual air temperature, is changing. Permafrost distribution patterns were estimated for a test area (Corvatsch-Furtschellas) and for the whole Upper Engadin region (eastern Swiss Alps) using a relation between permafrost occurrence, potential direct solar radiation and mean annual air temperature. The simulations for the glaciers are based on the assumption that an increase or decrease in ELA leads to a mass-balance change. Calculations for future changes in ELA and mass balance include estimates of area, length and volume. Mass changes were calculated for 1850 to 1973 using measured cumulative length change, glacier length and estimated ablation at the terminus. Since 1850, permafrost became inactive or disappeared in about 15% of the area it originally occupied in the whole Upper Engadin region and mean annual glacier mass balance was –0.26 to –0.46 m w.e. a^{-1} for the larger glaciers in the same area. The estimated loss in glacier volume since 1850 is 55–66% of the original value. With an assumed increase in mean annual air temperature of + 3°C, the area of permafrost might be reduced by about 65% and only three glaciers would continue to partially exist.

Alpine permafrost distribution

(F. Keller and M. Hoelzle, VAW)
Two different empirical models were developed to simulate permafrost distribution in different areas of the Alps. The first, PERMAKART, uses 'rules-of-thumb'. These are based on knowledge collected using different geophysical methods as well as from geomorphological indications of creeping permafrost bodies. The model uses topographic rules to differentiate between aspect, altitude, slopes and foot of slopes. The second model, PERMAMAP, is more physically based. A relation between BTS measurements, which reflect permafrost distribution, and two important climatic factors, air temperature and potential direct solar radiation, was used to model the permafrost-distribution patterns. Both models are fully integrated in a GIS and need a digital-terrain model to simulate local to meso-scale permafrost distribution.

Permafrost, hydrology and hydrogeology in the Alps

(J.-M. Gardaz, GGUF)
Fontanesses (Arolla) has been added to the sites already

prospected: Rechy, Lona and Turtmanntal. The work consists of mapping periglacial forms, installating hydrological and climatological stations, and the geological, hydrogeological and geophysical investigations of the frozen rocky bodies or those that can be permanently frozen. The ground- and surface-water of the permafrost is studied as well as the hydrological regime of the periglacial torrents issuing from the Fontanesses and Rechy rock glaciers. Electrical resistivity soundings and BTS were performed in addition to stream-flow measurements, tracer experiments and hydrochemical analyses of stream and spring water.

Slope instability in alpine permafrost areas

(R. Lugon, GGUF)
Factors relating to slope instability in Alpine permafrost are being investigated at two active sites of the Valais Alps: the moraine of Glacier du Dolent (Val Ferret) and periglacial talus near Grächen (Zermatt valley), both having already experienced catastrophic debris-flow events. Geophysical prospecting (BTS and DC resistivity sounding) is combined with geotechnical and climatological methods to determine the main causes of instability. Lower limits of local permafrost occurrence, modelled using a GIS, are compared with snowline and ELAs to better understand effects on the stability of non-consolidated sediments from altitudinal shifts related to climate change.

Geo-ecological studies in the periglacial belt of Swiss high mountains (Valais Alps, Gemmi)

(C. Döbeli and H. Leser, GIB)
Snowmelt, the soil nutrient and soil water regime will be assessed in the "Lämmerensee" catchment area, a glacial to fluvial/nivo-fluvial drainage system in the Valais Alps (2350 m a.s.l.) for 1994 to 1997. Runoff and nutrient transport in relation to snow dynamics are of special interest.

Snow cover and high-mountain permafrost

(F. Keller, VAW and ILU; H. U. Gubler, ALPUG; K. Mellini, L. Bernhard and F. Sutter, GIUZ)
The influence of the snow cover on the thermal regime of high-mountain permafrost bodies and the effects of reduced heat flow on snow characteristics are being investigated in the Murtèl/Corvatsch area (Upper Engadin, eastern Swiss Alps). Direct coupling between the atmosphere and the active layer, via funnels in snow covers less than 60 cm thick, are being analyzed. The relation between snow-cover thickness, solar radiation and snow disappearance is studied using field measurements and digital-terrain information. Ground cooling and changes in snow cover resulting from ski-run preparation are being evaluated with respect to the earlier postulated autumn-snow effect on mountain permafrost.

Permafrost and rockwall stability

(M. Wegmann and W. Haeberli, VAW; H. R. Keusen, GEOTEST; C. Schindler, IGZ)
Detailed qualitative and semiquantitative observations in the Jungfraujoch area form the basis of a study on the effects of permafrost dynamics and glacier recession on the geotechnical properties of strongly jointed rockwalls. In different boreholes, equipped with highly precise thermistors, extensiometers and inclinometers, temperature-related deformations are measured. The observations are supplemented by geological, geomorphological, glaciological and geophysical field investigations (mapping, soundings). The description of the thermal and geotechnical characteristics of permafrost in rockwalls is expected to lead to new insights into frost-shattering processes. The stress redistribution and change in thermal conditions of rockwalls in deeply-cut glacier troughs are also being studied.

Geophysics of Svalbard rock glaciers

(D. Vonder Mühll, M. Hoelzle and S. Wagner, VAW)
Geophysical soundings of rock glaciers near Ny Ålesund, Kongsfjord area, Svalbard, are performed in collaboration with the Institute of Geography, University of Oslo. Using DC resistivity soundings, refraction seismic and gravimetry, the aim is to investigate possible drill sites in creeping permafrost. Field measurements were performed in 1992 (DC resistivity soundings), 1993 (refraction seismics) and 1994 (gravimetry). Bedrock depth, geophysical properties and ice content will be calculated. Long-term measurements of surface velocity are carried out and the geophysical measurements will be compared with results from the Alps.

Active layer as a hydrological and nutrient storage system in the Arctic

(H. Leser and M. Potschin, GIB)
Studies on permafrost and active-layer depth will provide a quantitative measure of water and nutrient storage within the ecosystem in terms of seasonal variations. In the summers of 1990–1992 measurements were made at 12 locations (3 parallel measurements) within the catchment of Liefdefjorden (NW Spitsbergen, 79°3′ N, 13° E). The work included sampling soil-, surface- and stream-water for chemistry (every second day).

ICE-CORE STUDIES

Scavenging study of air constituents into an Alpine snowfield

(M. Schwikowski, U. Baltensperger, H. W. Gäggeler [also at IAC], D. T. Jost and U. E. Nieveler, PSI)
A field campaign was conducted at Jungfraujoch (3450 m a.s.l.), within the framework of ALPTRAC, from 18 October to 18 November 1993, to study the scavenging of air-contained species into fresh snow. Three different constitutents were investigated: gaseous species (e.g. nitric acid), aerosol particles from the accumulation model (e.g. sulfate, ammonium) and soil particles (e.g. calcium). Largely different scavenging ratios were found: the highest values were observed for gaseous species and the lowest for aerosol particles from the accumulation mode. Such investigations are essential for future quantitative interpretation of atmospheric records from Alpine ice cores.

150 year record of sulfate, nitrate and ammonium ions from a high-alpine glacier

(A. Döscher, H. W. Gäggeler [also at IAC], U. Schotterer and M. Schwikowski, PSI)
A 109 m ice core, drilled in 1982 at Colle Gnifetti (4450 m

a.s.l.) was analyzed for acidifying ions. First, a ^{210}Pb nuclear dating was performed, extending back to about 1850. For all measured species, pronounced annual concentration variations were found with maxima in summer and minima in winter. The summer sulfate concentrations increased about ten times from the second half of the 19th century to about 1960. A less-pronounced increase, a factor of about four, was found for nitrate starting about 1950 and reaching a maximum after 1970.

Search for an Alpine core-drilling site with high accumulation rates

(H. W. Gäggeler, PSI and IAC; A. Döscher and M. Schwikowski, PSI; B. Stauffer, Th. Blunier, H. Rufli and KUP; M. Funk, A. Kääb and S. Suter, VAW)

Previous ice-core drillings in the Swiss Alps aiming for palaeo-atmospheric studies have been mainly on Colle Gnifetti (4450 m a.s.l) where the average deposition rates are only about 3035 cm w.e. a^{-1}, much of the annual deposition being removed by wind erosion. For high-resolution studies, a site with more regular deposition of fresh snow was sought in the Monte Rosa area. Three shallow firn cores were drilled in June and September 1993 at Seserjoch (4307 m a.s.l.) and two adjacent lower sites on Grenzgletscher (4256 and about 4200 m a.s.l.). At the lowest site, the main acidifying ions clearly indicated the deposition rates were high, about 2 m w.e. a^{-1}. So in June and October 1994, a 35 m and a 125 m core were drilled here. These will be used to reconstruct the most important atmospheric constituents over the past about 200 years with a seasonal resolution.

Ice-core drilling in Greenland

(B. Stauffer and J. Schwander, KUP)

A group from the University of Bern is participating in the "Greenland Ice Core Project" (GRIP). The coring at Summit (72°35′ N, 37°38′ W) reached bedrock in July 1992 at 3028.8 m. The age of the ice close to bedrock exceeds 250 000 years. The ice cores are now being analyzed in different laboratories to reconstruct the history of climate changes and earth-system processes of the past 250 000 years. The Bern group had a substantial share in the drilling and also in performing first measurements on the core already in the field.

History of atmospheric composition

(J. Schwander, M. Anklin, Th. Blunier, B. Stauffer and J. Tschumi, KUP)

CO_2 and CH_4 concentrations have been measured in air extracted from the GRIP ice core. These measurements are being performed in collaboration with LGGE in Grenoble. The results so far cover about the last 40 000 years (2250 m depth). The general trends, as obtained from previous studies, have been confirmed. CH_4 concentration is 350–400 ppbv in the Ice Age, and 650–700 ppbv in the Holocene. The new CH_4 record has a much better time resolution. During and at the end of the glaciation, the methane concentration runs parallel with rapid climatic variations, as revealed by the isotopic record (Dansgaard–Oeschger events). The shift in CH_4 between cold and warm stages is in the order of 100 ppbv. Surprisingly, variations of up to 100 ppbv are also observed during the Holocene. Further investigations are needed on the CO_2 record. Though confirming the general pattern known from Antarctic records, an excess of CO_2 is observed in Greenlandic ice-core samples. There are indications it originates from a carbonate-acid reaction, which can be excluded in Antarctic cores due to the lower impurity concentrations.

Stable isotopes in nitrogen, oxygen and carbon dioxide of bubble-air and elemental ratios O_2/N_2 and Ar/N_2 in air hydrates from cold ice

(A. Fuchs and M. Leuenberger, KUP)

Air in bubbles, and partly also that in hydrates, is extracted by milling the ice in an evacuated container. The air and the trace gases (CO_2 and N_2O) are trapped separately. The $\delta^{13}C$ in CO_2 and the N_2O/CO_2 ratio are measured on the trace gas fraction. The $\delta^{15}N^{18}O$ in O_2 and the ratios O_2/N_2 and Ar/N2 are measured in the air fraction. The $\delta^{13}C$ yields information about the carbon cycle and its variability. The $\delta^{15}N$ allows the determination of the enrichment of heavy gases in the porous firn due to gravity. The $\delta^{18}O$ is a proxy for ice volume and sea-level changes and a tool for synchronizing records from ice cores with records from deep-sea sediments. The O_2/N_2 and Ar/N_2 ratios make it possible to investigate air hydrates in deep ice cores.

H_2O_2, HCHO, $NH_4{}^+$ and Ca^{++} in ice cores

(K. Fuhrer, M. Hutterli and M. Anklin, KUP)

Simultaneous high-resolution measurements of H_2O_2, HCHO, $NH_4{}^+$ and Ca^{++} concentration were performed with a "Continuous Flow Analysis" technique along the GRIP ice core from 1300 m below surface to the bottom of the ice core. In summer 1993, a 100 m core was recovered to measure the concentration of the four constituents using this new technique. The H_2O_2 and HCHO concentration increased a factor of two during the past 200 years. The average $NH_4{}^+$ concentration has not been increasing in the past few hundred years. The H_2O_2, HCHO and $NH_4{}^+$ concentrations have also been measured along two 10 m firn cores and on several pit samples taken during the SWEDARP traverse in Antarctica. To interpret the ice-core results, a better knowledge of the transfer of the atmospheric constituents into snow and ice is needed. To investigate this H_2O_2 and HCHO, gas-phase measurements were performed at Summit in Greenland and in Antarctica along SWEDARP, and on air extracted from the firn at different depths at Summit.

Air mixing in firn

(J. Schwander, M. Leuenberger and B. Stauffer, KUP; with LGGE)

The CO_2, CHO_4, Freons, ^{85}Kr and the isotopes of O_2 and N_2 have been measured in air collected from a drill hole at Summit in the firn at several depth levels. As the measured trace gases all show increasing trends in the atmosphere, they can be used as tracers for the air mixing in the firn. The measured data are compared with results from a diffusion model. At Summit the mixing is explained mainly by molecular diffusion. Ventilation by barometric and wind-induced pressure variations play a minor role at sites with relatively flat surface topography and moderate wind speeds. The mixing time down to the firn–ice transition is in the order of 10 years. An enrichment of the heavier isotopes due to separation by gravity has been observed. Measurements at Summit and Vostok suggest that the air diffusivity depends not only on firn porosity but is probably also strongly affected by the firn structure. We are collaborating with different projects to determine parameters for models which describe the mixing of air in the firn and the enclosure process at the firn–ice transition.

SNOW AND ICE CLIMATOLOGY/HYDROLOGY

Spatial distribution of the energy balance in complex terrain

(C. Plüss and A. Ohmura, GGEZ; P. Föhn, SFISAR)
Energy balance measurements over the seasonal snow cover were performed during spring 1992 and 1993 near Davos in the eastern Swiss Alps. During the snowmelt period, the energy balance is dominated by the net radiation, accounting for more than 90% of the energy available for melt. Parameterizations of the fluxes are verified against the measurements and used to model the spatial distribution of the energy balance.

Energy and mass balance at the equilibrium line altitude on the Greenland ice sheet (ETH Greenland Expedition)

(A. Ohmura, GGEZ)
A meteorological experiment was carried out during the summer months of 1990 and 1991 near the mean equilibrium line altitude in the Paqitsoq area on the western slope of the Greenland ice sheet (69°34′ N, 49°17′ W, 1155 m a. s. l.). The study included the monitoring of all energy flux components at the ice surface and in the atmospheric boundary layer on a 30 m high tower, and regular launches of upper air-sounding balloons. The evolution of the snow cover was monitored through the entire melt seasons. An automatic weather station recorded air temperature and wind speed, as well as the temperature profile in the top 10 m of ice from spring 1991 to spring 1994.

Structure of the stable boundary layer over snow and ice surfaces in Greenland

(J. Forrer, GGEZ)
The main objective of this work is to improve the understanding of the structure of the stable atmospheric boundary layer and the turbulent exchange (i.e., turbulent fluxes of sensible and latent heat) over a permanently snow- or ice-covered surface. The data used for this study were collected during the two summers 1990 and 1991 at the ETH camp. Profiles of mean variables (wind speed, temperature and humidity) were measured on a 30 m tower. In addition, three turbulence units at different heights provided the fluctuating variables.

Katabatic wind over the Greenland ice sheet

(G. Niederbäumer, GGEZ)
The gravity-driven surface winds produced by radiative cooling of the sloping ice (katabatic wind) are of great importance for the understanding of the energy- and mass balance of the Greenland ice sheet. A three dimensional model is used to simulate different conditions, such as winter versus summer, melting ice surface versus fresh snow, and very shallow synoptic pressure gradient versus cyclonic pressure gradient. Measured data from different sources, including the ETH camp, are compared with model results.

Radiation balance in and above the snow cover on the Greenland ice sheet

(T. Konzelmann, GGEZ)
As part of the ETH Greenland Expedition, all radiative fluxes at the surface and the radiation penetration into the snow cover were measured. During the melt period, the decrease in global radiation due to increasing cloud amount is compensated for by an increase in longwave incoming radiation. Because of steady values of longwave outgoing radiation, net radiation at the surface is mainly determined by albedo and its variation. The radiation balance in the snow cover is caused by the total reflectivity at the surface and the surface absorptivity. The absorbed energy is used mainly for melt and less for heat conduction into the ice.

Atmospheric moisture flux convergence over Greenland

(P. Calanca, GGEZ — presently at University of Helsinki)
The convergence of the atmospheric moisture flux has been inferred from assimilated data of the ECMWF. In the long term, the moisture flux convergence becomes equal to difference between precipitation and evaporation at the surface. It therefore provides a good estimate of the accumulation. For all of Greenland, the average annual total moisture flux convergence for the three years 1989 to 1991 amounts to 315 mm. This figure is close to the 310 mm for the annual total accumulation. Large-scale features of the accumulation distribution are also well reproduced in the spatial distribution of the moisture flux convergence.

A possible change in mass balance of Greenland and Antarctic ice sheets in the coming century

(A. Ohmura and M. Wild, GGEZ)
The surface mass balance of the Greenland and the Antarctic ice sheets is simulated using the high-resolution ECHAM 3/T-106 atmospheric general circulation model (MPI, Hamburg) experiment. The experiment is based on the five-year equilibrium test, part of the ECHAM 1/T-21 transient experiment which provided the boundary conditions for the present and the year 2050, when carbon dioxide is expected to be doubled. On Greenland one sees a slight decrease in accumulation and a substantial increase in melt, while on Antarctica a large increase in accumulation without melt is projected. The change in the combined mass balance of the two continents is almost zero.

Thermodynamics of earth climate in response to polar ice sheets

(H. Ozawa, GGEZ)
Present climate is known to be at a state of maximum increasing rate of entropy through irreversible heat transport processes in the atmosphere and in the ocean. Thus the Earth system is stabilized so as to increase entropy in the universe at a possible maximum rate. A simple thermodynamic model is being used to seek several meta-stable states in response to variations in the size of

ice sheets to clarify intransitive change of the Earth climate during glaciation and deglaciation.

Climate conditions and thermomechanical state of Hansglacier, Spitsbergen

(H. Blatter, GGEZ; cooperation with University of Silesia, Poland)
During 1994, three holes were drilled down to or close to the glacier bed. Temperature measurements give a clear picture of the polythermal structure: a temperate accumulation zone and a cold surface layer up to 80 m thick above temperate basal ice in the ablation zone. An automatic weather station has operated since April 1994 at the mean ELA on Hansglacier. Global radiation was measured at the Polish base camp during the 1994 melt season. The project will serve as a test case for numerical glacier modelling.

Water balance of high Alpine regions

(L. Braun, R. Hock and U. Steinegger, GGEZ; H. Müller, TERGESO; M. Aellen, VAW; G. Kappenberger, SMI - Locarno Monti)
Investigations of climate, glacier mass balance and runoff in the Glaronese Alps use long measurement series of snow accumulation and ablation (e.g. Clariden Firn since 1914), storage-gauge precipitation, inflow into Limmern reservoir and discharge of the Linth River. Winter precipitation is assessed using maximum snow accumulation, and the spatial distribution of summer and winter precipitation is analyzed. A reference series of high-alpine precipitation is being derived for 1914–1983, and of glacier mass balance such as basin precipitation, evaporation, snow accumulation and ablation, and discharge based on standard meteorological data. Long-measurement series are used as an additional basis for calibrating and verifying the model.

Snow storage, glacier mass balance and discharge, French Alps

(L. Braun and M. Rohrer, GGEZ; collaboration with Météo France and Eléctricité de France, Grenoble)
Continuing a cooperative project completed in 1993, studies concerned the simulation of snow storage, glacier mass balance and discharge of the Romanche river basin. Physically based models (SAFRAN-CROCUS) are compared with conceptual ones and tested against measured values. The hydrological consequences of climate change are being assessed.

Discharge forecasts from Alpine regions

(M. Rohrer, U. Steinegger, H. Jensen and H. Lang, GGEZ)
Developments in short- and long-range forecasting of discharge are pursued with various hydroelectric power companies. Measurements of snow-water equivalent as well as its simulation based on standard meteorological variables with high temporal resolution are used.

Runoff and snow/ice storage in high Alpine regions

(R. Hock, H. Lang and L. Braun, GGEZ)
Using data from Storglaciären (Sweden) and Vernagtferner (Austria). studies are underway to adjust the conceptual precipitation-runoff model HBV/ETH to highly glaciated basins, to reduce the time step from daily to hourly resolution, and to include climatological data, beside temperature and precipitation, as model input. The project included field work in the Storglaciären basin in summers 1993 and 1994. Emphasis is on snow accumulation processes, snow and ice melt, and the modelling thereof.

Snow-water equivalent in Switzerland

(M. Rohrer, A. Fischer, H. Lang and U. Steinegger, GGEZ)
Long-term records of the water equivalent of the snow cover (SWE) are analyzed in order to produce maps for the beginning of January, March, April and May covering the whole of Switzerland, based on a 2 km × 2 km grid. Direct measurements of the SWE are complemented with simulated values based on snow-depth measurements and the settling-curve model.

Monitoring and forecasting of snowmelt surface runoff

(H. Haefner, GIUZ; K. Seidel, W. Brüsch, C. Ehrler and C. Steinmeier, IKT; J. Martinec, formerly SFISAR)
Operational applications of the Snowmelt Runoff Model for short-term and seasonal forecasts are being investigated in various catchments of the Swiss Alps. Satellite data are used to monitor the snow cover and establish depletion curves for each elevation zone. The results are also used to map regional distribution patterns of water equivalents at specific dates, e.g. the beginning of the melt period.

Climate change, alpine snow cover and their influence on runoff

(K. Seidel, J. Martinec, J. Wiedemeier and C. Ehrler, IKT)
This project emphasizes realistic evaluation of snow-cover conditions by satellite remote sensing. Adequate spatial resolution for periodic snow-cover maps is achieved using Landsat-TM and SPOT-XS data. It is hoped snow cover and the annual redistribution of runoff envisaged can be predicted for any climate scenario — of interest for hydro power and water management. The three basins in the Swiss Alps selected sample regional climate differences in the NS and WE direction. Accelerated snow ablation due to expected higher temperatures affects winter tourism and the resulting lower albedo may be used as a feedback to climate models.

Snow accumulation and runoff in Bohemian catchments

(C. Hottelet and L. Braun, GGEZ; collaboration with Water Research Institute, Prague)
The conceptual precipitation-runoff model HBV/ETH, developed for Swiss basins, was applied in various Bohemian catchments, and its performance for simulating snow cover and runoff is being assessed. Special emphasis is being placed on the influence of vegetation on the snow cover.

Snow and glacier hydrology, Nepalese Himalaya

(L. Braun, M. Rohrer, U. Steinegger, C. Hottelet, GGEZ)
In a joint research project with the Technical Cooperation Agency (GTZ) of Germany and the Government of Nepal

(Dept. of Meteorology and Hydrology, Mr. Shankar) a conceptual runoff model is being applied to various watersheds in the Nepalese Himalaya, and a snow- and glacier-measuring programme is being undertaken. There is special emphasis on snow-accumulation studies at higher elevations, and on the continued training of Nepalese scientists in field work and data analysis.

GLACIAL GEOLOGY/ PALEOGLACIOLOGY

Genesis of Antarctic and Alpine till

(M. Helfer, QUAB)

The genesis of the Cenozoic Sirius Formation, from the Dry Valleys of McMurdo Sound, is a key to Antarctic glacial history. This till is compared with that from Alpine valley glaciers, using macrofabrics, physical properties, thin sections and clay mineralogy, etc.. The sediments are the product of glaciers in a dry polar environment. Their lithologic characteristics provide a new reference point for interpreting till from the Swiss Plateau.

Paraglacial sedimentation and denudation processes

(B. Müller, QUAB)

Using drill results from the Walensee area, a new model of glacial erosion and sedimentation in Alpine valleys was developed and the question of lake formation in the Rhein-Linth drainage area resolved. The lithological model and some radiocarbon datings enabled calculation of local sedimentation and denudation rates and changes in them during late- and postglacial time. Sediment budgets since the last glaciation point to minimum denudation rates of $1.5\,mm\,a^{-1}$ for the catchment of the lake at Walenstadt; much higher than earlier estimates from tectonic and isostatic evidence.

Last Glacial Maximum, central Alps

(D. Florineth, QUAB)

Models of the Last Glacial Maximum show uncertainties for the area above the ELA. The geometry of Ice Age glaciers was generally assumed to be strongly related to the present river system, i.e. ice-flow being the same as that of today's rivers. This is incorrect since glacial-erosion features indicate transfluences over high-altitude passes, like Julier or Grimsel Pass; and upstream flowing of some Ice Age glaciers, especially at high altitudes in the central Alps. Detailed mapping of trimlines, measurements on striated bedrock, the distribution of erratic boulders, and the orientation of roches moutonnées, as well as crescentic fractures and lunar fractures, in a GIS, will permit a new reconstruction of the Last Glacial Maximum with the solution of the transfluences.

Glacier fluctuations in the Pre-alpine zone during the Late Glacial

(N. Durussel and P. Schoeneich, IGUL)

Detailed mapping of landforms and deposits, as well as analysis of lacustrine and palustrine sediments and absolute datings are used to reconstitute the deglaciation stages of the last glacial period with special emphasis on the lower alpine region on both sides of the Rhone valley. In the region to the NE of the Rhone valley, the identification of numerous fluctuations of local glaciers reflects a pluri-decennial to pluri-centennial rhythm, similar to the historic variations. Some major stages correspond to the beginning of the Late Glacial period (the Bühl to Clavadel stages), between 17 000 and 13 000 ^{14}C BP. In the valleys of lower Valais, SW of the Rhone, the study area includes glacial deposits of both local glaciers and the Rhone glacier. This study aims at emphasizing the different fluctuations of the glaciers, the stages of glaciation of the whole area, to obtain a global view of the events in the Lemanic region during Late Glacial times. Later, sediment fillings of the Rhone valley between these areas will be studied.

Late- and Post-glacial glacier stages, central Valais

(C. Dorthe-Monachon, N. Durussel, F. Golaz and E. Reynard, IGUL)

Glacial and periglacial landforms and deposits along the Rhone valley are studied, in the Trient and Moiry valleys on the left side and in all tributary valleys on the right between Leuk and Martigny, where it was possible to document an important retreat stage of the Rhone glacier. The geomorphology and permafrost of the Moiry valley have been mapped. Paleogeomorphological reconstructions and relative chronologies are tentatively correlated with late-glacial stages of neighbouring regions. Lichenometric datings have been made on the proglacial margin of Moiry glacier.

Geomorphological mapping, Swiss National Park

(K. J. Graf and collaborators, GIUZ)

Based on field studies from 1988–93, surficial deposits and the geomorphology have been mapped at 1 : 10 000, within the mapping programme GMK-25 SNP. The data base shows the importance of former glacial processes and periglacial and karstic phenomena within the $168\,km^2$ area of the Swiss National Park (eastern Swiss Alps, Grisons). Many Late Glacial moraines and striated rock surfaces were observed. The information is transformed into a multilayered GIS which already contains a 3-D model of the topography as well as of the vegetation and geology.

Early and middle Holocene glacier fluctuations in the Alps

(C. A. Burga, GIUZ; cooperation with Istituto di Geologia, Milano)

Interactions between glacier fluctuations and vegetation change were investigated by pollen analysis of a profile near the front of the Rutor Glacier, 2510 m (Aosta Valley, Italy). This provided information about the early and mid-Holocene glacier extensions. The profile reflects the following phases: glacigenic (Preboreal–Boreal); limnic (transition Boreal/Older Atlantic); telmatic-terrestric (Older Atlantic); glacigenic (Younger Atlantic, moraine); terrestric (transition Younger Atlantic/Subboreal, peat); and again a glacigenic phase (Subboreal, moraine). The peat-bog grew from 6735–6055 BP. During the Younger Atlantic it was covered by the glacier (Piora I Stage). The peat-forming period was the optimal phase of warm climate with timber-line 100–200 m higher than today.

Deglaciation of the Rhine glacier system in the Upper Würm, Cantons St. Gall and Grisons

(O. Keller and E. Krayss, GIUZ)
Ice-marginal sediments and melt forms were found at 1400–2000 m a.s.l. They are proof of warmer periods of interstadial type during the late High-Würm. Masses of fluvioglacial and glaciolacustrine deposits in the Rhine system are interpreted as ice-dammed refillings, and are evidence of the foundering of the ice-stream network which still existed during the Weissbad–Koblach stade (about 14 500 BP). But the next marked stade in the central Alps, Gschnitz (13 500 BP at the latest) only shows independent local glaciers. So a collapse of the ice-stream network must have occurred during these 1000 years. In this period the Rhine glacier melted back from 110 km to 30 km. This event requires an interstadial warmer climate during the older Late Glacial.

Structure, stratigraphy and climatic significance of the Isola delta, Upper Engadin (Eastern Swiss Alps, Grisons)

(P. Fitze, C. A. Burga, K. J. Graf, W. A. Keller and M. Maisch, GIUZ)
A limnic delta (Isola delta, Lake Sils) was investigated by ram-profile technique and different chemical, stratigraphical and pollen analytical methods. Borehole samples from the upper delta surface (max. depth 13 m), will permit reconstruction of the former geomorphological history and an explanation of the present delta structure. Links between stratigraphy, geomorphology and climate changes in the Val Fex/Val Fedoz drainage basins are being investigated. Detailed analysis of multilayered debris cone sediments, near the Holocene glacier moraines, will reveal the entire history of valley formation since the late-glacial.

A GIS for Ice Age glaciology

(J. M. Hegner, F. Keller and W. Haeberli, VAW)
The topographic map representing Ice Age glacierization of Switzerland (published by H. Jäckli in 1970) is being digitized for use with ARC/INFO. The map shows maximum glacier extent during the last Ice Age (Würm, around 20 000 BP). It is hoped the digital data base will serve as a basis for new presentations and calculations with respect to ice volumes, basal shear stresses or local isostatic rebound patterns, etc. An inventory of all the glaciers on the map will be compiled. Special attention will be given to ice conditions in the Rhine catchment where detailed reconstructions are available from extensive field mapping.

Abbreviations

ALPUG: ALPUG (consultants), Davos
BUB: Botanical Institute, University of Basel
ELA: Equilibrium line altitude
ETHZ: Swiss Federal Institute of Technology, Zürich
GEOTEST: Geotest (consultants), Zollikofen
GGEZ: Institute of Geography, ETHZ
GGUB: Geomorphology Group, Institute of Geography, University of Bern
GGUF: Institute of Geography, University of Fribourg
GIB: Institute of Geography, University of Basel
GIS: Geographical Information System
GIUZ: Institute of Geography, University of Zürich
GK/SANW: Glacier Commission, Swiss Academy of Sciences
IAC: Institute of Inorganic Chemistry, University of Bern
IGP: Institute of Geodesy and Photogrammetry, ETHZ
IGUL: Institute of Geography, University of Lausanne
IGZ: Institute of Geology, ETHZ
IKT: Image Science Division - Remote Sensing, Communication Technology Laboratory, ETHZ
ILU: ILU alpin (consultants), Samedan
ISE: Institute for Structural Engineering, ETHZ
ITESP: Institute of Terrestrial Ecology, Soil Physics, ETHZ
IUZ: Institute of Informatics, University of Zürich
KUP: Climate and Environment Project, Physics Institute, University of Bern
LGGE: Laboratoire de Glaciologie et Géophysique de l'Environnement, Grenoble, France
PSI: Paul Scherrer Institute, Villigen
QUAB: Geological Institute, University of Bern, Quaternary Geology
SFISAR: Swiss Federal Institute for Snow and Avalanche Research, Weissfluhjoch-Davos
SMI: Swiss Meteorological Institute
TERGESO: TERGESO (consultants), Sargans
VAW: Laboratory of Hydraulics, Hydrology and Glaciology, ETHZ

Submitted by Wilfried Haeberli

International Glaciological Society

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BRANCH NEWS

NORDIC BRANCH

25 November 1994 saw the second meeting of the IGS-Nordic Branch in Stockholm. Organisers were Per Holmlund, Veijo Pohjola and Peter Jansson of the Department of Physical Geography, Stockholm University. Participants came from Denmark, Finland, Norway and Sweden. The subjects of the talks ranged widely covering: the Tarfala Research Station and the Rovaniemi Arctic Centre; Norwegian glacier mapping; projects in connection with the hydropower project underneath Engabreen, northern Norway; Danish research in Antarctica and Greenland; Swedish research in Antarctica; and research on Austerdalsbreen and Storglaciären.

During the meeting the strategy for future meetings was laid out. The IGS President, Bjørn Wold, started the discussion by providing a detailed description of IGS history and current objectives. This fuelled the constructive discussions that followed. A decision was made to set a permanent date of the last weekend in November for future meetings in order to make long-term planning easier. Furthermore, the importance of enabling and encouraging students to participate in these meetings was discussed. The discussions on these and many other topics continued at the lively Friday night dinner arranged in the old cellar of the astronomical observatory in Stockholm. The observatory was erected in 1747–53 and is the site of the longest continuous temperature record in Sweden, initiated 1756. The 1995 meeting is to be arranged in Finland by Matti Leppäranta. Denmark, through Claus Hammer, has expressed interest in arranging the 1996 meeting in Copenhagen.

Peter Jansson

JOURNAL OF GLACIOLOGY

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

D M McCLUNG AND A I MEARS
Dry flowing avalanche run-up and run-out

V LIPENKOV, F CANDAUDAP, J RAVOIRE, E DULAC AND D RAYNAUD
A new device for the measurement of air content in polar ice

M P FISCHER, R B ALLEY AND T ENGELDER
Fracture toughness of ice and firn determined from the modified ring test

G E LISTON AND D K HALL
An energy-balance model of lake-ice evolution

G KOH AND R JORDAN
Subsurface melting in a seasonal snow cover

P HOLMLUND AND H FUENZALIDA
Anomalous glacier responses to 20th century climatic changes in the Darwin Cordillera, southern Chile

D J CAVALIERI, K M ST GERMAIN AND C T SWIFT
Reduction of weather effects in the calculation of sea-ice concentration with the DMSP SSM/I

A H GOODWIN AND D G VAUGHAN
A topographic origin for double ridge features in visible imagery of ice divides in Antarctica

F M JACOBSEN AND W H THEAKSTONE
The use of planimetric surface area in glacier mass balance calculations: a potential source of errors

T KONZELMANN AND A OHMURA
Radiative fluxes and their impact on the energy balance of the Greenland ice sheet

R E GAGNON AND P H GAMMON
Triaxial experiments on iceberg and glacier ice

R B ALLEY, R C FINKEL, N NISHIIZUMI, S ANANDAKRISHNAN, C A SHUMAN, G R MERSHON, G A ZIELINSKI AND P A MAYEWSKI
Changes in continental and sea-salt atmospheric loadings in central Greenland during the most recent deglaciation: model-based estimates

A C FOWLER AND CLARE JOHNSON
Hydraulic runaway: a mechanism for thermally regulated surges of ice sheets

SLUSHFLOW/SLUSH AVALANCHE TERMINOLOGY

Following the realization by participants at the Circum-Arctic Slushflow Workshop (see report in this issue of ICE) that three different terms (slushflow, slush avalanche and snow water flow) were being used to characterise the processes under discussion, it was decided to establish a common or standard international nomenclature. Agreement was reached on the following terms to be applied to slushflow processes and characteristics.

Slushflow is the preferred term for the predominantly linear flow of water-saturated snow, as defined by Washburn (1979); it describes the process specifically. However, it is recognized that some other terms (see Nyberg, 1989) may be useful when emphasizing the rate of slush movement, and that the Russian term, *Snow Water Flow*, is useful when describing qualitatively the consistency of the material flowing.

The following terminology was agreed, to reflect consistency with that used in avalanche literature:

Starting Zone: the area from which the slushflow is released.

Catchment Area (or *Drainage Area*): that part of the drainage basin above the starting zone which contributes free water to the slushflow release area.

Track: the path through which the slushflow moves. Comment: it lies between the starting zone at the top and the runout zone at the bottom.

Runout Zone: the area over which the slushflow material is deposited.

Slushflow Path: includes the starting zone, the track and the runout zone of the slushflow.

Slushflow Fan: a fan, or whaleback-shaped, deposit of material transported and deposited by multiple slushflows.

Slushflow Deposit: the material transported and deposited by slushflows

Multiprocess Fan: a fan-shaped deposit and combined fluvial and slushflow origin.

Multiple Releases: more than one slushflow release that may be experienced in a single catchment area given an appropriate set of conditions during periods of slushflow activity.

Nyberg, R. 1985. Debris flows and slush avalanches in northern Swedish Lapland: distribution and geomorphological significance. *Lunds Universitets Geografiska Institution Meddelanden* 97.

Washburn, A. L. 1979–1980. *Geocryology: a survey of periglacial processes and environments*. New York, etc., John Wiley & Sons.

Lawrence J. Onesti

WORLD GLACIER MONITORING SERVICE (WGMS)

The Service continued its work with respect to its five major tasks:

Fluctuations of glaciers

Preparation of the next report, 1990–95, will start in 1996. Maps for possible inclusion are now being considered.

Glacier inventory

A parameterization scheme using simple algorithms for unmeasured glaciers is being applied to glacier inventory data to estimate the basic glaciological characteristics of the inventoried ice bodies and to simulate potential climate-change effects on mountain glaciers. Responses to assumed mass-balance changes are calculated as step functions between steady-state conditions for time intervals which approximate the characteristic dynamic response time (a few decades) of the particular glaciers. To test the procedure, a pilot study was carried out in the European Alps where detailed inventories were compiled in the mid-1970s, when the estimated total glacier volume was about 130 km^3. Strongly negative mass balances since then caused a loss of 10–20% of this volume from 1980–1990. Backward calculation of glacier-length changes, using a mean annual balance of 0.25 m w.e. a^{-1} since the end of the Little Ice Age in central Europe (around 1850 AD), gives considerable scatter but satisfactory overall results compared with long-term observations. The total loss of Alpine glacier mass since 1850 is estimated at about half its original value. An acceleration of this, to an annual mass loss of about 1 m a^{-1} as anticipated by scenario A of the Intergovernmental Panel on Climate Change for the coming century, could eliminate major parts of the existing Alpine glacier cover within decades.

Similar analyses will be made for all detailed glacier inventories when loading them into the new data bank and as a basic data check, in cooperation with the national WGMS correspondents. Ways are being investigated for retrieving additional information on glacier dynamics (downwasting/retreat, rock/sediment beds, etc.) or hydrology (seasonal runoff variations, etc.). Perhaps the most important potential is the possibility of quantitatively inferring average decadal mass balances for unmeasured glaciers using field evidence of cumulative length change (moraine mapping, satellite imagery, aerial photography, long-term observations). The repetition of detailed regional glacier inventories would thereby not only furnish important information on local to regional environmental changes, but could also provide a basis for evaluating global warming scenarios.

Glacier mass balances

Bulletin No.3 has been published. Preliminary analysis shows average mass balance was strikingly less negative in 1993 than in other recent years. It will be interesting if this is confirmed as a global, short-term signal.

Satellite observations of remote glaciers

Efforts continue to estimate secular glacier-mass changes from cumulative glacier-length change and inventory data along two meridional transects (Mount Kenya to Svalbard and Patagonia to Alaska) from maps, air photos and satellite images. The main goals are: to assess the representativeness of ongoing mass-balance programmes; to investigate latitude and continentality effects; and to lay the foundation for future remote-sensing programmes.

Periodical assessments

Summaries and analyses were prepared on mass-balance and cryospheric data, glacier-melt rates, climate change, glacier monitoring and glacier fluctuations.

100 years of worldwide glacier monitoring

In 1893 the Swiss Glacier Commission was established to coordinate long-term observations of glacier fluctuations. The following year the 6th International Geological Congress endorsed an international programme. A report now in preparation, entitled 'Into the 2nd Century of World Glacier Monitoring: Prospects and Strategies' will review and redesign this basic strategy to address future problems, particularly those related to greenhouse warming and global water resources.

Wilfried Haeberli

IPA GLOBAL GEOCRYOLOGICAL DATABASE

A long-term goal of the International Permafrost Association is the retrieval, organization and dissemination of frozen-ground data at local, regional and global scales. To accomplish this, a Global Geocryological Database (GGD) is being developed. Information from regions of perennially and seasonally frozen ground is assembled in National Geocryological Databases (NGDs) and/or selected World Data Centers and accessed through the GGD, an internationally distributed system of linked data centers or nodes.

The GGD will help identify, acquire and disseminate data on permafrost and frozen ground to:

- Advance the scientific understanding of permafrost;
- Improve the basis of engineering design;
- Aid in understanding and predicting global and regional climatic change;
- Offer a basis for detecting environmental change; and to
- Enhance the basis for developing environmental scenarios and assessing environmental impact.

At the moment there are four designated nodes:

(1) Federal Center for Geoecological Systems, Moscow, Russia
(2) GeoData Institute, Southampton, UK
(3) World Data Center A for Glaciology, Boulder, Colorado, USA
(4) World Data Center D for Glaciology and Geocryology, Lanzhou, China

For further information see *Frozen Ground*, No.16, December 1994 or contact: Secretary General, IPA, P.O. Box 9200, Arlington, VA 22219-0200, USA.

Jerry Brown

GLACIER MAPS FROM CHINA

Four maps of glacierized areas at a scale of 1:100,000 (40 m contours, 52 × 74 cm, US$16) are available:
(a) Mt. Qomolangma (8848 m)
(b) K2 (Mt. Qogori, 8611 m)
(c) Mt. Xixiabangma (8012 m)
(d) Kongun Tagh (7719 m) Muzta Ata (7546 m)
as well as the following two
(e) Snow, Ice and Frozen Ground in China, scale 1 : 4 million, 100 × 158 cm, US$8
(f) Sketch Map of Landsat Image of the Karakorum, scale 1 : 500 000, 74 × 206 cm, US$5
All were produced by cartographer Mi Desheng, published by Science Press, are in colour with an English introduction and can be purchased from the Lanzhou Institute of Glaciology and Geocryology, Academia Sinica, Lanzhou 730000, People's Republic of China. The price includes postage.

Xie Zichu

OBITUARY

William Osgood Field (1904–1994)

William O. Field's work spans the whole period of modern glaciology in the United States, beginning in the 1920s and ending only with his death on 16 June 1994.

He was born in New York City on 30 January 1904 and was educated at the Hotchkiss School and Harvard University, where he received his B.S. degree in Geology. While a student he became interested in glaciers, as a result of his mountaineering activities. He climbed several peaks in the Canadian Rockies and Alaska, then, after graduating in 1926, climbed in the European Alps and the Caucasus mountains. He had inherited his father's interest in photography, and was an accomplished photographer by the time he visited these areas.

He was scrupulous in saving his photographic records and gathering information about glaciers in western U.S.A. and the contingent parts of western Canada. By the end of his long life, he had amassed a large and remarkable collection, meticulously catalogued, of photographs and maps. The major part of this collection stemmed from his own work in Alaska and is now housed in the University of Alaska Fairbanks. The collection consists of 304 boxes, plus 51 boxes and one four-drawer filing cabinet from his film vault: motion picture film, negatives, prints, transparencies, glass plate negatives and hand-coloured lantern slides. Some of these images date back to the late 19th century. The collection is a fitting memorial to Bill Field's lifelong work.

It was Glacier Bay that inspired him to retrace the steps and follow up the late 19th and early 20th century glacier observations of H. F. Reid and John Muir. He also followed up, in 1931, the work of the 1899 Harriman Expedition, surveying the glacier termini of Prince William Sound. It was by this work that Bill Field resurrected interest in Alaskan glaciers after decades of neglect.

In the 1930s he became a researcher in the Department of Field Exploration and Research of the American Geographical Society (AGS), was appointed a research associate in 1940 and was eventually director of the department until he "retired" in 1969. During World War

Two he served for three years in the photographic branch of the U.S. Army Signal Corps, working as a photographic officer with the Air Force Cold Weather Test Detachment in Alaska in 1943 and in the India–Burma theatres later.

After the war he continued research on glacier variations in Alaska and the Canadian Rockies, on the assembly of archival material and on the operations of World Data Center A Glaciology. He helped initiate and direct AGS glaciological projects, including the Juneau Icefield Research Project and studies of some 200 glaciers in Alaska, Western Canada, Greenland and the southern Andes. During the International Geophysical Year (IGY) he visited U.S. bases in Antarctica and directed the activities of WDC-A Glaciology.

Bill had early in his career conceived the idea of returning to the various glaciers previously observed by Reid, Gilbert, Tarr and Martin, relocating the old photo and survey stations, and determining what had happened during the intervening years. Some other observers, he knew, had been to these localities, but as far as he could tell they had not begun a systematic programme nor had they followed it up by periodic visits. His plan was to extend such observations over a period of several decades or at least through a normal lifetime.

The main objective has been the recording of the variations of glaciers by means of photography, surveying and visual observations. Not only were the changes in the extent and volume of the ice noted, but also the growth of vegetation in deglaciated areas and the normal processes of erosion and deposition connected with the changes in the glaciers. The effects of earthquakes on glaciers were studied after the events of 1958 in the St. Elias mountains and of 1964 in the Kenai and Chugach mountains. Bill's projects also devoted special attention to advancing glaciers and to the glaciers on which massive landslides occurred, in order to determine any future terminal response to those slides.

More than 200 glaciers were observed during Bill's time at the American Geographical Society and in his ensuing "retirement" in 1969. He continued his work from home in Massachusetts, producing some of his most important work in that period. By now he had become a central figure for communication within the glaciological community and had served on many national and international committees. He was a member of the Committee of Glaciers, Section of Hydrology, American Geophysical Union for most of its time since its formation in 1931, and was its Chairman from 1948 to 1954. He served as Reporter on Glaciology of the U.S. National Committee for the International Geophysical Year and later became Chairman of its Technical Panel on Glaciology. At the close of the IGY he continued as chairman when that panel became the Glaciology Panel of the Committee on Polar Research, National Academy of Sciences/National Research Council.

This Panel had a big influence on the growth of glaciology in the USA, initially through the direction of bold, new glaciological programmes in Antarctica and the Northern Hemisphere during the IGY. After the IGY it was not necessary to direct actual programmes, and the Panel undertook uninhibited and stimulating examination of current research activity. The success of the Panel stemmed in no small part from Bill Field's wonderful ability to mediate, organize and quietly direct the ruminations of a diverse group of busy and strong-minded scientists.

His qualities were no less appreciated on international committees. He served from 1960 to 1963 as one of the Vice-Presidents of the International Commission of Snow and Ice (IAHS/IUGG) and from 1962 to 1965 as one of the Vice-Presidents of the Glaciological Society. In glaciological and mountaineering circles, in community affairs and educational groups, his "I'd love to help" resulted in generous interest, wise counsel and much quiet hard work. He interested and excited young people to go into the field — as field assistants, as colleagues and as scientists receiving grants to do projects that he helped to nurture through academic and bureaucratic channels. He also set an example by showing that simple observations, continued in the long term, can yield unique and useful results. In the 1990s, many people are now trying to sort out a world review of the changes of ice on Earth, and are realising the paucity of real data. Bill Field's results from southern Alaska fill a vital temporal and spatial gap in the global data set. His great achievement was to consolidate 100 years of glacier observations by explorers, climbers and early scientific expeditions. Many observations were published in ephemeral forms that would surely have been lost forever if Bill had not stepped in; furthermore, much painstaking detective work was required to disentangle the changes of name and inconsistent usage.

The honours bestowed on Bill reflected the immense respect he and his work gathered internationally. In 1961 he received an honorary doctorate from the University of Alaska, in 1969 the Explorers Medal from the Explorers Club and the Daly Medal from the American Geographical Society, in 1977 the Busk Medal from the Royal Geographical Society, and in 1983 the Seligman Crystal from the International Glaciological Society (IGS).

His publications span many decades. They include the monumental three-volume work, *Mountain glaciers of the Northern Hemisphere*, which remains, even in the current era of remote sensing and GIS, the definitive source.

His links with the IGS began in the early 1950s, when he met Gerald Seligman and other leaders of the Society for the planning of glaciological programmes for the IGY. He was the first non-British member to serve on the Committee of what was at that time the British Glaciological Society, and encouraged us during the next 10 years to transform the society into an international body.

In recording his achievements, we remember above all his great personal qualities of kindness, thoughtfulness and charm. In his homes, whether in New York City or in the country, he and his wife Mary, also a film-maker, for the World Health Organization, provided warm and generous hospitality for their many friends from all over the world, encouraged lively conversation on topics as disparate as the history of film, politics past and present, the emergence of jazz and swing across America, and the history and operation of the railway system.

His last working expedition to Alaska in 1983 was at the age of 83. Up to a few weeks before he died in Great Barrington, Massachusetts, a well-loved part of the Berkshires where his family had a country home, he was busy with worldwide professional correspondence and involved with cataloguing and interpreting photographs from coastal Alaska. His death on 16 June 1994 marked the end of an era. It was fitting that some of his ashes were taken by his son John and daughter Diana to Glacier Bay to be scattered on places he had come to love.

Hilda Richardson

CIRCUM-ARCTIC SLUSHFLOW WORKSHOP

A Circum-Arctic Slushflow Workshop was held at Geostation MGU in Kirovsk, Murmansk region, Russia 9–18 August 1992. Scientists from the Laboratory of Snow Avalanches and Mudflows, Moscow State University (MSU), the Norwegian Geotechnical Institute (NGI) and the Department of Geological Sciences, Indiana University (IU) participated. Lawrence J. Onesti chaired the workshop and Sergey M. Miagkov translated Russian to English.

Valery S. Freidlin (MSU) presented findings from a 10-year study of slushflows in the Khibiny Mountains. A statistical model was developed to establish interactions between meteorological conditions, basin morphology, meltwater discharge and slushflow activity. Dendrochronological dating was used to link seasonal weather conditions to slushflow frequency. Erik Hestnes (NGI) reported on slushflow release prediction based on variables such as winter cyclonic storms, starting zone, morphology, snowpack characteristics and meteorological conditions; ongoing slushflow research in Norway was also discussed. Lawrence J. Onesti (IU) reviewed three years' slushflow research in the central Brooks Range, Alaska. Meteorological and snowpack conditions, starting zone characteristics and slush density were all related to slushflow release. Lichenometric evidence suggests slush-avalanche activity is episodic in nature and may be linked to climatic variation. Valentin N. Supunov's work (MGU) suggests slushflow releases are related to topographic and meteorological conditions in the Khibiny Mountains.

Slushflow defence structures were also discussed. Slushflow/slush avalanche terminology was reviewed and agreement reached on some standardization (see NEWS in this issue of *ICE*).

During the two-week workshop, one field trip to the southeast and central Khibiny Mountains examined the Koashva basin to observe slush-avalanche tracks studied intensively for nine years. Some 20 other slush and snow avalanche tracks were also visited as well as defence structures (dams) in the Koashva and Gakman basins. A second trip visited Rasvumchor Plateau, near the summit of the Khibiny Mountains, and the Anti-Avalanche Service meterological and snow-avalanche station.

Lawrence J. Onesti

AMERICAN GEOPHYSICAL UNION FALL MEETING

The Fall meeting of the AGU was held, as usual, in San Francisco, during the week of 5–9 December. Glaciological sessions included two half-day oral sessions on glaciers and ice sheets, a half-day oral session on modelling former Northern Hemisphere ice sheets, a half-day session on the surge of Bering Glacier, Alaska, and poster sessions. Abstracts were published in a supplement to *EOS*, **75**(44), 1994.

Joe Walder

INTERNATIONAL SYMPOSIUM ON SNOW AND RELATED MANIFESTATIONS

Manali, India, 26–28 September 1994

The International Symposium on Snow and Related Manifestations, held at the Snow and Avalanche Study Establishment, Manali, was attended by 31 foreign delegates from Austria, Canada, Finland, France, Japan, Norway, Russia, Switzerland, the UK and USA and 89 delegates from 35 organisations within India.

The opening speakers, Dr Raja Ramanna, former Chairman of the Atomic Energy Commission and Scientific Adviser to Raksha Mantri, Lt. Gen. Surrinder Singh, GOC-in-C Northern Command, Dr A. P. J. Abdul Kalam, Scientific Adviser to Raksha Mantri, and Mr L. A. Mandalia, on behalf of UNESCO, emphasized the need for interdepartmental and international cooperation, praised the role played by SASE in saving lives, and pointed to improvements in avalanche forecasting expected as a result of further cooperation and the use of modern techniques, such as remote sensing.

There were 11 plenary sessions, posters and a concluding session; 68 technical papers and 19 posters were presented. Those on snow physics encompassed the microstructure and metamorphism of snow, thermal and optical properties including their modelling, the effect of capillary discontinuities on water flow, acoustic emissions in polycrystalline ice and physics of snow friction, etc. Those on snow mechanics included non-linearity in snow creep, constitutive relationships incorporating microstructure, strength of snow derived from its microstructure, effect of melt water on snow-pack strength, and the effect of the presence and fracture of a weak layer on the release of avalanches, etc.

Avalanches were considered under dynamics, forecasting and control structures. The former sessions included papers on flow models, velocity measurements and runout distance variations. The next, after a lucid review on the state-of-art, reported on various snow-cover simulation models and different forecasting techniques. Nearest-neighbour criteria, use of expert systems and the semi-quantitative process-oriented avalanche-forecasting approach were some of the highlights. The session on avalanche control started with reviews of control measures in Norway and France and then dealt with snow gallery and snow rake design and afforestation for avalanche control. The theme sessions ended with one on meteorology, instrumentation, snow hydrology and cold-region engineering.

The Symposium concluded with the following recommendations:

- Greater emphasis should be laid on building the necessary infrastructure for continued research in snow science.
- Field measurement of snow and avalanche parameters, e.g. deformation and densification (creep), metamorphism and grain growth, albedo, velocity, impact pressure, runout zone, etc., be given greater importance.
- The Himalayan network should be enlarged and system and sensors be subjected to extensive field trials and calibration before commissioning.

- A dynamical–statistical numerical weather-forecasting model be developed for the central and western Himalaya.
- The physics and mechanics of snow in a tropical/maritime climate be given adequate emphasis.
- Control of avalanches by afforestation be given proper consideration in the Himalaya.
- Codes of practice be developed for the design of control structures and artificial triggering of avalanches in the Himalayan context.
- Development of cold-region sciences for the Himalaya form part of ICSI's charter of duties.
- Application of remote-sensing techniques to identify terrain details and avalanche paths be enlarged.
- A formal post-graduate training programme in Glaciology/Snow Hydrology be initiated. This might culminate into the establishment of a 'Cold Region Sciences Department' in some universities.
- International cooperation in terms of the exchange of scientists, exchange of data, etc. be considered by all agencies.
- An International Conference/Symposium be held regularly (23 years) under the auspices of a central organisation like ICSI.

S. G. Nair

NORTHWEST GLACIOLOGISTS

The annual meeting of Northwest Glaciologists was held at the University of Puget Sound in Tacoma, Washington, 2–3 December 1994. It was organized primarily by Dennis Trabant of the U.S. Geological Survey. Two thirds of the approximately 60 attendees were from the western U.S. and Canada, with the remainder from Colorado, Delaware, Maryland, Minnesota, Ohio, Ontario, Virginia, Wyoming and Norway.

The 43 presentations covered a variety of subjects, including Antarctic ice streams; surge of Bering Glacier, Alaska; Columbia Glacier, mechanics of calving; mechanics of crevasse formation; remote-sensing applications; glacier-flow modelling; glacier-bed processes; glacier hydrology and hydroclimatology; glacier mass balance; glacial outburst floods; and glacial geology. A down-borehole videotape from Worthington Glacier, Alaska, attracted attention for the details it revealed of englacial structures. A talk describing peculiar engineering problems encountered in designing an aircraft landing strip in Antarctica brought home the message that glaciology can occasionally have practical applications. All presentations were oral, with no abstracts or manuscripts submitted.

The evening of 2 December brought many attendees to the home of Bob Krimmel, of the U.S. Geological Survey in Tacoma, for dinner and socializing. The venue of the 1995 meeting is not yet settled, although the likeliest choice is Seattle.

Joe Walder

Future meetings (of other organizations)

GLACIATION AND HYDROGEOLOGY: WORKSHOP ON THE IMPACT OF GLACIATIONS ON ROCK STRESSES, GROUNDWATER FLOW AND HYDRO-CHEMISTRY — PAST, PRESENT AND FUTURE

April 1966, Sweden

Assessment of the long-term safety of radioactive waste disposal requires assimilation of evidence for the impact of glaciations on the geosphere, particularly in terms of its implications for the distribution and stability of stress regimes, for ground-water flux and flow patterns and for ground-water chemistry.

This workshop is intended to promote an informal, but focused, scientific discussion and exchange of information and ideas between a wide range of disciplines such as glaciology, hydrology, hydrogeology, geochemistry, rock mechanics and structural geology. Participants from outside the radioactive-waste disposal community will be particularly welcomed, although workshop numbers will be limited.

Of particular need are paleosignatures, direct observational information and models of the impact of continental ice sheets and periglacial conditions on crystalline bedrock.

For further information contact: Dr. Louisa King-Clayton, Intera Information Technologies Ltd., 47 Burton Street, Melton Mowbray, Leics, LE13 1AF, UK (Fax: +44 1664 411402)

7TH INTERNATIONAL WORKSHOP ON ATMOSPHERIC ICING OF STRUCTURES

2–6 June 1996, Chicoutimi, Quebec, Canada

The Workshop comprises any field and laboratory research, meteorological study, mathematical analysis, modelling, physics of ice and monitoring related to atmospheric icing of structures such as overhead lines, telecommunication masts, wind turbines, trains, airplanes, vessels and buildings. It encompasses the development and application of instrumentation and equipment for ice measurement, ice prevention and de-icing.

Topics include:

- Recent developments in theoretical studies on in-cloud icing, freezing rain and wet-snow adhesion, accumulation and shedding mechanisms;
- Field observations and storm analyses of various types of atmospheric icing;
- Mechanical and electrical effects of ice accumulation on structures;
- Assessment and mapping of climatic risks affecting various types of structures;
- Protection against atmospheric icing and methods for reducing risk and damage.

Abstracts are due 28 April 1995. For further information contact IWAIS'96, Prof. M. Farzaneh, Dept. Applied Sciences, UQAC, 555 boulevard de l'Université, Chicoutimi (Québec), G7H 2B1, Canada (Tel: +1 418 545 5044; Fax: +1 418 545 5012)

Books Received

Andersen, B. G. and H. W. Borns, Jr. 1994. *The ice age world: an introduction to Quaternary history and research.* Oslo, Scandinavian University Press. ISBN 82 00 21810 4; NOK 295.

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Gloersen, P., W. J. Campbell, D. J. Cavalieri, J. C. Comiso, C. L. Parkinson and H. J. Zwally. 1992. *Arctic and Antarctic sea ice, 1978–1987: satellite passive-microwave observations and analysis.* Washington, DC, National Aeronautics and Space Administration. (NASA Special Publication SP-511, Scientific and Technical Information Program.)

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Makkonen, L. 1994. *Ice and construction: state-of-the-art report prepared by RILEM Technical Committee TC-118, Ice and Construction.* RILEM (The International Union of Testing and Research Laboratories for Materials and Structures) RILEM Report 13. London and New York, E & FN Spon, Chapman & Hall. ISBN 0 419 20020 7; £35.

Glaciological Diary

1995

27-30 March
Solar System Ices, Toulouse, France (M. Festou, Observatoire Midi-Pyrenees, 14 av. Edouard-Belin, F-31400 Toulouse, France. Fax: +33 61 53 67 22)

18-20 April
63rd Annual Western Snow Conference, Reno/Sparks, Nevada, USA (H. Klieforth, Desert Research Inst., P.O. Box 60220, Reno, NV 89506-0220, USA. Fax: +1 702 677 3157)

21-22 April
Midwest Glaciology Meeting, Chicago, Illinois, USA (Christina Hulbe, Dept. of Geophysical Sciences, Univ. of Chicago, IL 60637, USA. Fax: +1 312 702 9505, chulbe@midway.uchicago.edu)

25-28 April
Sea Ice Mechanics and Arctic Modeling Workshop, Anchorage, Alaska (Max Coon, NorthWest Research Assoc. Inc., Box 3027, Bellevue, WA 98009-3037, USA. Fax: +1 206 646 9123; max@nwra.com)

1-5 May
North East Water Polynya Symposium, Helsingør, Denmark (Henning Thing, Danish Polar Center, Strandgade 100H, DK-1401 Copenhagen K, Denmark. Fax: +45 32 88 01 01; dapchth@pop.denet.dk)

22-26 May
Cold-Season/Region Hydrometeorology, Banff, Alberta (Terry Kraus, NHRC, 11 Innovation Blvd., Saskatoon, S7N 3H5, Canada. Fax: +1 306 975 5143; krausst@nhrisv.nhrc.sk.doe.ca)

6-8 June
52nd Eastern Snow Conference, Toronto, Ontario (Mike Ferrick, CRREL, 72 Lyme Road, Hanover, NH 03755-1290, USA. Fax: +1 603 646 4644)

11-16 June
5th International Offshore and Polar Engineering Conference, The Hague, The Netherlands (ISOPE, P.O. Box 1107, Golden, CO 80402-1107, USA. Fax: +1 303 420 3760)

18-24 June
14th International Conference on Offshore Mechanics and Arctic Engineering, Copenhagen, Denmark (OMAE'95, c/o DIS Congress Service Copenhagen A/S, Herlev Ringvej 2C, DK-2730 Herlev, Denmark. Fax: +45 4492 5050)

14-18 August
Frost and Glaciers over the Earth (Pk-8), International Geographical Congress, Moscow, Russia (Secretariat of the IGU'95, Staromonetny 29, Moscow 109017, Russia. Fax: +7 95 230 2090; geography@glas.apc.org)

20-25 August
** IGS International Symposium on Glacial Erosion and Sedimentation, Reykjavik, Iceland (Secretary General, International Glaciological Society, Lensfield Road, Cambridge, CB2 1ER, UK)

27 August-6 September
Modelling of Glaciers and Ice Sheets, EISMINT Summer School, Grindelwald, Switzerland (Prof. J.Oerlemans, IMAU, Princetonplein 5, NL-3584 CC Utrecht, The Netherlands)

18-22 September
* EISMINT International Symposium on Ice Sheet Modelling, Chamonix, France (Philippa Pirra, EISMINT, European Science Foundation, 1 quai Lezay Marnésia, F-67080 Strasbourg, France. Fax: +33 88 37 05 32)

29-30 September
* British Branch Meeting, Leeds (Tavi Murray, School of Geography, University of Leeds, Leeds LS2 9JT, UK. Tel: +44 113 233 6753; tavi@leeds.geog and Andrew Evans, Tel: +44 113 233 3324; geoaje@leeds.west-01)

19-20 October
100 Years of Glaciological Research in Italy, Torino, Italy (Comitato Glaciologico Italiano, via Accademia delle Scienze 5, Torino, I-10123, Italy)

25-26 November
** IGS Nordic Branch Meeting, Finland (Matti Leppäranta, Department of Geophysics, University of Helsinki, Fabianinkatu 24 A, Helsinki, FIN-00014, Finland. Fax 358 191 3385; lepparan@kruuna.helsinki.fi)

1966

April
Glaciation and Hydrogeology, Sweden (Dr. Louisa King-Clayton, Intera Information Technologies Ltd., 47 Burton Street, Melton Mowbray, Leics, LE13 1AF, UK. Fax: +44 1664 411402)

26-31 May
6th International Offshore and Polar Engineering Conference, Los Angeles, California (ISOPE, P.O. Box 1107, Golden, CO 80402-1107, USA. Fax: +1 303 420 3760)

2-6 June
7th International Workshop on Atmospheric Icing of Structures, Chicoutimi, Quebec (IWAIS '96, Prof. M. Farzaneh, Dept. of Applied Sciences, UQAC, 555 boulevard de l'Université, Chicoutimi (Québec), G7H 2B1, Canada. Fax: +1 418 545 5012)

17-20 June
International Conference on Quaternary Glaciation and Paleoclimate in the Andes Mountains, IVIC, near Caracas, Venezuela (M. Bezada, Departamento de Ciencias de la Tierra, Universidad Pedagogica Experimental Libertador, Ave. Paez el Paraiso, Caracas, Venezuela. Fax: +58 2 872 1443)

24-26 June
* Workshop on Valley Glaciers, Norway (O. Orheim, Norsk Polarinstitutt, Middelthunsgate 29, Postboks 5072, Majorstua, Oslo, N-0301, Norway. Fax: +47 22 95 95 01)

24-28 June
Interpraevent 1996: Protection of Habitat against Floods, Debris Flows and Avalanches, Garmisch-Partenkirchen, Germany (Interpraevent 1996, c/- Bayerisches Landesamt für Wasserwirtschaft, Lazarettstr. 67, D-80636 Munich, Germany)

8-16 July
High Arctic Joint Field Meeting, IPA Working Group on Periglacial Processes and Environments and IGU Commission on Frost Action Environments (Antoni Lewkowicz, Dept. Geography, University of Ottawa, Ottawa, Ontario, K1N 6N5, Canada. Fax: +1 613 564 3304; alewkowi@acadvm1.uottawa.ca)

1 August
8th International Cold Regions Engineering Conference, Fairbanks, Alaska

12-15 August
** Representation of the Cryosphere in Climate and Hydrological Models, Victoria, B.C. (Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, UK)

27-31 August
* IXth International Symposium on the Physics and Chemistry of Ice, Dartmouth College, Hanover, NH, USA (Victor Petrenko, 8000 Cummings Hall, Dartmouth College, Hanover, NH 03755-8000, USA)

23-24 November
** IGS Nordic Branch Meeting, Denmark (Claus Hammer, Department of Geophysics, The Niels Bohr Institute, University of Copenhagen, Copenhagen N, DK-2200, Denmark)

1997

14-18 July
** Antarctica and Global Change, University of Tasmania, Hobart, Australia (Secretary General, International Glaciological Society, Lensfield Road, Cambridge, CB2 1ER, UK)

1998

23-27 June
7th International Conference on Permafrost, Yellowknife, N.W.T., Canada (J. A. Heginbottom, Terrain Sciences Division, Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, K1A 0E8, Canada)

** IGS Symposia
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