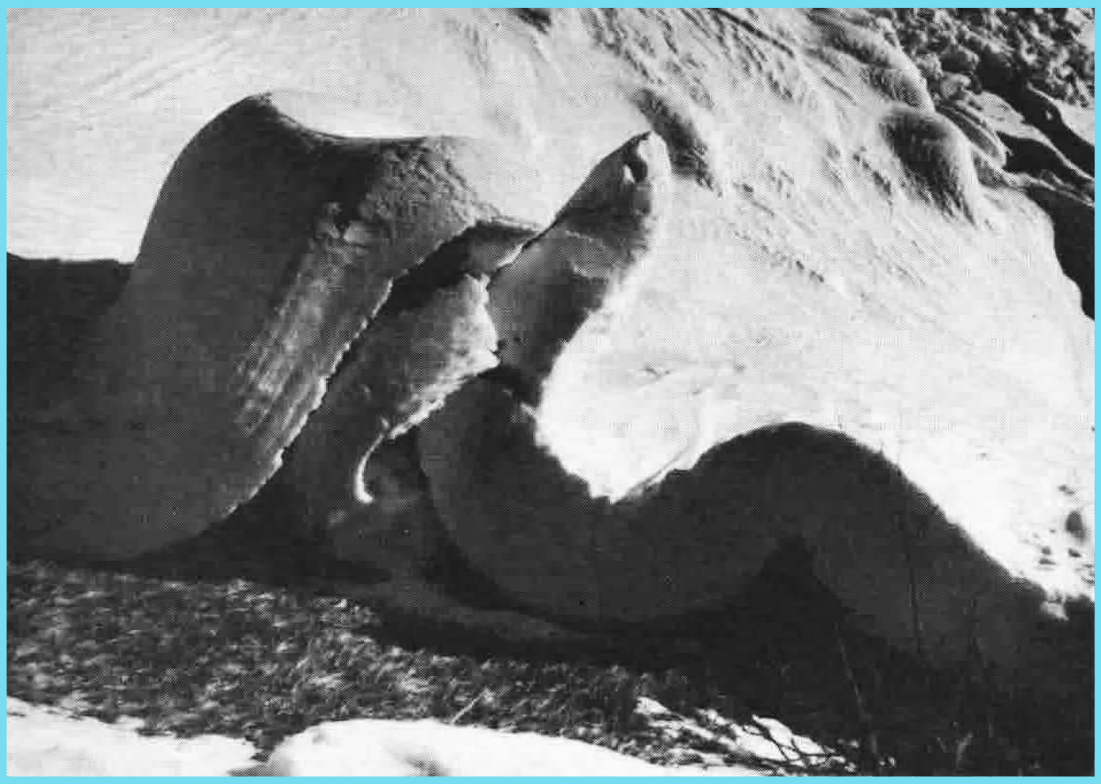
NUMBER 86 1st ISSUE 1988

ICE

NEWS BULLETIN OF THE INTERNATIONAL GLACIOLOGICAL SOCIETY



INTERNATIONAL GLACIOLOGICAL SOCIETY

SYMPOSIA

1988

14-19 February	Ice Dynamics. Hobart, Tasmania, Australia. Proceedings volume: *Annals of Glaciology*, Volume 12
4-9 September	Snow and Glacier Research relating to Human Living Conditions. Lom, Norway. Proceedings volume: *Annals of Glaciology*, Volume 13

1989

21-25 August	Ice and Climate. Seattle, WA, U.S.A. Proceedings volume: *Annals of Glaciology*, Volume 14

1990

August (dates to be finalised)	Ice–Ocean Dynamics and Mechanics. Hanover, NH, U.S.A. Proceedings volume: *Annals of Glaciology*, Volume 15

We are investigating the possibilities for symposia in China in 1991 and other venues thereafter. Post-symposium study tours will take place after some of these events.

ISSN 0019-1043

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COVER PICTURE: Creeping snowcover in a zone of compression at the base of a slope, showing compression folds. Photograph by A. Roch. Copyright: Eidg. Inst. für Schnee- und Lawinenforschung, Weissfluhjoch, Davos, Switzerland.

RECENT WORK

CHINA

GLOF STUDIES

In 1986, the Karakoram Glacier Flood (GLOF) Research Expedition led by Zhang Xiangsun of the Lanzhou Institute of Glaciology and Geocryology, Academia Sinica, entered the dammed lake area of the Kyagar Glacier from the eastern waterhead of Shaksgam River. The shape and the depth of the lake were observed; the estimated maximum water reserves are approximately 6×10^7 m^3 at the present time. More than a hundred terraces were found along both sides of the valley slopes. Judging from the highest terrace, the maximum historical water reserves were 3.18×10^8 m^3.

In 1987, the expedition was divided into two groups, one for the Kyagar Glacier and the other for Tramkanly Glacier which lies on the lower reaches of Kyagar Glacier. The mechanism of the burst of the glacier-dammed lake as well as the possiblities of future re-damming of the Tramkanly Glacier were studied.

In the spring of 1987, under the leadership of Xu Daoming of the Lanzhou Institute of Glaciology and Geocryology, Academia Sinica, the Chinese glaciologists, in collaboration with the Nepalese scientists from the Secretariat of Water and Energy Committee of Nepal, organized the China–Nepal Himalayas GLOF Expedition. The glacier-dammed lakes at the waterheads of the Arun River and Pote-Kosu River, which lie in Chinese territory, were investigated. A scientist from Canada also participated in this expedition.

ICE CORE STUDIES

In 1986, under the leadership of Wu Xiaoling of Lanzhou Institute of Glaciology and Geocryology, Academia Sinica, as well as L. Thompson of the Byrd Polar Research Center, the Ohio State University, U.S.A., the China-America Ice Core Climatology Expedition drilled a number of test holes on the Dunde ice cap in the Qilian Mountains. This research is to be continued in 1987, with the aim of drilling through the ice cap (140–160 m). Several ice cores will be taken by this expedition and analyzed in China and the United States. The studies of BHQ Ice Core of Law Dome, Antarctica, led by Huang Maohuan, chief of the Division of Applied Physics in Snow and Ice of Lanzhou Institute of Glaciology and Geocryology, had achieved its final results. An academic discussion held at Lanzhou in August 1986 was attended by N.W. Young, a glaciologist from the Glaciology Section of the Antarctic Division, Australia.

CHINA-JAPAN GLACIOLOGICAL EXPEDITION ON WEST KUNLUN MOUNTAIN

The China-Japan Glaciological Expedition of West Kunlun Mountain, headed by Xie Zichu, Director of the Lanzhou Institute of Glaciology and Geocryology, Academia Sinica, and K. Higuchi, Director of the Water Research Institute of Nagoya University, Japan, is preparing for thorough glaciological research in West Kunlun, one of the largest glaciated regions. The project involves glacioclimatology, glaciohydrology, ice core drilling, glacial geomorphology, and underground ice studies. Forty scientists will be engaged in the exploration, some on the northern slope and others on the southern slope. A scientific documentary film will be made.

CHINA-GERMANY GLACIOLOGICAL AND GEOMORPHOLOGICAL EXPEDITION IN K2 AREA, KARAKORAM

In the autumn of 1986, under the leadership of Xu Daoming of Lanzhou Institute of Glaciology and Geocryology, Academia Sinica, and Kuhle of Göttingen University, Federal Republic of Germany, the China-Germany Expedition for the first time studied the glaciers and landforms in this area. Scientists from Poland and Australia also participated in the expedition.

TIANSHAN COMPREHENSIVE GLACIAL EXPERIMENTAL STATION

One important part of the research at Tianshan Comprehensive Glacial Experimental Station in 1987 was the China-Swiss glacio-climatological research, headed by Kang Ersi of the Lanzhou Institute of Glaciology and Geocryology and A. Ohmura of the Geography Institute of ETH, Zurich. The heat balance on the glacier surface was studied.

RESEARCH ON UTILIZATION OF ICE AND SNOW RESOURCES

Under the leadership of Shi Yafeng, the feasibility of transferring water from the southern slope of Bogda Mountain, Tianshan, to the Urumqi River was studied. In 1987, research will focus on the water balance of the lower reaches of the Urumqi River as well as the regional consumption project.

STUDY OF SNOWMELT RUNOFF FORECAST

A forecast model of snowmelt runoff was put forward successfully by the Division of Application of Remote Sensing in Cold Regions of Lanzhou Institute of Glaciology and Geocryology, headed by Zeng Qunzhu. In 1987, the research on snowmelt runoff was carried out at the headwaters of the Yellow River.

STUDY OF THE PHYSICAL PROPERTIES OF SNOW

A group led by Hu Ruji of Xinjiang

Geographical Institute, Academia Sinica, has been working on the study of the physical properties of snow at the Tianshan Snow Avalanche Station. The formation of snowmelt runoff was also studied in 1987.

INSTRUMENT TRIAL-MANUFACTURE

Under the leadership of Wang Liangwei, chief of the Division of Developing Instruments of the Lanzhou Institute of Glaciology and Geocryology, a system of a water-lever recording telemeter was successfully developed which could be used in high cold regions, and this device has been used at the Tianshan Comprehensive Experimental Station. An automatic alarm device for the outburst of a glacier-dammed lake was invented and used in the research at Kyagar glacier-dammed lake, Karakoram.

GLACIOLOGICAL RESEARCH IN ANTARCTICA

Since 1957, a number of young glaciologists from the Lanzhou Institute of Glaciology and Geocryology has been studying the Nalson ice cap near Great Wall station on King George Island. The mass balance, physical characteristics and geochemistry of the snow and ice are mainly studied from the shallow snow/firn/ice cores and pits.

Xie Zichu

RESEARCH PROJECTS OF THE INSTITUTE OF GLACIOLOGY AND GEOCRYOLOGY IN QINGHAI-XIZANG (TIBET) PLATEAU AND ALPINE REGIONS OF WESTERN CHINA DURING THE LAST 5-10 YEARS

1. Investigation into natural calamities by GLOF, the glacial debris-flow and snow avalanches in the Himalaya, the Karakoram and the eastern part of Qinghai-Xizang (Tibet), and research into the mechanisms of their formation, and methods of prevention.
2. The investigation of permafrost in Qinghai-Xizang (Tibet), including remote-sensing methods; research into the interaction of permafrost and the natural environment, and the influence of permafrost on ecological conditions and engineering structures. The focal point of the work rests on the basis of the comprehensive research station for permafrost studies and meteorology being built in the central region of Qinhghai-Xizang (Tibet) Plateau, with regional extensions along the Highway. We warmly welcome the fact that people, organizations and international organizations are investing in the station and building it together. We hope to make it available for world-wide use.
3. Research into glacial climatology, including paleoclimatology, ice–air interaction and climatic observation, and the reflection in large-area snow cover of climatic change. The research regions provided are in the western part of the Qilian Mountains, West Kunlun Mountain, Tanggula Mountains at the head of the Yangtze River, the head area of Huanghe (Yellow) River, Anyemaqen Mountains and the northern slope of Mt Shishapangma.
4. Research into glacial hydrology, including the formation of ice–snow runoff, runoff models and rational use of the runoff. We can provide these main regions: Tianshan Region (on the basis of the Tianshan Glaciology Station at the head of the Urumqi River), the northern slope of the Qilian Mountains, and the northern slope of Kunlun Mountain. The regions of snow cover studied also include the eastern part of Qinghai-Xizang (Tibet) Plateau and the Himalaya area.
5. Research into periglacial processes, alpine geomorphology, and Quaternary glacial deposition. The main research areas include the central part of Qinghai-Xizang (Tibet) Plateau (on the basis of the comprehensive research station for permafrost and meteorology), and the Pomi area in the eastern part of Qinghai-Xizang (Tibet) Plateau.

DENMARK - GREENLAND

Abbreviations: GGU : The Geological Survey of Greenland
Geol. I/AU: Geological Institute, University of Aarhus
GCI/UCPH: Geographical Central Institute, University of Copenhagen

QAMÂNARSSÛP SERMIA, WEST GREENLAND 1986-87

(R.J. Braithwaite, GGU)

The field station (64°28′ N, 49°30′ W) is at the head of Godthåbsfjord. Fieldwork was carried out in 1986 for the seventh and last full summer of operations at Qamânarssûp sermia, an outlet glacier from the Inland Ice. The work included mass balance and ice movement measurements in a sparse stake network covering 150 km², as well as daily climatological observations at base camp and daily ablation readings near the ice edge. Fieldwork in 1987 was confined to short visits in May and late August to make stake readings and assess balance changes. An automatic climate station continued year-round measurements at the base camp.

Ablation in 1985/86 was a little below average as extremely low temperatures in June 1986 offset above-average temperatures in July and August. By contrast, ablation in 1986/87 was very high due to the exceptional warmth and dryness of the 1987 summer.

ENERGY BALANCE AT QAMÂNARSSÛP SERMIA

(N.T. Knudsen, Geol I/AU)

In 1986, an energy balance station (about 950 m a.s.l.) was operated throughout the ablation period. Net radiation and in and outgoing shortwave radiation were measured.

Temperatures were recorded as instantaneous values, and wind speeds and directions as average values, both measured in profiles. The air humidity was measured by thermo-hygragraphs in sheltered huts. Ablation was measured at three stakes a total of 32 times, supplemented by measurements of ice density. Data collection covered the period 10 June to 25 August. A first evaluation of the data indicates that they are useful, and that it will be possible to determine the components of the energy balance.

MASS BALANCE STUDIES AT THE TASERSIAQ AND QAPIARFIUP SERMIA BASINS IN 1986-87

(Ole B. Olesen, GGU)

At both basins mass balance studies have been carried out without interruption since 1981.

Of the seven years on record three have shown equilibrium (1980/81, 81/82 and 85/86), two years have been positive (1982/83 and 83/84) and two years have been negative (1984/85 and 86/87). Extremes have been 1982/83 with a mean specific balance of 0.9m and 1984/85 with −0.6 (results quoted from Qapiarfiup sermia with Tasersiaq basin showing the same trend).

An outlet glacier from the local "Amitsulôq" ice cap at Tasersiaq has advanced 48 m since 1981, with yearly variations from 5.7 to 9.9 m/a.

MASS BALANCE MEASUREMENTS ON THE INLAND ICE NE OF JAKOBSHAVN

(H.H. Thomsen, GGU)

Mass balance measurements on the Inland Ice at Paakitsoq northeast of Jakobshavn have been continued. A stake line was set up in August 1982 starting on the outlet glacier IGE07001 (69°28′ N, 50°12′ W). The stake net ranges from about 300–1200 m a.s.l. It is visited by helicopter twice a year in May and August. Transient balance and annual balance have been measured for 1982/83, 83/84, 84/85, 85/86 and 86/87.

RUNOFF MODELLING FROM THE INLAND ICE NE OF JAKOBSHAVN

(R.J. Braithwaite and H.H. Thomsen, GGU)

Earlier simulations of runoff from the Inland Ice near Jakobshavn (see *Ice*, nos. 72 and 73) were updated with GGU's MBI/SMI/ROI model. The new simulations, based upon improved data sets, confirmed earlier results for the available runoff and its variability under present climatic conditions. However, using new information on internal and sub-glacial hydraulics, predictions of runoff were also made for possible "worst case" scenarios involving drastic changes of drainage patterns. Although the annual runoff from the basin could be much less than assumed at present for planning hydroelectric power, the economic consequences will be small because of the nonlinearity of the runoff–price relation.

DETAILED MAPPING OF SURFACE HYDROLOGY ON THE INLAND ICE NE OF JAKOBSHAVN

(H.H.Thomsen, GGU)

A detailed photogrammetric glacier map of the Inland Ice margin at Paakitsoq, northeast of Jakobshavn, has been produced. The mapping is based on aerial photographs from 10 July 1985. The map covers the area between 69°15′ N to 69°35′ N and 48°50′ W to 50°35′ W. The map scale is 1:75 000 with contour intervals of 50 m in the ice-free area and 20 m on the ice. All possible details have been plotted for the glacier area and trimline zone. This includes features on the ice especially related to surface hydrology such as rivers, lakes and moulins as well as crevasses and lineaments influencing the drainage pattern. The map plotting is supported by observation in the field on foot or from helicopter.

MODELLING OF GLACIER HYDRAULIC CONDITIONS FOR DRAINAGE BASIN DELINEATION

(H.H. Thomsen, GGU)

Surface and subglacial topographical data has been used for modelling subglacial drainage at a sector of the Inland Ice northeast of Jakobshavn.

Subglacial water potential has been calculated and potential maps have been plotted to form the basis for delineation of subglacial drainage basins. By far the largest amount of water draining is meltwater from the surface which mostly drains down into the ice through crevasses and moulins. From surface hydrological mapping, the ice surface has been divided into many separate drainage cells each draining to a moulin or moulin complex. It is then assumed that water which escapes down into the ice flows quickly to the bottom of the ice and there drains according to the subglacial potential. The drainage basin area has been used as input for modelling of the runoff from the area.

DRILLING WITH A HOT WATER JET NE OF JAKOBSHAVN

(O.B. Olesen, A. Clausen, H.H. Thomsen, GGU)

A newly constructed hot water jet was successfully tested on the margin of the Inland Ice. Eight holes, between 382 and 250 m, with a total length of 2 686 m, were drilled to the bottom of the ice.

The drilling equipment is capable of delivering 18 l of 85°C hot water per min. at a pressure of 100 bar. Mean drilling speeds from 0–100 m, 100–200 m and 200–300 m were: 5.2, 3.0 and 2.3 m/min. respectively. The fastest drilling for the first 100 m was 6.4 m/min.

All drillings were made with an unshielded high-pressure hose in lengths of 100 m and a pressure drop over the nozzle of 35-50 bar.

Fuel consumption was approximately 12 l/h of jet A1 for the heater and 2.5 l/h of gasolin for the pump and generator.

The total system, consisting of heater, power-unit, tripod and winch, monitoring cable, 500 m of drilling hose, tools, feeding pump and 300 m of low pressure hose, weighs approximately 480 kg.

MEASUREMENTS OF ICE TEMPERATURES ON THE ICE SHEET NE OF JAKOBSHAVN

(H.H. Thomsen, GGU)

For measuring englacial temperatures two sets of thermistor strings were drilled down to depths of 202 and 300 m in the ablation area. The 202 m hole is situated 4.4 km upstream from the ice margin, with an ice surface elevation of 490 m a.s.l. The 300 m hole which extends to the bottom of the ice is situated 3.2 km upstream from the ice margin with an ice surface elevation of 455 m a.s.l. Temperature readings reveal a minimum temperature of −2.1 °C at a depth of 150 m, increasing to −0.9 °C at the bottom 300 m depth.

ICE VELOCITY MEASUREMENTS NEAR THE ICE MARGIN NE OF JAKOBSHAVN

(H.H. Thomsen, GGU)

Ice velocity has been measured on an outlet glacier IGE07001 (69 °28′ N, 50 °12′ W) from the Inland Ice. The ice tongue ends in a lake. Ice velocity is measured by theodolite to stakes drilled into the ice from fixed points established on the ground. Mean yearly ice velocity on the central part of the glacier tongue, 250 m from the ice margin, is 0.08 m/day. Mean winter velocity at the same location is 0.06 m/day and mean summer velocity is 0.13 m/day. Mean yearly ice velocity is 0.23 m/day at the central part of the tongue, 1400 m upstream from the ice margin at the foot of a smaller ice fall.

RADIO-ECHO SOUNDING OF THE INLAND ICE MARGIN NE OF JAKOBSHAVN

(L.Thorning. GGU)

Following the first successful acquisition of radio-echo sounding data in the marginal areas of the inland ice northeast of Jakobshavn in July 1985, the fieldwork has been continued in April 1986 and May 1987. The 300 MHz ice-radar was used with a two-element-fed paraboli antenna from a Bell 206 Jet Ranger Helicopter at a constant flight altitude of approximately 10 m over the ice surface. An electronic navigation system was used, and positions recorded with the radar data. Data from 1985 and 1986 have been processed into a detailed contour map of subglacial relief by digitization of hard copies of the I-traces, merging with navigation data, simple migration of travel time data into ice-thickness data, computer gridding of data and calculation of the subglacial relief using also photogrametrically constructed surface maps. On the basis of these datasets maps of hydrological potential under various conditions have been calculated The measurements in 1987 were carried out to elucidate problem areas revealed by the interpretation of the 1985/1986 data. The latest data are now being processed and will be used in an updated, final set of maps for the area. All data will be kept available in a data base for the continued glaciological–hydrological evaluation of the Pakitsoq basin, which is the planned position of the future hydroelectrical power plant for Jakobshavn.

A monopulse radar has been constructed by GGU for use in areas unsuitable for airborne work such as the outermost parts of glaciers. The instrument was tested in August 1987 and provided the first good estimates of ice-thickness of an important glacier in the Pakitsoq basin.

CONTINUED ISOTOPE STUDIES ON THE ICE SHEET MARGIN

(N. Reeh and H.H. Thomsen, GGU)

Oxygen-isotope studies of the marginal zone of the inland ice are very useful in a variety of fields. Results from Paakitsoq northeast of Jakobshavn and Warming Land, N. Greenland confirm that isotope studies have various uses:

1) Their variation in meltwater runoff can help in delineating drainage basins on the ice sheet.

2) Linking locations with the same observed isotope ratios in the accumulation and ablation zones gives information on ice dynamics.

3) Surface isotope profiles from the outermost kilometre of the ice sheet margin provide records dating back into Wisconsinan.

Snow, ice and water samples for stable isotope analysis ($\delta^{18}O$) have been collected on and near the Greenland ice sheet margin at different locations.

1) Samples from nine different locations in the Thule area, North Greenland, including the ice sheet margin and a local ice cap, around 76 °30′ N and 68 °00′ W.

2) Samples along several profiles on the ice sheet margin at Paakitsoq, northeast of Jakobshavn, West Greenland around 69 °28′ N and 50 °00′ W.

3) Samples from the ice sheet margin southeast of Godthåb, West Greenland at 63 °48′ N and 49 °34′ W.

4) Samples from a local ice cap southwest of Angmagssalik, East Greenland at 64 °23′ N and 40 °25′ W.

5) Samples from the ice sheet margin northwest of Angmagssalik, East Greenland at 66 °10′ N and 38 °12′ W

ARCTIC GEOMORPHOLOGY, DISKO, CENTRAL WEST GREENLAND

(Ole Humlum, GCI/UCPH)

During the summer of 1987 an inventory of selected glaciers and rock glaciers has been carried out on Disko, central West Greenland. This is a continuation of a project initiated in 1983 on past and present glaciological and periglacial conditions within the area. Frontal variations are monitored at 15 glaciers and 18 rock glaciers. This summer 8 glaciers and all 18 rock glaciers were resurveyed. During the

period 1983-86 all observed glaciers were melting back, typically 4–15 m per year. Observations from 1987 showed a rather pronounced decrease in back-melting rate, 1–5 m/yr, and 2 glaciers were found to be advancing. The reason for this change in frontal behaviour may partly be the very cool and wet summer of 1986.

Repeated resurveying has proven all observed rock glaciers to represent active features, although several of these display features usually regarded as typical for inactive or fossil features (e.g. a dense cover of lichens and mosses, no apparent frontal activity). Typically frontal velocities have been found to be in the range of 1–35 cm per year; the smallest for talus-derived rock glaciers, and the highest for glacier-derived rock glaciers. At two glacier-derived rock glaciers the existence of a core of glacier ice has been proven close to the rock glacier terminus.

GLACIO-HYDROLOGY, MITLUAGKAT GLACIER, AMMASSALIK, EAST GREENLAND

(B. Hasholt, GCI/UCPH)

Records of the glacier terminus exist from 1933. Detailed measurements at the terminus and at stakes have been carried out since 1985. Discharge and water quality have been measured during the period of field-work. A map based on airphotos of the glacier at a scale of 1:20,000 with a contour interval of 10 m has been elaborated. The terminus is still retreating, but preliminary results indicate a slightly positive mass balance.

DEPARTMENT OF GLACIOLOGY, GEOPHYSICAL INSTITUTE, UNIVERSITY OF COPENHAGEN, 1986-87

(W. Dansgaard)

CAMP CENTURY

In 1986, N. Gundestrup and H.B. Clausen located the top of the Camp Century drill tower 7 m beneath the 1986 snow surface, using a differential magnetometer and a hand auger. The position of the 60 m meteorological tower near the borehole was measured in 1977 and 1986 with satellite navigation equipment, showing a surface velocity of 3.5 ± 0.2 m/yr in the direction 235° ± 2°. Measurement of the surface topography in 1986 shows that the borehole is situated on a local sloping ice divide. Further details are reported jointly with B.L. Hansen and J. Rand in *Cold Regions Science and Technology* (in press).

CENTRAL GREENLAND

H.B. Clausen and S.J. Johnsen have studied $\delta^{18}O$ profiles along shallow ice cores, particularly from Central Greenland. It seems to be a general feature that 8% change of the accumulation rate corresponds to 1‰ change in $\delta^{18}O$.

DYE SITES

The 1983 and 1985 logging of temperature, diameter, inclination and azimuth along the deep borehole at Dye 3 was repeated in 1986 by N. Gundestrup and B.L. Hansen. However, due to hole deformation, a 2 m long logging devise was unable to penetrate to more than 1850 m depth, where previous ice core analyses have indicated very high dust content in the ice deposited in late Wisconsin. No significant *c*-axis effect on the flow of Holocene ice could be detected. In 1986 and 1987, N. Gundestrup and L. Riishøjgaard further measured the position and velocity of the Dye 2 station, and the surface topography around it within a 3 km radius.

RENLAND

In 1987, a Danish-Icelandic-Swedish team, led by N. Gundestrup, performed detailed studies in a 3.5 × 4.5 km area of the separate ice cap on the Renland peninsula, East Greenland. A strain net was established. Radar reflection layers to 80 m depth were measured from the surface by P. Ulriksen, University of Lund. A number of firn cores were hand augered. The Danish Meteorological Institute put up an automatic weatherstation. Ice thickness was measured by radar installed in a Twin Otter airplane, and a small area with 250 m ice thickness was selected on a local dome for core drilling to bedrock in 1988.

ISUNGUATA SERMIA

The Danish-French-Swiss Blue Lake expedition II, 1987, to an ice margin area *ca.* 50 km NE of Sondre Stromfjord AB, was a continuation of the French-Danish cooperation in 1984, initiated by C. Hammer, and M. Maurette (Lab. René Bernas, Orsay). The 1987 expedition expanded the cosmic dust collection along a 60 km flow line in the ablation zone, starting a little below the equilibrium line and ending in Isunguata Sermia.

The collection of cosmic dust was combined with glaciological investigations e.g. dating the ice margin by volcanic acid signals in the surface ice. Two base camps were placed in the area. Along a 20 km line more than 12,000 el. conductivity measurements were made *in situ*. *Ca.* 2000 samples for oxygen isotope analyses were collected, and around 250 cosmic dust samples.

In situ preparation of more than 1 ton of black dust was accomplished by the French participants.

MODELLING

D. Dahl-Jensen is studying present and past ice flow in south Greenland using the flow parameters measured on the Dye 3 deep hole. A heat transport model reproduces the temperature profile along the deep hole within the experimental error ± 0.03 °C, if the mean surface temperature under glacial conditions is assumed to have been 12 ± 2 °C lower than now, and the accumulation rate 50 ± 25% of the present value.

S.J. Johnsen and W. Dansgaard, in co-

operation with J. White, have measured the deuterium excess $d = \delta D - 8\delta^{18}O$ in snow on the Greenland ice sheet under glacial and interglacial conditions. A vapour transport model indicates that the bulk of snow at high altitudes is formed by moisture from the sub-tropical Atlantic, whereas local moisture sources probably contribute substantially to low altitude precipitation.

DENMARK - NORWAY

METEOROLOGICAL AND HYDROLOGICAL INVESTIGATION AT OKSTINDAN AND SVARTISEN

(N.T. Knudsen and J.T. Møller, Geol I/AU; W.H. Theakstone, Manchester University)

During 1986 the number of stakes at Austre Okstindbre was increased to 25 by inserting 12 stakes in the accumulation area. Observations of winter accumulation were made, as were observations of the ablation through the summer. It was possible to calculate a tentative mass balance during the period 1985–86. The mass balance was slightly positive, showing a value of +0.4 m weq. In the future more accurate information on the mass balance will be gained. Measurements of meteorological variables, meltwater flow and ice velocity were continued. Reports on the oxygen isotopic composition of glacial river water and drainage of an ice-dammed lake have been prepared. Observations at a near-stagnant, high-altitude glacier during the period 1970–85 have been completed.

Anker Weidick

SWEDEN

RESULTS OF 1987 FIELD PROGRAMME AT TARFALA FIELD STATION

The mass balance of Storglaciären was strongly positive this year. Winter balance was slightly more than +1.69 m.w.e., which is about average, while summer balance was slightly less than −1.22 m.w.e., leaving a net balance of +0.48 m.w.e. This was the fourth highest positive balance we have measured on Storglaciären in 42 years of record. As might be summarised by these figures, the summer was unusually cold.

Mass balance was also measured on Rabots Glaciär (+0.22 m.w.e.), Tarfalaglaciären (+0.88 m.w.e.), S.E. Kaskasatjåkkaglaciären, Björlingsglaciär, and Riukojietna, all of which are in the vicinity of Storglaciären. The final figures are not available for the last three of these, but balances appear to have been positive.

On Storglaciären we continued daily velocity measurements (weather permitting) on two 5-stake strain nets this past summer. In general, velocities seem to have been slightly lower than in 1986, a change that we attribute to the colder weather. However, despite the lower water inputs, water pressures periodically rose to the point that summer velocities were as much as twice the winter velocity for periods of a day or two.

Deformation measurements were made in a borehole located in the upper half of the ablation area about half-way between the centreline and the southern margin of the glacier. Throughout this part of the glacier, the bed is overdeepened. In this hole, the fraction of the surface velocity that could be attributed to movement at the base increased progressively during the summer from about 70% in early July to about 80% in late August. We attribute this to an increase in water pressure in a layer of water-saturated till at the base of the glacier (Brand and others 1987). Water pressure measurements in boreholes indicate high piezometric pressures at the bed throughout the overdeepening. The velocity vector near the bed was rotated about 10° toward the margin compared with that at the surface.

Three successful dye-trace experiments were run this year, utilizing a borehole slightly below the equilibrium line as an injection point. Of considerable interest is the fact that in all successful dye-trace tests run to date from locations in or above this overdeepening, the dye has been detected in an outlet stream that is generally relatively clean, compared with the high sediment load carried by the other principal outlet stream. This suggests that drainage through the overdeepening is englacial, a conclusion that is consistent with the existence of a subglacial layer of deformable till.

In 1984 we began detailed measurements of water input to and discharge from the glacier (Östling and Hooke 1986). These measurements suggested storage of about 500 000 m^3 of water in the glacier in June and release of that water in August. From the point of view of glacier dynamics it is important to determine where this storage occurs. Through the end of July this past summer, 50% of the meltwater or rain on the glacier surface entered the glacier in the area above the equilibrium line, while 35% entered through moulins near the middle of the ablation area. The rest ran off directly from the surface. Thus initial storage in firn seems reasonable. Near the middle of July, we suspect that this water manages to make its way into the till layer in the overdeepening, causing dilation of the till and uplift of the glacier (Hooke and others 1983). By early to mid-August, it begins to drain out of the glacier.

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Roger LeB. Hooke
Wibjörn Karlen

USA - WESTERN REGION

GLACIAL GEOLOGY AND GEOMORPHOLOGY, ROCK GLACIERS

BANK RECESSION PROCESSES, LAKE SAKAKAWEA, NORTH DAKOTA

(John R. Reid, Department of Geology and Geological Engineering, University of North Dakota, Grand Forks, ND 58202)

Continuation of a project begun in 1983 to assess the causes of the average 2.2 m/year recession of banks along Lake Sakakawea, the Corps of Engineers' largest reservoir. Failure accompanying spring thaw accounts for 22% of total recession. Factors controlling this are fall moisture amounts, number of freeze–thaw cycles, depth of the frost, orientation of the bank, and the effectiveness of wave erosion over late summer. Project funding was temporarily suspended due to absence from country 1986-87. Renewed funding is expected from Corps of Engineers. Data collection continues.

ANISTROPY OF MAGNETIC SUSCEPTIBILITY STUDIES OF LATE WISCONSINAN TILLS DEPOSITED BY THE DES MOINES LOBE IN CENTRAL IOWA

(Michael J. Sweat* and Robert A. Stewart, Department of Earth Sciences, Iowa State University, Ames, Iowa 50011: *Present address U.S.G.S. Water Resources Division, 6520 Mercantile Way, Suite 5, Lansing, Michigan 48910)

This study was undertaken to establish whether anisotropy of magnetic susceptibility (AMS) techniques could be successfully applied to till deposited by the Des Moines lobe. It became evident early in the study that AMS techniques worked extremely well with till, so the focus of the research was narrowed. As a result of extensive earlier work by the Iowa Geological Survey, glacial deposits of the Des Moines lobe were separated into two stratigraphic units: the Morgan Member, of supraglacial origin, and the Alden Member, deposited by basal processes. The basis for this subdivision was till composition, rather than fabric, so it was decided to use AMS techniques to test and refine the theory of basal deposition of the Alden Member.

At each of the study sites the orientation of magnetic fabric was compared to other fabric indicators, including striated and faceted clasts in till ("bulletstones"), flutings on till surfaces, till pebble fabrics, striae on boulder pavements, and moraine orientations. The long and short axes of the ellipsoid of the anisotropy of magnetic susceptibility, $K_{maximum}$ and $K_{minimum}$, were consistently found to be, respectively, parallel to the direction of glacier movement, and imbricated upglacier. Furthermore, the orientation of $K_{maximum}$ and $K_{minimum}$ always compared favorably to the azimuth and direction of plunge of the A (long) and C (short) axes of prolate pebbles in till. The results demonstrated that magnetic fabric developed parallel to local and regional directions of till emplacement. Specific examples included, respectively, till desposition around a large, streamlined boulder in a boulder pavement, and the parallelism of $K_{maximum}$ data to the regional movement of the Des Moines lobe according to end moraine orientations. The results of this study strongly imply a basal, lodgement origin for Alden Member till.

PALEOMAGNETIC STUDIES OF PLEISTOCENE GLACIAL SEDIMENTS IN SOUTHEAST IOWA

(Robert A. Stewart and Joseph L. Baker, Department of Earth Sciences, Iowa State University, Ames, Iowa 50011)

This study was conducted concurrently with the work of Sweat and Stewart (see above) to determine the paleomagnetic characteristics of glacial sediments in Iowa. Our efforts in southeast Iowa focused on two goals: first, the establishment of a polarity stratigraphy for Illinoian and pre-Illinoian glacial deposits, and second, the relationship of the anisotropy of magnetic susceptibility (or "magnetic fabric") to the nature of till genesis and magnetic polarity. The materials studied included mainly basal tills and proglacial lacustrine silts of the Illinoian Glasford Formation, and pre-Illinoian Wolf Creek Formation (Hickory Hills, Aurora and Winthrop till Members), and the underlying Alburnett Formation.

Analyses of magnetic fabric, pebble fabric and till composition in southeast Iowa suggested that basal tills were deposited by lodgement at the outcrops that were samples. Where striated bedrock was observed, magnetic particle and pebble long-axis maxima were parallel to striations.

A stable magnetic polarity does not characterize southeast Iowa basal tills. This is likely due to glacial shearing which seems to destroy effectively detrital remanant magnetism during or after till deposition. Stable magnetic remanence was observed only in proglacial lacustrine silts associated with Illinoian and pre-Illinoian basal tills. As expected, the Petersburg Silt found below Illinoian Glasford

Formation basal till displayed normal polarity. Lacustrine silt associated with pre-Illinoian Alburnett Formation basal till exhibited reversed polarity, and was probably deposited during the Matuyama polarity epoch. On the basis of its reversed polarity, the Alburnett Formation of southeast Iowa is believed to correlate with Hersey Member till of the Pierce Formation in southwest Wisconsin, and with the A_4 till in eastern Nebraska. The magnetic polarity of Alburnett Formation basal till is also reversed; however, the remanent magnetism has been dispersed by glacial shearing. Southeast Iowa pre-Illinoian basal tills younger than the Alburnett Formation also show this effect to varying degrees, although their polarity is normal.

THE PRE-LATE WISCONSINAN GLACIAL RECORD IN IOWA: EVIDENCE FROM STRIATIONS AND TILL FABRICS

(Robert A. Stewart, Department of Earth Sciences, Iowa State University, Ames, Iowa 50011)

Study of the Pleistocene geology of Iowa has been facilitated and hindered by the multiple stacked till sheets and loess that mantle the state. Only within the past 10-15 years has enough orientation data been collected, in the form of striations and till fabrics, to begin to assemble a regional map of glacier movements. The original effort in this field began with the publication in 1888 of T. C. Chamberlin's *The rock-scourings of the Great Ice Invasions* as part of the USGS Seventh Annual Report. Chamberlin noted at that time that study of ice movements was hindered by the general dearth of outcrop in much of the midwest. This situation improved over the years in Iowa as the bedrock surface in much of the state became exposed in limestone quarries.

In the present study earlier data, supplemented with more recent personal observations, have been compiled and plotted on a large-scale (1:500 000) map of Iowa. This investigation emphasizes pre-Late Wisconsinan ice movements inasmuch as the behavior of the late Wisconsinan Des Moines lobe is apparent from its youthful, well-preserved glacial landforms. Striation orientations in Iowa relate almost exclusively to pre-Illinoian glacier movements. Illinoian and younger glaciers advanced mainly over older tills and loess; in such cases striations typically were found only upon boulder pavements deposited at till–till and till–loess contacts. Striation data from bedrock and boulder pavements were supplemented with till fabric measurements where multiple superposed tills occurred.

The oldest and least frequently occurring striations observed indicate ice movement from the northeast and north. At present these striae cannot be firmly associated with a specific till. These striations are probably also related to the event that eroded and dispersed erratics of native copper and banded iron formation across much of eastern Iowa. The oldest striations are cross-cut by a younger set that trends east–west. Till fabrics and glaciotectonic bedrock disruptions point to a westerly source. This event produced a clay-rich black till derived from black shale of the Pennsylvanian Galesburg (?) Formation. This till is further distinguished by a lack of Sioux Quartzite erratics. The youngest and most frequently occurring striations are associated with pre-Illinoian glaciers moving into Iowa from the west-northwest. In western and central Iowa these striations are associated with tills that commonly contain erratics Sioux Quartzite.

The Illinoian glaciation in Iowa is manifested by a well-developed end moraine in the southeastern part of the state; the few associated striations and till fabrics reflect the east-to-west movement. The direction of movement of the middle Wisconsinan glacier, which deposited the Tazewell till in much of north-central Iowa, is known only from till fabrics. Till fabric data suggest that the middle Wisconsinan glacier advanced southward without the lobate expansion exhibited by late Wisconsinan Des Moines lobe.

THE NATURE AND ORIGIN OF CORRUGATED GROUND MORAINE OF THE DES MOINES LOBE, STORY COUNTY, IOWA

Robert A. Stewart, Deborah Bryant and Michael J. Sweat*, Department of Earth Sciences, Iowa State University, Ames, Iowa 50011: *USGS, Water Resources Division, 6520 Mercantile Way, Suite 5, Lansing, Michigan 48910)

Corrugated ground moraine in Story County, Iowa, consists of low relief (1–2 m) ridges which most commonly consist of Late Wisconsinan till. The average spacing between ridges is about 105 m, and they generally parallel the configuration of the Bemis Moraine, the terminal moraine of the Des Moines glacial lobe. Till fabric (pebble orientations and anisotropy of magnetic susceptibility), facies variations and landform fabric were analyzed at three sites in typical corrugated ground moraine landscape near Ames in Story County, Iowa. At sites 1 and 2, the ridges consist of till probably deposited by lodgement. At site 3, two ridges consist of till and massive to cross-bedded sand. Till at site 3 is also probably lodgement till. The nature of the till and related glaciofluvial sediments at each site suggests that the corrugation ridges formed in basal cracks or crevasses in the Des Moines lobe. The cracks are postulated to have formed during extending flow of the Des Moines lobe as it advanced toward its terminal position. Retreat of the Des Moines lobe was rapid enough to preclude significant accumulations of supraglacial sediment upon corrugated ground moraine.

HISTORY AND DYNAMICS OF PLEISTOCENE GLACIATIONS, JACKSON HOLE, WYOMING

(K.L. Pierce, U.S. Geological Survey, Denver,

and J.M. Good, Jackson, WY)
Mapping, dating, and defining the complex history of the last two glaciations of Jackson Hole is well underway. A reconstruction of these glaciations based largely on contouring their upper surfaces will be used in glaciological analysis of basal shear stress, mass balance, basal slip, and subglacial excavation of deep lake basins. Snowmelt modeling of Pleistocene glaciers near the Jackson Hole Ski Area will examine departures from the present of different combinations of temperature and precipitation.

QUATERNARY GLACIATION IN NORTH-EASTERN WASHINGTON STATE
(Eugene P. Kiver and Dale F. Stradling, EWU, Cheney, WA)
Field work was conducted during the summers of 1986 and 1987 and will continue into the 1988 field season. In addition to glacial and glacial outburst chronologies in the area, the relation of alpine glaciers to lobes of ice from the Cordilleran ice sheet is under study. A nunatak and ice margin map are also being constructed. At least two major ice levels separated by about 150 m near the U.S.–Canadian border and about 75 m some 54 km south of the border are recognizable. The higher, older ice level is considered pre-Wisconsin in age and the lower levels Wisconsin.

ROCK GLACIERS
(J.R. Giardino, Texas A & M, College Station, TX)
During 1987 I have continued my research with rock glaciers. Much of this work has been cooperative research with Jack Vitek of Oklahoma State University. Specifically, we have been examining the rheological characteristics of these features. During this past summer we have installed a strain-net on the surface of a tongue-shaped rock glacier in the Sangre de Cristo Mountains of southern Colorado. In addition, we are attempting to simulate rock glacier movement in the cold-room lab on campus. We are creating ice-sediment mixtures similar to those found in rock glaciers, and with the use of a shear-box we are trying to determine strength characteristics for the rock glacier.

We have initiated a program this year to investigate the hydrological aspects of rock glaciers, too. We are attempting to determine the relationship between permafrost in the rock glacier and its contribution to water flow.

NUMERICAL MODELING OF GLACIAL LANDFORM DEVELOPMENT
(B. Hallet and J.M. Harbor, Quaternary Research Center, University of Washington)
We are developing a quantitative model of glacial erosion based on a fundamental analysis of the physics of glacial abrasion and plucking. By coupling such models with glaciological models which simulate the detailed characteristics of glacier motion, we can study the progressive development of glacial landforms. Such simulations include crucial feedbacks between ice flow, erosion patterns and topographic development, and allow for realistic boundary conditions, such as complex spatial distributions of rock resistance. To date we have constructed an iterative model which simulates the gradual evolution of a glacial channel to an approximately parabolic (U-shaped) steady-state form, which accords with field data from glaciated valleys. This new approach to modeling landform development promises to inprove our understanding substantially of a wide range of glacial erosional landforms and the large-scale controls on glacial erosion. In future work we intend to model the development of other characteristic glacial landforms such as cirques, fjords and glacial overdeepenings.

FRESH WATER ICE

EFFECT OF ICE ON FLOODING AND INTAKE PROBLEMS IN MINNESOTA
(Heinz G. Stefan, Charles C.S. Song, John S. Gulliver, SAFHL-UM, Minneapolis, MN)
Ice covers on rivers affect runoff by additional resistance and may turn into ice jams during snowmelt flood runoff. The collection of field data, which can be transmitted to the international coalition water planning process among others, analysis of ice resistance to flood flow and ice breakup mechanics, and the development of a computer model for the prediction and simulation of ice problems during spring flooding will be undertaken. Studies will be undertaken to improve various devices to eliminate intake clogging and to study the effects of natural and waste heat inputs on ice covers and ice jams.

Product timelines

	Jul '87	Jan '88	Jul '88	Jan '89	Jul '89
Model development	xxxxxxxxxxxx				
Field work		xxxxxx	xxxxx		
Analysis	xxxxxxxxxxxxxxxxxxxxx				
Model application			xxxxxxxxxxxx		
Final report					xxxx

Benefits
The ice/flooding research will result in a better understanding of the ice breakup process and its effects on flooding in Minnesota's rivers, especially the Red River of the north. The mathematical model developed under this program will make possible more accurate prediction of spring flooding in Minnesota. The analysis and field work will identify the causes and potential solutions to ice jam and intake clogging problems in Minnesota. The data collected under the field program will be used in the development of the flood prediction model. The effects of waste heat from powerplants on prevention of ice jams and safety will be evaluated. Recent advances in research on

river ice, further research development, and application of this research to specific Minnesota problems will alleviate the significant damage and economic loss which may be attributed to river ice problems. The mathematical model will help more accurate spring flood forecasting in Minnesota's rivers.

SNOW

THEORETICAL DETERMINATION OF THE EFFECTIVE DIFFUSION COEFFICIENTS FOR WATER VAPOR IN SNOW

(Pat Burns, Mark Christon, Department of Mechanical Engineering, Colorado State Univesity, Fort Collins, Colorado 80523; and Richard Sommerfeld, Rocky Mountain Forest and Range Experiment Station, 240 West Prospect, Fort Collins, Colorado 80526)

Temperature gradient metamorphism in snow is characterized by the evolution of the ice crystals which constitute a snowpack, and has been well established as a mechanism for increasing the probability of avalanching on steep mountain slopes. The development of depth hoar, and its destabilizing effect on snowpacks, has been the topic of a tremendous amount of research over the past 50 years. While the relationship between temperature gradient metamorphism and snowpack stability is of interest, the metamorphosis of the ice lattice constituents is also related to the acid pulse phenomenon. It is possible for a snowpack to lose an estimated 40–50% of its acidity in the first meltwater of spring, resulting in an acid pulse or shock. The evolution of ice lattices during the winter season may have a significant influence on how pollutants are redistributed and accumulated in the strata of a snowcover. This can ultimately impact the observed springtime acid pulse which occurs at a critical time in the life cycle of many aquatic species in Alpine regions. A clear understanding of the thermodynamics and the geometrical evolution in ice lattices of snowpacks is important for both the avalanche and the acid pulse problem, and is best addressed on the scale of the ice lattice pores in snow.

A majority of the past work on temperature gradient metamorphism has relied on observations of snow metamorphism on a macroscale which can only reveal the gross behavior of the process. The evolution of a snow layer experiencing a temperature gradient is due to the coupled, simultaneous, non-linear transport of heat and mass in the microscopic ice lattices of snow. Recent work by Colbeck (1983), Sommerfeld (1983), Gubler (1985), Christon (1986), and Christon and others (1986), has focused on the mass transport problem on the microscale. One of the principal issues has been the characterization of the ice lattice constituents on the microscale because of geometrical perturbations to the transport rates in the ice lattices of snow. Past researchers have presented the geometric perturbations to the mass transfer rates in snow as an effective diffusion coefficient; however, the estimates for the effective diffusion coefficients have varied widely. Given the importance of temperature gradient metamorphism, accurate diffusion coefficients are imperative for any preventive measures to be effective.

A cooperative research effort between the Department of Mechanical Engineering at Colorado State University and the Rocky Mountain Forest and Range Experiment Station was initiated in late 1985 to develop strategies, mathematical models, and large scale computer codes for the evaluation of effective diffusion coefficients for water vapor in snow. The research program was set up as a two stage effort with the first stage being a complete two dimensional analysis and the second being the three dimensional work for mean snow densities between 100 and 450 kg/m^3 and a broad array of ice lattice pore geometries. The approach taken has been to solve the governing conservation equations for temperature gradient metamorphism using a finite element model which incorporates deforming meshes. The modeling effort has included the solid/vapor interface thermodynamics and the evolutionary nature of the ice lattice geometries. The research has produced computer codes for both pre- and post-processing of data which describes the ice lattice geometry in both 2 and 3 dimensions using high resolution graphics workstations at CSU's Computer Aided Engineering Lab. The simulation models have been developed using the Cyber 205 supercomputer at Colorado State, although the most current codes are now running on a Cray X-MP/48. Time series output generated by the large scale simulations has been post-processed to generate a color videotape for direct comparison with existing film of temperature gradient metamorphism experiments.

Effective diffusion coefficients from the 2-D analysis varied from 1.1–2.5 times the diffusion coefficient for water vapor in air. The videotape of the 2-D transient analysis verified that the model represented the primary characteristics of temperature gradient metamorphism. Both mass flux and mass concentration distributions verified the importance of geometric perturbations on the vapor transport of ice lattices of snow. The 2-D analysis demonstrated that the controlling factors in temperature gradient metamorphism are the ice lattice geometry, and the thermodynamic processes at the solid/vapor interface. The time series images of the pore spaces illustrated the relationship between temperature gradient metmorphism and the structural integrity of the ice lattices, in addition to showing the formation of branch grains in certain situations. The current research effort is focused on the continued development of the 3-D finite element model for the fully coupled heat and mass transport problem. To date, the 3-D pre- and post-processors have been fully implemented

and have the capability to represent arbitrary ice lattice configurations. The 3-D simulation model has been verified for the de-coupled vapor transport process, and is currently being tested for the fully coupled problem. Future analyses with the 3-D model will encompass multiple ice lattice pores with and without protruding branch grains. Time series snapshots of mass flux and mass concentration distributions and ice lattice geometries will be used to demonstrate the primary characteristics of the process. A second videotape will be generated using output from the transient model to illustrate the complete evolution of the ice lattice components. Ultimately, the results from the model will be incorporated with data for both wet and dry deposition to predict the timing and severity of the acid shock phenomenon.

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A COMPARISON OF SNOW COVER LIQUID WATER MEASUREMENT TECHNIQUES

(H.S. Boyne, Department of Earth Resources, Colorado State University, Fort Collins, CO 80523, D. Fisk U.S. Army Cold Regions Research and Engineering Laboratories, Hanover, NH 03755)

The amount and distribution of liquid water is important for assessing the mechanical strength, meltwater generation and meltwater transmission in snow cover. It also has a profound effect on the performance of active and passive remote sensing systems operating in the microwave and millimeter wave region of the electromagnetic spectrum. New methods of measuring liquid water have been reported which show considerable promise. Our purpose was to determine measurement equivalence by comparing the three direct methods of freezing calorimetry (Jones and others 1983), alcohol calorimetry (Fisk 1986), and dilution (Davis and others 1985) and by comparing the precision of a calibrated capacitance probe (Denoth and others 1984) with one of the direct methods. All comparisons were made in a laboratory cold room with snow having a mass liquid water content of 0–14 g per 100 g of snow. The comparisons show that the methods are equivalent with an uncertainty of ± 1.8G per 100 g of snow.

Each of the methods has various pecularities. Therefore, the method chosen will depend on the particular experimental circumstances. The length of time necessary to accomplish a measurement is 30 min for freezing calorimetry, 10 min for alcohol calorimetry, 5 min for the dilution method and 2 min for the capacitance method. Sample size is limited to 150–200 g in the calorimeter methods, and in freezing calorimetry the specific heat of the working fluid must be determined throughout the operating temperature range. Snow liquid water profiles can be made with the capacitance method.

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SNOW COVER PARAMETER RETRIEVAL FROM VARIOUS DATA SOURCES IN THE FEDERAL REPUBLIC OF GERMANY

(A.J. Schweiger, R.G. Barry, R.L. Armstrong, CIRES/COLO)

Snow depth and water equivalent point measurements from 60 synoptic stations in West Germany have been gridded and contoured for 2 seasons. These maps are compared to the results of a simple snow extent algorithm based on brightness temperature data from the Scanning Multichannel Microwave Radiometer (SMMR). Visible band Defense Meteorological Satellite Program (DMSP) imagery as well as NOAA/NESDIS snow charts are used for comparison. Although specific problems arise from the incompatibility of the correlative data, results indicate that snow extent mapping using microwave satellite data is feasible.

THE MEASUREMENT OF SNOW WETNESS IN UNDISTURBED SNOW

(James A. Bergman, Pacific Southwest Forest & Range Experiment Station, FS, USDA, Berkley, CA)

The threat of damaging floods caused by excessive snowpack outflow from rain-on-snow and abonormal snowmelt has created a need to know the liquid water content (wetness) of the snowpack. Tracking

water during snowmelt and rainfall events would provide informative and timely data to streamflow forecasters and reservoir managers in the event of excessive snowpack outflow. Knowing the extent of liquid water loading prior to actual snowpack outflow would allow timely application of mitigation procedures which could reduce the potentially damaging effects of above normal streamflow.

A twin-disc sensor that measures changes in snow capacitance has been developed. It is capable of tracking water in transit in undisturbed snow during all conditions, including rain-on-snow, and snowmelt. Increases of up to 2% volume wetness and subsequent snowpack drainage have been observed during and after rain-on-snow. Surface diurnal melt-water flux ranging from 0.5–2% volume wetness has been measured consistently by sensors near the snow surface. Buried sensors have indicated an average seasonal progressive snow wetting of about 2.5% volume wetness. A variation of 0.06% volume wetness was determined from a test to check the sensor's ability to repeat measurements, and a standard error of estimate of 0.5% volume wetness was determined from a comparison between the sensors and the Denoth-Foglar portable snow moisture meter. Application of the sensor in the remote environment is being investigated.

RAIN-ON-SNOW AND SOIL MASS FAILURE IN THE SIERRA NEVADA OF CALIFORNIA

(James A. Bergman, PSF & RES, FS, USDA, Berkley, CA)

(Research concluded in 1985)

Midwinter rain storms are commonplace in the lower elevations of the Sierra Nevada snow zone of California. Rainfall events usually occur between December and April. Larger rain events, depending on antecedent and current soil and snow conditions, may contribute to the frequency and size of soil mass movement under snow cover. The extent of this contribution is difficult to assess because of the areal variation in the physical characteristics of soil and snow. Measuring the variation within the snowpack and soil mantle, however, may provide information that could help minimize landslide hazard during short term intense outflow from the snowpack.

Soil mass movement under snow cover was associated with rain-on-snow and spring snowmelt, especially in the transient snow band. During water years 1982 and 1983, 25 of the 33 documented mass failures on the west slope of the Sierra Nevada, south of Lake Tahoe, occurred during rain-on-snow events. The remaining documented mass failures appeared to be the result of saturated soils overburdened by spring snowpack outflow. The occurrence of each mass failure, however, depended on a succession of events and conditions specific to that site.

DEVELOPMENT OF IMPROVED METHODS FOR SNOW PRECIPITATION SAMPLING

(Neil Berg, Bruce McGurk PSF & RES, FS, USDA, Berkley, CA; Dan Marks, Dan Dawson, John Malack, Jeff Dozier, University of California, Santa Barbara)

At snow zone sites in California atmospheric chemical loading resulting from snowfall has been measured up to 8.5 times the loading due to rainfall. The need to monitor adequately the chemical loading in environments dominated by snowfall is clear. However, in mountainous environments, wind speeds are often sufficiently high to cause major undercatch of snowfall in traditional precipitation gauges. Even with shielding, gauge catch may be only 65% of "actual" at wind speeds of 20 ms^{-1}. This problem is exaggerated when shallow unshielded cylinders, such as the typical "wet-dry" collector, is used for precipitation volume estimation and sampling for pollutant analysis.

A prototype precipitation collector was evaluated during the winter of 1986-87. Comparisons of precipitation volume and chemistry were made at two sites in the Sierra Nevada of California: one in a sheltered forest clearing, the second on the wind-swept shoulder of a major peak in the range. Snow boards, snow pits, and shielded and unshielded collectors were monitored at event and weekly intervals. Preliminary results show close agreement at the sheltered site between precipitation volumes in the shielded and unshielded collectors. At this site less snow was measured on the snow boards than in the gauges. Measured accumulations were much more variable at the wind-swept site, with snow boards monitored on a weekly basis apparently receiving the greatest deposition. Snow chemistry comparisons were not available at the time of this writing. The study will continue for one more winter.

MELT MODELS, SNOWPACK STRUCTURE, AND MEASUREMENT OF SNOWPACK FEATURES

(Bruce McGurk, PSF & RES, FS, USDA, Berkley, CA)

Physically-based and simple index snowmelt models have been tested by comparing lysimeter outflows in both forested and open sites with predicted values based on measurements made at a highly instrumented site at 2100 m in the central Sierra Nevada, California. Snowpack structure studies have shown that boundaries between major storm layers can be recognized and have similar spacing across a 50 m grid throughout the year, but other thin ice layers are common and unpredictable in a melting snowpack. Central Sierran snowpack temperatures are generally isothermal near 0 °C. New snow layers that are subfreezing typically warm to near 0 °C within a few days due to insolation and meltwater percolation. An active instrument evaluation program is underway: snow pillows and liquid water measurement techniques have been assessed, and ultrasonic

snow depth sensors will be evaluated during the coming year.

RIME ICE OCCURRENCE AND CHEMISTRY
(Neil Berg, PSF & RES, FS, USDA, Berkley, CA)
Conifers at high elevations on the west coast of the United States are suffering decline. Although the causes of the decline are complex and not well understood, atmospheric deposition has been implicated as a stress-causing agent. These sites are often enshrouded in cloud cover, and the acidity of precipitates on the vegetative material is generally much higher than that of bulk precipitation. The chemistry of rime ice, glaze, or other condensates resulting from direct impact of moist air onto vegetation or topographic surfaces is not well understood. Studies in Colorado suggest that rime deposits contribute approximately 10% to the water equivalent of the snowpack and up to 86% of the trace chemical constituents in the snowpack.

Observations of icing at a site in the central Sierra Nevada of California during the winters of 1981-82, 1985-86, and 1986-87, plus measurements at six other locations in California and Nevada during water year 1987, suggest that riming is common. Rime occurrence was greater in 1981-82 than during the past two winters, with rime occurring during 60 and 71% of the days in November 1981 and March 1982 respectively, at Squaw Peak near Lake Tahoe. On an hourly basis, rime was less frequent, with 19% of the winter hours experiencing rime on the average at all seven sites during the three winters. The solute concentrations of nitrate, chloride, hydrogen, and sulfate ions in rime were typically two to three times those of snow. The means for solute nitrate in rime and snow, for instance, equalled 0.51 ppm and 0.12 ppm respectively. Samples will be collected from both surrogate and vegetative surfaces this winter at the sites monitored in water year 1987 plus an additional site in southern California.

WATER FLOW THROUGH SNOW
(Richard Kattelmann and Bruce McGurk, PSF & RES, FS, USDA, Berkley, CA)
Water movement through snow has been studied under conditions of rainfall, normal snowmelt, and artificial irrigation at a site at 2100 m in the central Sierra Nevada, California. The interaction between impeding horizontal layer boundaries and vertical channels controls the storage and movement of liquid water in the snowpack. Water retention by new snow is below 5% in all cases, and is usually below 2%. Wave front speeds of 0.2–0.8 m/hr were observed in layered, old snow, and speeds of 1–6 m/hr were observed in semi-homogenous new snow. During rainfall, lag times before water release from a snowpack with or without forest cover varied by less than 2 hours.

HYDROLOGIC EFFECTS OF CHANGES IN THE SEASONAL SNOWPACK IN THE CENTRAL SIERRA NEVADA
(Lee MacDonald, PSF & RES, FS, USDA, Berkley, CA)
In California the deep winter snowpack supplies much of the water used for irrigation, municipal use, and hydroelectric power generation. Managers have used both vegetation management and cloud-seeding to alter snowpack accumulation or modify snowmelt timing, but there is a paucity of data linking changes in the snowpack to the volume and timing of runoff. From 1985-87 a field experiment was conducted on a 50 ha forested catchment in the central Sierra Nevada to determine the effect of additional snow on the amount and timing of streamflow. 10–12 days of additional snowmelt was simulated at the end of the normal snowmelt period by irrigating four 960 m^2 plots with 2.0–2.5 cm of water per day. Groundwater measurements indicated that this supplemental snowmelt caused a short-term rise in the water-table. For some plots this rise extended to the stream channel. The simulated snowmelt also caused an increase in soil moisture which apparently persisted throughout most of the summer. In contrast, less than 1% of a bromide tracer added to the first year's simulated snowmelt appeared at the outlet to the watershed later that spring or summer. Taken together, these results suggest that efforts to delay snowmelt on small plots may be misguided, and a higher efficiency of yield could result from management techniques which would accelerate rather than delay snowmelt.

Present efforts are directed at using the field data to calibrate and verify a numerical groundwater model for a hillslope segment. This model will allow more precise estimates of the changes in streamflow as a result of various treatments. By also taking into account the variation in different site factors (e.g. slope, soil type, evapotranspiration rates) it should be possible to predict changes in the delivery of water to the stream channel under different site and snow conditions.

STATISTICAL EVALUATION OF WILDERNESS SNOW SENSOR PERFORMANCE
(Clay Brandow, California Department of Water Resources, and Dave Azuma, PSF & RES, FS, USDA, Berkley, CA)
Water supply, flood, and drought forecasting procedures require information on snowpack water equivalent at high elevation sites. In many areas of the western United States such sites are in designated wilderness areas. Current land management direction often does not allow installation of sensors in these sites. The need to develop correlations or other statistics to utilize information from sites at lower elevations as a proxy for high elevation data becomes paramount.

A statistical evaluation of snow sensors within and without designated wilderness areas

in California is underway. A set of statistical techniques, including traditional least squares regression procedures, is being used in the assessment. Initial results from the project are expected by early 1988.

COMPARISON OF CONTINUOUS ELECTRO-CHEMICAL MONITORING EQUIPMENT DURING SPRING SNOW MELT IN UTAH

(R.C. Metcalf, M.A. Stapanian, R. Hoenicke, L.J. Arent, Lockheed Engineering and Management Services Company, Acid Deposition Project, Environmental Programs Office, 1050 E. Flamingo, Ste. 209, Las Vegas, NV 89119; R.E. and L. Reiner, University of Denver, High Altitude Research Lab, Mount Evans Highway, Idaho Springs, CO)

During April 1987 three brands of field instruments were tested for suitability in measuring pH, conductivity, and water temperature by continuous digital logging through episodes of snow melt in Utah at 2800 m. Laboratory tests under argon in 10^{-2}–10^{-6} M HCl standards, at 1° and 25°C, with and without stirring, showed a $20K system was unsuitable, due to pH stirring errors of over 1 pH unit and a conductivity detection limit above 100 $\mu S\,cm^{-1}$ at 25°C. These laboratory tests also demonstrated a $10K system had reasonable response characteristics, but a $3K system made by the USGS was superior in performance. Field tests during snow melt emphasized errors found in laboratory tests, but provided additional information on cold weather power consumption, inadequate LCDs, digital data loggers, and the pH electrode drift recorded by employing dilute acid quality control checks.

CHEMISTRY OF FRONT RANGE SNOWFALL, ROCKY MOUNTAINS, COLORADO

(J.E. Rocchio, R.C. Metcalf, M. Reese, L. Todechiney, L.J. Arent, S.L. Pierett, J.R. Baker, D.J. Chaloud, LEMSCO; R.E. and L. Reiner, UDHAL)

Chemistry of Front Range snowfall was monitored during the winter of 1986-87 on Mt Evans, Colorado, between 3260–4020 m by analyses of melt from snow pits, snow boards, NADP samplers, and USGS bulk samplers. The low solute content snow melt (less than 10 $\mu S\,cm^{-1}$ at 25°C) had pH values in the low to mid 5s. It was not established whether these pH values are caused by pollution effects from nearby Denver, or merely represent normal atmospheric background acidity, as hypothesized in 1982 by Carlson and Rohde.

SNOW SURVEY AND WATER SUPPLY FORECASTING

(Soil Conservation Office, Portland, OR)

Drought is a part of life in the West. In 1934, a particularly severe drought resulted in farmers demanding better predictions of the streamflow available for growing crops. Others who counted on water for industry, power generation, and domestic use echoed this request. Congress responded in 1935 by passing legislation creating a federal snow survey and water supply forecasting program under the direction of the Bureau of Agricultural Engineering in the Department of Agriculture. In 1939, the bureau was transferred to the Soil Conservation Service (SCS); this agency continues to direct a cooperative federal, state, and private snow survey program. The National Weather Service (NWS) is a major cooperator with SCS in making these water supply forecasts which are routinely issued for over 600 locations in the West.

CENTRALIZED FORECASTING SYSTEM

(SCS, USDA, Portland, OR)

Many developments have occurred since the original legislation. Most recently, the Water Supply Forecasting and Snow Survey Units in the Western United States have supported and provided to over 400 SCS Field Offices interpretive products in the discipline areas of hydrology, engineering, soils, range management, agronomy, biology, forestry, watershed management, and public information. The computer system providing the information is called the Centralized Forecasting System (CFS) and covers the states of Alaska, Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming.

CFS can support 64 simultaneous users and contains monthly summary data on stream (800 stations), reservoir (268 sites), precipitation (1532 stations), and snowpack (1926 stations), and daily data including NWS Climate Stations (1607) providing primarily precipitation and temperature, and SCS SNOTEL (SNOwpack TELemetry) stations (551) providing high elevation snowpack, precipitation, and temperature data. In addition, CFS provides a wide array of analytical and interpretive programs to evaluate the data stored in CFS.

Future CFS development is geared towards providing comprehensive water management and snowpack information to the entire user community.

SNOpack TELemetry (SNOTEL)

(SCS, USDA, Portland, OR)

To improve the data provided for resource management and water supply forecasting, the SCS is expanding and changing the automated SNOTEL system. This modernization effort will include capability to increase measurement cycles and improve telemetry performance. There are over 550 existing SNOTEL sites in the Western United States, all with the ability to provide current snowpack, precipitation, and temperature data. Of these approximately 100 sites currently report maximum, minimum, and average daily temperature and can report their data within one hour of sampling. At the end of the installation of new SNOTEL equipment, over the next three years, all 550

sites will have this capability in addition to other improvements. These improvements will give western streamflow forecasters, using state-of-the-art simulation modelling techniques, data that will improve water supply forecasting. The first 115 will be installed during fiscal year 1988 which begins on 1 October.

SNOW SURVEY RESEARCH

(SCS, USDA, Portland, OR)

These responsibilities are being met through activities of the Snow Survey Program in the West along with research sponsored by the SCS. Research activities are being carried out by the Agricultural Research Service, Boise, Idaho, and the Geological Survey Research Branch, Denver, Colorado. The research itself is in two main areas. The first was to investigate the use of SNOTEL data in simulation models, and what improvements might result from its use. These investigations were completed and demonstrated that SNOTEL data does improve water supply forecasts. The second was to investigate data obtained from the SNOTEL system and correct sampling problems identified. These corrections are still under investigation and many corrections are being implemented.

RADIATIVE PROPERTIES OF SNOW

(T.C. Grenfell and S.G. Warren, Atmos. Sci., UW, Seattle, WA)

Solar radiation incident on, and reflected by, the snow surface was measured near the South Pole as functions of wavelength, angle, and distance from the station. The objectives were (1) to observe spectral albedos of snow across the solar spectrum, (2) to obtain depth profiles of snow grain radius in order to construct theoretical models of spectral albedo for pure snow, (3) to document the extent and degree of soot pollution due to station activities and to assess whether it could invalidate solar radiation measurements made close to large stations, and (4) to investigate the effect of sastrugi on the angular distribution of reflected sunlight.

Spectral albedo measured on many days repeatedly agreed with the results of theoretical models. The visible albedo values were 98–99%, relatively insensitive to grain size. The near-infrared albedo, however, varied substantially among the experiments, due to day-to-day variations of snow grain size caused by precipitation and wind-drifting. We collected samples from the top 20 cm of snow, melted and filtered them, and analyzed the filters. The conclusion is that the pollution is very minor. Just 500 m upwind of the station there is normally less than 1 nanogram of carbon per gram of snow.

SNOWMELT-RUNOFF SIMULATION

(G.H. Leavesley and L.G. Saindon, U.S. Geological Survey, Denver)

Evaluation of the use of U.S. Soil Conservation Service SNOTEL network data for modeling snowmelt runoff using the U.S. Geological Survey Precipitation-Runoff Modeling System (PRMS) was expanded to include Salmon Falls Creek, NV and ID, Cedar River, WA and and Animas River, CO. The National Weather Service Extended Streamflow Prediction (ESP) program was incorporated into PRMS and forecasting of seasonal-flow volumes, peaks, and timing are being investigated using the ESP approach.

WATERSHED RESEARCH

(Rocky Mountain Forest and Range Experiment Station, 222 South 22nd St, Laramie, WY)

The Laramie, Wyoming watershed research project is part of the Rocky Mountain Forest and Range Experiment Station and has the mission to improve the understanding of physical processes controlling relocation of snow by wind in order to provide a better technological basis for managing and controlling the blowing snow resource. Three scientists are assigned to the Laramie Unit, David L. Sturges, Project Leader, and R. A. Schmidt and John W. Pomeroy.

Schmidt and Pomeroy are investigating physical processes that control the relocation and deposition of windblown snow. These activities include electrical charges on saltating snow particles, snow surface strength, and development of an aerodynamic-based theory relating snow retention to surface roughness. Sturges is involved with projects involving measurement of winter precipitation, characteristics of snow drifts developing behind living vegetative barriers compared to drift characteristics of wooden snow fences, and evaluating the effects of snow fencing on water and sediment yields in a paired watershed study.

WET SNOW AVALANCHE RELEASE

(Howard Conway, Geophysics Program, UW, Seattle, WA)

A program of concurrent measurements of water penetration and mechanical properties of snow packs is being undertaken to establish operational monitoring methods to improve avalanche hazard assessment during warm storm cycles in Washington passes.

AVALANCHE PREDICTION, SAN JUAN MOUNTAINS, CO

(R.L. Armstrong, CIRES/COLO)

The more than 150 avalanche paths adjacent to U.S. Highway 550 in southwestern Colorado represent one of the greatest potential avalanche hazards in the United States. On average, more than 120 avalanche events block the highway each winter. Weather, snow structure, and avalanche event data were again collected for the study area during the 1986-87 winter adding to the 15 year data set. These data support the development of a regional avalanche hazard prediction technique. Current work focuses on incorporation of a general snow structure component into the prediction model.

SEA ICE

SEA ICE – SEDIMENT INTERACTIONS

(Peter W. Barnes and Erk Reimnitz, USGS, Menlo Park, CA)

Available information on the layer of sediment reworked by drifting ice in the Beaufort Sea is being synthesized. The active part of the "icekeel turbate" is about 5 m thick, roughly corresponding to the maximum incision depth of grounded sea ice. Icekeel turbates are not restricted to shelf surfaces ploughed by sea ice, but have also been produced by drifting glacial ice in the Norwegian Sea and are produced by icebergs in Baffin Bay today. Icekeel turbates should be recognizable in the geological record exposed on land as well.

ICE GOUGING IN THE BEAUFORT SEA

(Douglas M. Rearic, Peter W. Barnes, Erk Reimnitz, USGS, Menlo Park, CA)

Studies of ice gouging in the Beaufort Sea are continuing, with recent emphasis on the repetitive rates, and the sheltering effects of shoals on the intensity of ice gouging. The observed sheltering of the seafloor by subtle shoals could be used to advantage for the protection of pipelines.

SEDIMENT ENTRAINMENT IN SEA ICE

(Edward W. Kempema, Erk Reimnitz, Peter W. Barnes, USGS, Menlo Park, CA)

Field and flume studies have been conducted on the mechanisms of sediment entrainment into the ice canopy through the formation of underwater ice (both frazil and anchor ice) in supercooled water. In extreme years the resulting floating ice canopy can carry over 16 times more sediment than the annual sediment input from local rivers, and it obtained the sediment load without the need for actual bottom contact of the canopy. Underwater ice formation thus leads to the removal of sediments from shelf areas shallower than 20 m, and results in sediment rafting to the deep Arctic Basin.

RATES OF ARCTIC COASTAL RETREAT

(Erk Reimnitz and Peter W. Barnes, USGS, Menlo Park, CA)

It was concluded that sea ice does not play a generally protective role for the coast, as previously believed. The coastal retreat is restricted to 3 months per year, yet the rates for the Arctic are much higher than for the Texas coast, which in many respects is similar. Only a small portion of the retreat rates can be attributed to melting of excess ice in the sediment section, and wave energy is totally inadequate even to accommodate the sediment yield resulting from coastal retreat. Sea ice moves sediment by bulldozing, rafting, wallowing in a wave field, and indirectly through the processes of ice-flooding by river water each spring, resulting in the formation of large sub-ice scour craters. Sediment transport by these ice-related processes remains largely unquantified.

A LEAD–TEMPERATURE FEEDBACK MECHANISM AND CLIMATIC CHANGE

(Tamara Shapiro Ledley, Rice University, Houston, TX)

Impact of sea ice and the associated leads (cracks in the ice exposing open ocean) on the surface energy fluxes is being examined through experiments that have been performed with a coupled energy balance climate-thermodynamic sea ice model. In these experiments the winter lead fraction varies from 0–4.3%, and for contrast, is set to 100% (ice free conditions).

Results from this study indicate that changes in the winter lead fraction from a base case of 1.1% can cause changes in the simulated annual surface air temperature in the polar regions, ranging from a decrease of 1.0 °K when leads are eliminated, to an increase of 1.0 °K when the winter lead fraction is 4.3%. These temperature changes can range up to 2.0 °K seasonally. An examination of the surface energy fluxes shows that changes in the sensible heat flux contribute the most to these temperature changes.

The effect of leads on the air temperature is called the lead-temperature feedback. It operates in the following way. The lowering of atmospheric temperatures decreases the thermodynamic summer lead expansion, reducing the seasonal fraction of leads, and therefore the energy loss by the ocean to the atmosphere, and thus contributes to a further lowering of atmospheric temperature. An increase in atmospheric temperature would have the opposite impact on summer leads, and thus increase atmospheric temperature further. This positive feedback process between leads and air temperature is the result of the interaction between ocean, atmosphere, and sea ice, and has major implications for both polar and global climate.

POLAR RESEARCH

(Roland Picard and Robert Fett, Naval Environmental Prediction Research Facility, Monterey, CA 93943-5006)

The Naval Environmental Prediction Research Facility (NEPRF) atmospheric scientists are using satellite imagery to gain knowledge about temperate and polar climate interaction. The regions of interaction are typified by strong horizontal and vertical temperature gradients leading to mesoscale processes which act and are acted upon by the larger air-ocean system. Satellite case studies of Arctic phenomena are being developed for the Navy Tactical Application Guide series, a regionally oriented encyclopedia of weather satellite case studies of the world's weather. In addition, research has begun on updating the Navy Arctic Weather Forecaster's Handbook, an operationally oriented aid containing climatology, notes on structure and behavior of weather systems, objective and subjective forecasting techniques, and polar analysis methods. Both of these publications

will provide the necessary general information to enable Navy forecasters to assess and forecast accurately weather and ice conditions in an Arctic environment.

SEA ICE THICKNESS STUDIES

(Robert H. Bourke and Robert G. Paquette, Naval Postgraduate Sschool, Monterey, CA)
Based on ice thickness measurements at 10 m intervals from six ice floes in the central Arctic basin, established mean ice density and regression equations for prediction of ice freeboard based in known ice draft.

SEASONAL AND SPATIAL DISTRIBUTION OF ARCTIC SEA ICE

(Robert H. Bourke and Robert C. Garrett, NPS, Monterey, CA)
Established seasonal and spatial ice drift distribution for entire Arctic basin based on submarine under-ice sonic profiles.

USING SEA SURFACE TEMPERATURE AS A CLIMATIC SCALE INDICATOR OF ICE EDGE LOCATION

(John E. Walsh, Gordon Fleming, Robert H. Bourke, NPS, Monterey, CA)
Usings COADS data set to locate ice edge and SEIC data set to establish sea surface temperature, use both variables as input to climatic-scale ice distribution model. Compare results in Nordic seas against Soviet model.

EFFECT OF OZONE DEPLETION ON ANTARCTIC MARINE PHYTOPLANKTON

(S.Z. El-Sayed, R.R. Bidigare, J.A. Brooks, Department of Oceanography, Texas A & M)
In recent years reduced levels of atmospheric ozone observed in early austral spring (September–October) over the South Polar region have been accompanied by an increased level of incident ultraviolet (UV) radiation. UV is potentially very damaging to phytoplankton, the microscopic plants which constitute the base of the food web in aquatic ecosystems.

A quantitative assessment will be undertaken of the effect of UV on Antarctic phytoplankton coincident with the NSF-supported research that will monitor the changing levels of ozone/UV over the South Polar region during the upcoming austral spring. The effect of UV on primary productivity, pigments and species composition of Antarctic marine phytoplankton will be studied.

PHYTOPLANKTON INVESTIGATIONS IN THE BRANSFIELD STRAIT AND OFF ELEPHANT ISLAND (JANUARY 1987)

(S.Z. El-Sayed and L.H. Weber, Department of Oceanography, Texas A & M)
Investigations were carried out aboard the Polish research vessel *Prof. Siedlecki* as part of the U.S. Antarctic Marine Living Resources Ecosystem Monitoring Survey sponsored by the National Oceanic and Atmospheric Administration (NOAA). The objective of the phytoplankton research program was to assess the vertical and horizontal distribution patterns of phytoplankton biomass, primary productivity, and cell size distribution in relation to environmental parameters and to the distribution of krill.

THE BEAUFORT SEA MESOSCALE CIRCULATION STUDY AND THE FREEZE EXPERIMENT

(K. Aagaard, C. Pease, Pacific Marine Environmental Laboratory/NOAA)
Three major field efforts were conducted in the financial year 1987: an icebreaker cruise in the Beaufort Sea during October 1986; a comprehensive helicopter-supported operation on the ice in the Beaufort Sea during March-April 1987; and a conventional cruise in the northern Bering, Chukchi and Beaufort Seas during August–September 1987. The purpose in the first year of this two-year shelf circulation study was to (1) obtain sufficient measurements of currents and various passive tracers to provide a primary description of the large-scale shelf circulation and its low-frequency variability; (2) determine the time-dependent wind forcing by extensive long-term automated measurements over the sea ice; (3) investigate the seasonal hydrographic cycle in the Beaufort Sea, including that of nutrients and dissolved oxygen; and (4) relate the rate of the fall ice advance to the pre-existing heat content of the water column. A number of geochemical tracers for other investigators, including carbon-14, cesium, freons, strontium, and radium, were extensively sampled. The analysis of these various data sets is just now beginning. A second year of helicopter operations will be conducted on the ice in the Beaufort Sea during March–April 1988, and a Chukchi Sea cruise in September–October 1988. At that time moorings deployed in 1987 will be recovered.

SEA ICE PROCESSES AND MODELING

(C. Pease and J. Overland, PMEL/NOAA)
A coupled sea ice, barotropic ocean model with a 1 km resolution and a seaward domain of 200 km has been developed to examine three coastal processes: coupling of ice motion to wind-driven coastal currents, thickness re-distribution under compression at the coast, and the formation of coastal shear zones in the ice. Results of model calculations show that a new formulation of ice strength parameterization is necessary for the coastal sea ice problem compared to the parameterization used in previous large scale sea ice models. Analysis of ice drift from the vicinity of Bering Strait support this conclusion.

INVESTIGATIONS IN THE GREENLAND SEA

(K. Aagaard, J. Overland, PMEL/NOAA)
These have three primary thrusts: exchange with the Arctic Ocean through Fram Strait, Greenland Sea circulation in the context of deep ocean ventilation, and air/ice/ocean

exchange. With respect to the first thrust, substantial progress was made in analyses of both the west Spitsbergen and east Greenland currents. North of 79°N the west Spitsbergen current contains two separate warm cores that follow different isobaths. The western core, carried by the offshore branch of the current, follows the western flank of the Yermak Plateau, and north of 80°N at least part of this flow detaches from the plateau, probably to contribute to the recirculation in Fram Strait. In contrast, the inshore branch follows the shelf break into the Arctic Ocean. During the transit of the inshore waters past northwestern Spitsbergen, the core properties change primarily through vertical heat flux, which during ice-free conditions in winter is estimated to be of order 200 Wm^{-2} from the core layer alone. Together with some freshening within the Arctic Ocean, this process is responsible for fully transforming the original Atlantic water into Arctic intermediate water within about 600 km of Fram Strait. With respect to the East Greenland current, using long-term moored measurements near 79°N, it was found that its mean southward transport above 700 m is about 3 Sv and has no obvious seasonal variability. About one-half of this transport appears to be barotropic. There is a rich mesoscale structure in the current records, much of which can be interpreted as trains of eddies and eddy-pairs with cross-tream length scales of order 10 km. Despite the abundance of eddies, turbulent heat fluxes are very small even in the vicinity of the polar front. Baroclinic instability is therefore not a major source of these eddies. During June–July 1988 five new moorings will be deployed in the central Greenland Sea in a program coordinated with other research laboratories in Germany, Norway, and the U.S. At the same time the moorings deployed in the southwestern Greenland Sea during 1987 will be recovered.

With respect to the second thrust, viz. the circulation of the Greenland Sea itself in the context of deep ocean ventilation, participation in the Greenland Sea Project has begun. This is an international program to determine the mechanisms and rates of ventilation and water mass transformation within the Greenland Sea. An icebreaker cruise was conducted during June 1987, concentrating on the relatively unexplored western and southwestern Greenland Sea Basin. In addition to mooring work, a series of high-precision hydrographic sections was obtained. These substantially illuminate both the fate of the dense Arctic Ocean outflow in the Greenland Sea and the eastward recirculation of waters north of the Greenland – Jan Nayden ridge. Participating in the intensive 1988-89 volumetric census in the Greenland Sea is planned, designed to quantify the winter water mass transformation and ventilation.

Arctic meteorology studies will emphasize air–ice momentum and heat transfer through data analyses of previous aircraft experiments and modeling studies of the atmospheric boundary layer. Of particular concern is the interaction of the atmospheric radiation budget and seasonal ice growth, as determined by atmospheric boundary layer structure and surface ice properties. An aircraft experiment is planned for 1989.

DEVELOPMENT OF AN INTERACTIVE SEA ICE FORECAST WORKSTATION SYSTEM

(Wayne J. Fischer, NOAA/ERL, Boulder, CO)

A forecaster workstation system is being developed for operational use in the Navy-NOAA Joint Ice Center (JIC) in Suitland, MD. The Joint Ice Center has responsibility for operational analyses and forecasts of sea ice conditions in the Arctic, Antarctic and Great Lakes. A computer-based interactive workstation system, similar to the systems being developed by PROFS for weather-forecasting applications is being developed for the JIC.

Data from the NOAA/TIROS, GEOSAT, GOES and DMSP SSM/I satellite systems will be used in the workstation system. Additionally observation data from ships, buoys, and aircraft reconnaissance flights will be integrated into the system, along with forecast model products from the NOAA National Meteorological Center, the Navy Fleet Numerical Oceanographic Center, and the NOAA Ocean Products Center. Forecast products from other national forecast centers in Canada, Sweden, and Denmark will also be used.

The capability to integrate all of the available data sources into the JIC analysis is a key feature of the system. The analysts and forecasters at the JIC will be able to prepare analyses and forecasts inter-actively on the workstation itself, improving the timeliness and accuracy of the products prepared.

CLIMATOLOGY OF ARCTIC PRESSURE SYSTEMS

(M.C. Serreze and R.G. Barry, CIRES and Department of Geography, University of Colorado, Boulder, CO)

The frequencies and tracks of cyclones and anticyclones in the Arctic have been determined for all months for the period 1979–85. The study utilizes daily MSL pressure analyses for 1200 GMT in gridded format that incorporate coastal/island stations and buoy data from a drifting network maintained by University of Washington's Polar Science Center. Comparisons are made with earlier climatologies. The Beaufort Sea high pressure cell (or ridge) dominates the winter circulation although it is frequently replaced by lows that migrate from Baffin Bay, the Greenland Sea and to a lesser extent from the Bering Strait. Central pressures within the anticyclone are usually 1035–1040 mb, although values in excess of 1050 mb are observed. An important feature of the summertime circulation is the tendency for persistent quasi-stationary cyclones to develop in the

interior of the Arctic Basin. These systems are most frequent in August, resulting in a mean low for that month (1979–85) centered at 84°N, 140°W. These lows result in an annual reversal of sea ice motion in the Beaufort Gyre, a feature not previously noted. The synoptic character of these cyclones is being examined through a number of case studies.

SURFACE RADIATION BUDGET IN THE MARGINAL ICE ZONE

(Kristina B. Katsaros, Atmos. Sci., UW, Seattle, WA)

A study of the components in the surface radiation budget in the Marginal Ice Zone in the Bering Sea has been completed, with M. Barrett. The data were obtained from the NOAA-instrumented aircraft in the Mizex-West experiment, February 1983, supplemented with radiative transfer calculations. A matrix of conditions were sampled – three surface types: open water, mixed ice floes and open water, and snow covered ice; and three sky types: clear, broken cloudiness, and overcast. The percentage of the three surface types was determined from the sea surface temperature (SST) measured with a radiation thermometer. Albedo was found to correlate well with the SST or ice percentage. Because an upward facing pyrgeometer failed, an infrared radiative transfer model was used to estimate longwave irradiance.

ANALYSIS OF THE PLANETARY BOUNDARY LAYER AT THE MARGINAL ICE ZONE

(R. Brown, Atmos. Sci., UW, Seattle, WA)

This research is directed towards establishing a mesoscale model of the air – sea ice interaction, for linking local measurements to large-scale atmospheric and ocean modeling. A much tested two-layer PBL model has been used, which responds to variable stratification in both layers, variable surface roughness, and thermal winds. It is an equilibrium, point model containing organized large eddies which produce quick mixing throughout the layer. This produces equilibrium for mesoscale modeling on 50 km grid scales, as discussed by Brown (IUGG, Vancouver, Canada, August 1987).

The phenomenon of the cold air outbreak at the MIZ is the subject of Paul Hein's Master's thesis (1986), and a paper (Hein and Brown, submitted 1987). The transition in the dynamics of the flow from PBL scale roll vortices to large scale vortices and cells in the oceanic convective regime is the subject of P. Mourad's PhD thesis (1987). The mesoscale variation of stress, heat flux and winds at the ice edge, with the effects of ice edge irregularities, is the subject of papers (Brown, IUGG, 1987; Burke and Brown, to be submitted) under current development. This research has been supported by NSF (DPP) and ONR.

UPPER ARCTIC OCEAN STUDIES

(James Morison, PSC, UW, Seattle, WA)

The objective of this work is to understand the dynamics and thermodynamics of the upper Arctic Ocean. Experimental programs involving the use of a profiling current meter CTD system have recently been carried out during the MIZEX 83, MIZEX 84, and the Arctic Internal Wave Experiment (AIWEX) in 1985. The MIZEX work has focused on the exchange of mass and momentum between the ice and upper ocean in the marginal ice zone. The AIWEX work has involved determining the nature of the Arctic internal wave field and its relation to surface forcing.

Theoretical work is being carried out with Michael Steele to develop a model of air–ice–ocean interaction applicable to regions of variable ice concentration and floe size. Michael Steele is also developing improved ocean boundary layer models and a two-dimensional ice ocean model.

ARCTIC OCEANOGRAPHIC BUOY PROGRAM

(James Morison, PSC-UW, Seattle, WA)

Drifting buoys with an ARGOS satellite link and a chain of temperature and conductivity sensors are being deployed in data sparse regions of the Arctic in order to improve the hydrographic data base. The buoys will produce long-term records from areas where only spot measurements made in the spring season have been available before.

ANALYSIS OF OBSERVED SEA ICE MOTION IN SUPPORT OF REMOTE SENSING OF SEA ICE

(R. Colony, R. Moritz, D. Rothrock, PSC-UW, Seattle, WA)

This research makes use of the extensive drifting buoy data set to assess annual and seasonal statistics of sea ice motion, including the mean, variance and covariance structure of velocity and strain rate. These estimates will be combined with scenarios for the data collection schedule of ERS-1 SAR to estimate the probability of obtaining imagery of the same patch of sea ice at two different times. Time scales of interest range from 3 days to 2 years. The estimated probabilities will describe two different ensembles: (1) ice motions chosen at random from climatology, as described by the seasonal mean velocity and variance; (2) ice motions chosen at random from the set of all motions consistent with contemporaneous buoy displacement data.

It is anticipated that the results of the study will contribute to science planning for ERS-1 SAR by quantifying the number of image pairs that investigators can expect to obtain at various time lags, and by suggesting useful scenarios for data take scheduling in order to optimize the number of image pairs for particular studies. The strain rate information will aid in choosing areas of high and low deformational activity for intensive study with SAR data.

Support for the study is to be provided by the NASA Ocean Processes Branch.

ARCTIC BUOY PROGRAM

(Roger Colony, PSC-UW, Seattle, WA)

Since 1979 a network of automatic data buoys has been maintained in the Arctic Ocean. An assortment of buoy types is used. The mainstay of the program is the air deployable buoy which measures sea ice motion, surface atmospheric pressure, and surface temperature. Some special research buoys have also been built around microprocessors for the collection of meteorological, oceanographic, and ice data. Data are collected, analyzed, and archived at the Polar Science Center; distribution is through the World Data Center for Glaciology. Program objectives include: basin wide monitoring of surface atmospheric pressure, temperature, and sea ice motion; support of weather and ice forecasting; support of regional environmental studies; support of sea ice kinematic and dynamic modeling studies; and research and development of buoy technology.

ANALYSIS OF SEA ICE DRAFT PROFILES

(Roger Colony, PSC-UW, Seattle, WA)

The draft of sea ice has been measured by submarine-mounted sonar. A typical cruise may produce a measurement of draft every 1.5 meters along a 1500 km long track. Analysis of these data is directed towards both a descriptive treatment of bottom side topography and statistical models of ice draft geometry and features. The one dimensional spatial structure has been studied in two ways: (1) modeling and description of the two-point joint probability density function for ice draft; and (2) using the ideas of stochastic processes (Markov chains, renewal theory) in modeling the spatial structure of ice features.

SEA ICE REMOTE SENSING

(D.P. Winebrenner and D.A. Rothrock, PSC-UW, Seattle, WA)

The utility of polarimetric synthetic aperture radar (SAR) data for sea ice type discrimination is being investigated. This investigation is partly theoretical, using physical models for sea ice and electromagnetic scattering to reveal the geophysical information content of the scattering and Stokes matrices, and partly observational, making use of airborne polarimetric SAR data together with ground truth. This work is in collaboration with the polarimetric SAR program being conducted by the Jet Propulsion Laboratory.

SAR REMOTE SENSING OF SEA ICE

(Drew Rothrock, PSC-UW, Seattle, WA)

The 1990s will be a decade of intensive acquisition of satellite synthetic aperture radar imagery, beginning with the launch of ESA's ERS-1. In order to utilize this capability for global geophysical observations of sea ice, we will need efficient algorithms for automated digital extraction of geophysical data from image data, demonstrated applications of these geophysical data, and sampling strategies for requesting images from space agencies. We are contributing to these objectives.

An ice tracking algorithm has been developed which uses cross-correlation on images of a heirarchy of resolutions. With this algorithm, we have obtained observations of the discontinuous structure of the field of motion of compact ice. The ice moves in rigid pieces some of which are several hundred kilometers across – much larger than the visible "floes", which are tens of kilometers in diameter. Work is in progress on the relationship between these kinematic observations and the formation or loss of open water and thin ice areas, on the relation between ice deformation and gradients in the wind field, and on the spatial statistics of deformation and of concentration.

ARCTIC ICE BALANCE

(Drew Rothrock and Don Thomas, PSC-UW, Seattle, WA)

A goal of sea ice research is to describe and monitor the state of the ice cover, and to understand the physical processes which change that state. We are developing a method for integrating the satellite Scanning Multichannel Microwave Radiometer (SMMR) data set with the Arctic Buoy Program (ABP) data set for the purpose of quantifying the sea ice mass budget. Neither the SMMR data not the ABP data separately provide enough information to do that adequately. The microwave data carry information about the ice type, but suffer from an ambiguity in that neither wet ice nor second-year ice can be distinguished from a mixture of first-year ice and older multiyear ice. The surface temperature and surface type mixture ratios are also confounded. The buoys provide ice motion, deformation, and surface temperature data, but no direct information about ice conditions. Nearly eight years of multichannel microwave data and drifting buoy data are available now with plans for augmenting both data sets indefinitely into the future.

We are developing a model to estimate how well the processes in the model describe the changes in these abundances. A Kalman filter technique combines inputs consisting of the surface temperature, ice velocity and deformation derived form buoy data, and the brightness temperatures measured by the SMMR. The outputs are fractional areas of open water, first-year ice, second-year ice, and older multiyear ice. In the first phase, the temporal change is monitored following a buoy trajectory. Later, the mass balance of several regions will be monitored.

STATIONARY UPWARD LOOKING SONAR

(N. Untersteiner and R. Moritz, PSC-UW, Seattle, WA)

A new instrument is being designed and built by the Applied Physics Laboratory that will record the draft of sea ice passing over a shallow mooring. Technical specifications include a narrow sonar beam (1.5 deg), solid state data logger (1000 KByte), transducer depth sensor, and automatic alignment in

the vertical. First deployments are planned in the northern Greenland Sea, to study the volume and thickness distribution of sea ice exported from the Arctic BAsin.

OBSERVATIONS OF INTERNAL GRAVITY WAVES UNDER THE ARCTIC PACK ICE

(Murray D. Levine and Clayton A. Paulson, College of Oceanography, Oregon State University, Corvallis, and James H. Morison, PSC-UW, Seattle, WA)

Internal gravity waves measured under the Arctic pack ice were strikingly different from measurements at lower latitudes. The total wave energy, integrated over the internal wave frequency band, was lower by a factor of 0.03–0.07, and the spectral slope at high frequency was nearly −1 in contrast to the −2 observed at lower latitudes. This result has implications for theoretical investigations of the generation, evolution, and destruction of internal waves and is also important for other processes, such as the propagation of sound, and the wave-induced turbulent diffusion of heat, plankton, and chemical tracers.

ICE RADAR AND REMOTE SENSING

HIGH-SPEED DIGITAL DATA ACQUISITION SYSTEM FOR ICE RADAR SOUNDING

(David Wright and Jerry Bradley, USGS, Denver, CO; Steven Hodge, ICP, USGS, Tacoma, WA)

A high-speed digital data acquisition and signal-averaging system for borehole, surface, and airborne radio-frequency geophysical mesurements has been developed. Initially it will be used in surface and airborne ice radar sounding. The system permits signal-averaging at rates high enough to achieve significant signal-to-noise enhancement in profiling, even in airborne applications. It has an analog bandwidth of 100 MHz and can digitize to 8-bit resolution at 100 Megasamples/second. It can sample 256 to 8192 points/waveform, and can add any number of waveforms up to 65536, at rates of 3,000–50,000 waveforms/second (depending on the number of points/waveform). The system records on standard 9-track magnetic tape and uses a microcomputer to control its operation. It has been successfully used for airborne ice radar soundings of Greenland (see below), and will be used for surface radar studies in West Antarctica (see below). Funding for the development came from the National Science Foundation.

RADAR SOUNDING OF CENTRAL GREENLAND

(S. Hodge, D. Wright, J. Bradley, USGS, R. Jacobel, SOC Northfield, MN)

In cooperation with the Technical University of Denmark, the USGS (Hodge, Wright and Bradley, see above) conducted an airborne ice radar survey in central Greenland in the spring of 1987. The work used the 60 MHz ice radar developed by TUD and used for sounding Greenland and Antarctica in the 1970s. It was deployed from an LC-130 aircraft operated by the VXE-6 squadron of the U.S. Navy. Over 6000 km of radar soundings were recorded successfully in a 6-day period, covering a 150 × 150 km square grid centered on the highest point ("Summit") of the Greenland ice sheet. Grid lines were 12.5 km apart, 13 in a north-south direction, and 13 in an east-west direction. Data were recorded on film, Honeywell "Visicorder" paper, and on digital magnetic tape, using a new data acquisition system developed by the USGS (see above). The work was funded by the National Science Foundation and will be used to aid in the selection of a new ice corehole to be drilled in this area.

LOW FREQUENCY ICE RADAR STUDIES IN WEST ANTARCTICA

(S. Hodge, D. Wright, J. Bradley, USGS, R. Jacobel, SOC Northfield, MN)

The USGS (Hodge, Wright and Bradley, see above) and St Olaf College (Jacobel) will be using a surface-based profiling ice radar to study basal conditions and internal layering on ice stream B in West Antarctica during the 1987–88 field season. This will use a low frequency broadband monocycle ice radar and a digital recording system (see above). The work will be done along the same lines as seismic profiling done by the University of Wisconsin (Madison), to see what information low- and multi-frequency ice radar studies can shed on basal water, till layers, and other factors affecting the sliding of ice streams.

RADIO-ECHO SOUNDING STUDIES WITH A SMALL DIGITAL RECORDING SYSTEM

(R. Jacobel, SOC, Northfield, MN)

We have built a radio-echo sounder which utilizes a low frequency broadband impulse transmitter and a micro-processor based digital recording system. The unit is mounted on skis and is designed to be deployed in profiling as well as stationary modes. Power for the system is delivered by a small Honda generator and batteries. Though originally intended primarily for sounding temperate ice, the system has been modified to perform in polar conditions, and will be tested in the Antarctic in the 1987–88 field season. The system has been deployed on South Cascade Glacier, Washington, in several experiments in conjunction with the hot water drilling by A. Fountain of the USGS, and has produced a number of interesting results.

RADAR STUDIES IN CENTRAL GREENLAND AND WEST ANTARCTICA

(R. Jacobel, SOC, Northfield, MN)

Radar data acquired over central Greenland this summer have been processed by SOC, USGS and TUD (see Hodge, above). Currently the Visicorder film is being analyzed to produce a map of bedrock topography to aid in the site selection for the GISP II core.

During the 1987–88 Antarctic field season, joint work will take place in the deployment of a new echo sounding system (see Hodge,

above), to study internal layering and basal conditions on ice stream B in West Antarctica. Several undergraduate students have been involved in both projects, as well as the development work above, with funding from the National Science Foundation.

ANTARCTIC ICE RESEARCH USING LANDSAT IMAGES

(B.K. Lucchitta, JoAnn Bowell, U.S. Geological Survey, 2255 North Gemini Drive, Flagstaff, Arizona 86001, U.S.A.; Olav Orheim, Norsk Polar Institutt, P.O. Box 158, 1330 Oslo Lufthavn, Norway; Charles Swithinbank, 7 Home End, Fulbourn, Cambridge CB1 5BS, U.K.)

The USGS is currently engaged in a project to conduct Antarctic research with Landsat images (Lucchitta and others 1987). The goals are (1) to improve on existing maps of Antarctica by producing planimetric image-mosaic maps of ice sheets and other areas currently lacking good map coverage, and (2) to apply the images to a variety of research topics. To this end, about 170 computer tapes containing digital Landsat multispectral-scanner (MSS) images have been acquired of the coastal and near-coastal areas of Victoria Land, Marie Byrd Land, and the Antarctic Peninsula, and of selected areas in the Ellsworth Mountains, Shackleton Range, Queen Maud Land, and the Lambert Glacier – Amery Ice Shelf regions. The digital processing of computer-compatible tapes allows selective enhancement of Landsat images; though unenhanced Landsat images have proved useful for ice-sheet research in the past (Orheim 1978; Williams and others 1982; Marsh 1985), the enhanced images are an even more valuable resource and may significantly advance an understanding of the ice sheets.

The synoptic view of Landsat images (185 km on a side) is particularly suited to recognizing regional structures on ice sheets, ice streams, and ice shelves (Swithinbank and others 1987). Additionally, the low sun elevation angle on Landsat images of Antarctica emphasizes many subtle topographic features. These features include (1) flow lines on ice streams, delineating their precise courses; (2) flow lines on ice shelves, reflecting the components and courses of contributing ice streams (Swithinbank and Lucchitta 1986; Swithinbank and others 1987); (3) crevasses on ice streams or shelves whose identification can aid in planning of field traverses; (4) rolling topography probably reflecting subsurface inhomogeneities; and (5) buried mountain ranges, whose structure and morphology can be determined where ice sheets are thin (Marsh 1985).

Changes in coastlines, including changes in ice-shelf fronts and glacier margins, can be detected by comparing historical and current aerial photographs. Landsat images obtained at different times, however, offer an easier and more rapid method of measuring coastline changes (Ferrigno and Gould 1987). In addition, Landsat images can be used to measure ice velocities. In two separate locations, enhanced Lansat images that were acquired at an interval of about 10 years show rifts that have remained conspicuous in the floating part of ice streams: (1) for the Byrd Glacier, Landsat velocity measurements agree within 10% of those acquired earlier on the ground and by aerial surveys (Lucchitta and Ferguson 1987); (2) for the Jutulstraumen Glacier, well-preserved rifts permitted the additional measurement of strain rates (Orheim and Lucchitta 1987). Comparing archival Landsat scenes with later images will make feasible the compilation of Antarctica-wide inventories of ice-stream and glacier velocities.

In a collaborative effort with the Norsk Polar Institutt, a Thematic Mapper (TM) Landsat image of Antarctica was acquired over Jutulstraumen in Queen Maud Land. This digitally enhanced image reveals snow and ice features at a level of detail never before seen on satellite iamges. The six TM reflective spectral bands have a nominal resolution of 30 m, compared to 80 m for the MSS images. The TM near-infrared reflective spectral bands discriminate better between clouds and snow than do MSS spectral bands. They also reveal snow features not observed at visible wavelengths that are probably related to snow properties such as grain size (Orheim and Lucchitta 1987). The TM thermal band shows ground radiation temperatures, and it may serve to detect liquid water. In the investigated image, the TM-band temperatures are linearly related to elevations on the ice-sheet surface, agreeing with measurements that were made simultaneously on the ground (Orheim and Lucchitta, in press).

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CRYOSPHERIC DATA MANAGEMENT SYSTEM

(R.L. Weaver, CIRES, UC, Boulder, CO)

On June 19 1987 the Defense Meteorological Satellite Program launched the Special Sensor Microwave Imager (SSM/I), a high resolution microwave imager which is providing real-time microwave data on sea ice, atmospheric moisture and precipitation, soil moisture, and ocean parameters.

The National Snow and Ice Data Center in collaboration with the NASA Ocean Data System (NODS) and the Satellite Data Services Division (SDSD) at NESDIS has embarked on a project to establish a long-term, secure archive and distribution center for data products over the the polar oceans derived from the SSM/I. The project is accomplishing this goal by installation of a mini-computer based data management and data retreival system developed by the Jet Propulsion Laboratory, NASA Ocean Data System and delivered to NSIDC through a technology transfer agreement.

The specific functions of the Data Management System include: extract SSM/I cryospheric data from the orbital data stream; create mapped data sets; provide an interactive data catalog; distribute data to the user community (foreign and domestic); incorporate other non-SSM/I cryospheric data; implement revised microwave algorithms; and incorporate special products upon user request.

NSIDC will receive Level 1 data from NESDIS and will produce global, swath mapped, brightness temperature data and Level 3a temporally and spatially averaged, polar gridded data on ice concentration, ice edge and multi-year fractions. Algorithms for the geophysical data have been developed and used for Nimbus 7 SMMR. Analysis by the NASA Sea Ice Algorithm Working Group (SAWG) has recommended that the algorithm developed by GSFC be implemented by PODS for SSM/I data.

ANALYSIS OF PASSIVE MICROWAVE RADIATION

(Z.F. Danes, ICP-USGS, Tacoma, WA)

The purpose of this analysis is to find whether the variation in the spontaneous radiation of the Earth's surface can be used as a tool to measure the snow–water equivalent (SWE) of snowpacks.

Four signals (two frequencies in two polarizations) have been monitored every six days since the fall of 1978 by the Nimbus-7 satellite and data supplied to us by NASA. Those data are then confronted with whatever ground truth values are available: climatological data from NOAA, snow courses and automatic SNOTEL data from the Soil Conservation Service and others, as well as our own snowpit data obtained three times a year in the mountains of Colorado, Utah and Wyoming.

Results to date show an unmistakeable correlation between snowpack and the microwave signal, but other factors, such as snow wetness, grain size and icy crust also influence the signal.

Present work consists mainly in eliminating those additional factors and in improving the "ground truth", so that surface data would be more meaningful in terms of overall snowcover.

GLACIERS AND ICE SHEETS

MASS BALANCE HISTORY OF BLUE GLACIER, WASHINGTON

(R.L. Armstrong, CIRES/COLO; C.F. Raymond and S.G. Warren, UW, WA)

Mass balance and climate data have been collected for Blue Glacier (Olympic Peninsula, Washington) since 1957. This data set is now in the final stages of compilation. Preliminary results indicate that during the past three decades the average mass balance for Blue Glacier has been positive with a cumulative net balance of 9.2 m which corresponds to a gain in mass of 7%. Based on the analysis of this total data set, a method is being developed to compute mass balance in the future using a simplified set of field measurements. Analysis of the sensitivity of mass balance to various climatic components is also underway.

PROGLACIAL STREAM CHEMISTRY, MOUNT RAINIER VOLCANO, U.S.A.

(Catherine Hawkins, Mount Rainier National Park; Richard Frenzel, Cooperative Park Studies Unit, Oregon State University; Richard Metcalf, MCR Scientific)

A reconnaissance program of field measurements of pH, conductivity, dissolved oxygen, and water temperature, and laboratory measurements of major ions in rivers of Mount Rainier National Park was conducted during February–October 1986. In this initial attempt at a baseline survey of representative aquatic systems within the park, 13 rivers were sampled. The program is designed to assess long-term trends of acidic deposition within the park. Additional baseline data was obtained by G.L. Turney, N.P. Dion, and S.S. Sumoika of the U.S. Geological Survey in 1985 for 13 lakes. These initial surveys indicate water studies in Mount Rainer

National Park have been little affected by acidic deposition through 1986. However, the low solute content waters present in the park require vigilant future observation for preservation in a pristine state.

WEST GULKANA GLACIER STUDIES

(Melvin Miller, Geog–ASU, Tempe, AZ)

Glaciological and climatological research has been carried out on the West Gulkana Glacier, eastern Alaska Range, during summer field season in 1986 and 1987. West Gulkana is one of nine U.S. glaciers mapped at the 5 meter contour interval during the 1957-58 IGY. Recent work has included new aerial photography; remapping of the glacier; 2-year and 30-year mass balance determinations; heat balance climatology across snow, slush, ice, rock, and tundra surfaces; local glacial geology; and synoptic climate analysis. The project is jointly sponsored by Arizona State University and the U.S. Military Academy, West Point, with participating faculty and students from both institutions (M.G. Marcus, Project Director). Funding support has been provided by CRREL, Army Research Office, Durham, and the American Geographical Society.

SURGING POTENTIAL OF POLAR ICE STREAMS

(U. Radok, C. Lingle, T. Brown, CIRES, with W. Budd, D. Jenssen, B. McInnes, Melbourne, J. Fastook, Orono, D. Schilling, Rice Lake)

The possibility that Antarctic ice streams could accelerate their already fast motion in periodic surges has been investigated with Budd-McInnes model of self-surging glaciers in a 3-year project funded by the U.S. Department of Energy. Eight ice streams modeled (some of them with bedrock well below, and others above, mean sea level) tended to develop irregular fast sliding, rather than periodic surging, for any realistic choice of the tow controlling model parameters (representing the bulk viscosity of the ice and the lubricating effect of the basal friction, respectively). This may be explained by the strong mass flux convergence from the wide low-accumulation source regions into the narrow high-accumulation regions of discharge into the ocean; however, the possibility of ice stream surges clearly needs to be investigated further with more sophisticated parameterizations of the basal hydraulics.

The input data for the model simulations were constructed by updating the original Melbourne survey of derived physical characteristics of the ice sheet with 20 km grid digitizations of the surface and bedrock elevation contours in the SPRI Glaciological and Geophysical Folio of Antarctica. Other development work has produced a sliding law in terms of basal water pressure and computer algorithms for an ice shelf model due to W.S.B. Paterson. The entire work is described in a five-part report (obtainable from WDCA-Glaciology (Snow and Ice), CIRES, Campus Box 449, University of Colorado, Boulder, CO 80309).

OXYGEN ISOTOPE PALEOCLIMATOLOGY/ GLACIOLOGY

(P.M. Grootes and M. Stuiver, QRC, Seattle, WA)

Changes in $\delta^{18}O$ along the Ross Ice Shelf (Antarctica) core at J-9 are a combination of the West Antarctic ice sheet. The individual contributions have been estimated for the Ross Ice Shelf, as well as for the Law Dome BHF and the D-10 isotope records. We conclude that intermediate cores from the margins of the big ice sheets, or from ice shelves, can provide isotope records extending well into the last glacial period, thus providing, over long intervals, information on past climate as well as on ice flow and ice sheet elevation.

The 202 m and 354 m long cores from South Pole contain an isotope record covering the last three to four millennia. An improved time scale is needed to determine whether apparent correlations between the isotope profiles from these cores and isotope records from elsewhere in Antarctica are real.

Averaging surface $\delta^{18}O$ values are being obtained from shallow cores along two flow lines from the ice divide through Ice Stream B (West Antarctica) in collaboration with I. Whillans (IPS/Ohio). $\delta^{18}O$ trends indicate the precipitation regime on this part of the West Antarctic ice sheet. The trends are also important for the interpretation of the J-9 $\delta^{18}O$ record and possible future core records in the Ross Sea drainage.

$\delta^{18}O$ values in blue-ice areas (Recklinghausen moraine, G. Faure, Ohio; Allan Hills, J. Annexstad, NASA; I. Whillans, Ohio; Lewis Cliff Ice Tongue, P. Englert, W. Cassidy) are being studied to learn about the possible origin and age of the ice in these areas.

Detailed isotope measurements are in progress on the 302 m Siple Station core (E. Mosley-Thompson, Ohio), the 201 m Dominion Range core (P.A. Mayewski, UNH) and a 100 m core from Ridge B/C, Siple Coast (Antarctica) (R. Alley, Wisconsin).

BOREHOLE WATER LEVEL MEASUREMENTS, COLUMBIA GLACIER, AK

(M. Fahnestock and N. Humphrey, Geol-CalTech, Pasadena, CA)

A successful collaborative 1987 field season was completed on Columbia Glacier, Alaska. The project involved the California Institute of Technology group drilling five holes to the glacier bed and a group from the University of Colorado and the USGS (glaciology office Tacoma) obtaining data on surface motion, weather, and ablation. This summary will discuss the results of the drilling, which was organized by Barclay Kamb and Hermann Englehardt and also involved Neil Humphrey, Mark Fahnestock, Matthias Blume, and Mark Wumpkes.

The borehole sites were located 6 km

("lower site") and 13 km ("upper site") from the calving terminus. At the upper site, three holes were drilled to the bed, having depths ranging from 922–975 m. One of the holes at this site was enlarged to allow the lowering of probes and core and water sampling equipment to the bed. The results of this work are described in a paper by Humphrey and others (in process) and will be summarized in a later paragraph in conjunction with similar observations at the lower site. The lower site was below a topographic ramp in the glacier's surface and is thus in a heavily crevassed region. Two holes drilled 5 m apart at this site had depths of 526–527 m. One of these was enlarged for the lowering of probes, etc, and results from this are described below.

Water pressure measurements were made in all holes, with the records from one hole at the upper site and both holes at the lower site running with significant fluctuation from late July through the end of August, when recording equipment was pulled with the end of the surveying operation. Mean water levels at both sites were close to or at flotation. Strong diurnal fluctuations in pressure correlate with surface velocity variations at the upper site but are several hours out of phase at the lower site.

In addition to water pressure data, the physical character of the glacier bed was probed, using a penetrometer and corer. At the lower site, scratches on the penetrometer show a depth of 7 cm of debris, and mushrooming of the tip strongly implies that bedrock was reached. Turbidity, water sampling and vertical water velocity profiles in the borehole showed water to be flowing (approximately 1 cubic meter per hour) from the bed, into an englacial system. Fluidization of the basal debris was occurring up to a height of 2 m from the bed. At the upper site, approximately 50 cm of debris was detected. Analysis of the bending of a drill stem that was at the bed for 3 days implies an effective viscosity of the basal debris of 10^{10} poise.

S. CASCADE GLACIER MASS BALANCE

(R. Krimmel, ICP-USGS, Tacoma, WA)

S. Cascade mass balance for the 1987 balance year was very negative. The glacier average net balance, estimated by index station measurement, was −2.7 m water equivalent, which is the most negative since 1958. Precise surface altitude measurements in 1982 and 1987 show that the upper 70% of the glacier (that area above 1850 m) has lost an average of 4.0 m altitude in the last 5 years. The terminus continues to recede at about 15 m/year. A newly emerging tarn at the terminus was about 0.5 hectares in area by the end of the 1987 melt season.

COLUMBIA GLACIER PROJECT SUMMARY

(R. Krimmel, ICP-USGS, Tacoma, WA)

The Columbia Glacier continued its drastic retreat with an 800 m reduction in length in 1986. In July and August of 1987 INSTAAR, CalTech, and the USGS measured velocity, basal water pressure, and meteorological parameters for a zone of glacier above that influenced by the ocean tide. Distance was measured to two reflectors, separated longitudinally by 7 km, every 10 minutes. Basal water pressure was measured in boreholes at the reflectors. Ice ablation, solar radiation, rainfall, air temperature, wind speed and direction, barometric pressure, Kadin Lake stage, and stage of a nearby river were also measured.

GEOPHYSICS PROGRAM, UNIVERSITY OF WASHINGTON

CALCULATION OF BASAL SLIDING

(M. Balise, Geophysics, UW, Seattle, WA)

A systematic theoretical study of the relationship between variations in velocity at the surface and bed of a glacier has been expanded to include realistic non-linear power law rheology. Methods form geophysical inverse theory have been used to handle the unstable problem of calculating basal velocity from surface velocity measurements. Application to measurements from the mini-surges of Variegated Glacier show that amplitude of velocity changes at the bed was much larger than at the surface. Basal uplift by cavity formation may have happened, but cannot be proven.

STRUCTURE OF ICE STRAINED BY THE SURGE OF VARIEGATED GLACIER

(Tad Pfeffer, Geophysics, UW, Seattle, WA)

A structural study of the terminal lobe of Variegated Glacier after its surge discovered a transverse bubble layering and a pervasive set of longitudinal cracks which define two distinct foliations developed by the last surge. Extensive kinematic measurements during the surge and finite element modeling define the pattern of strain rate and finite strain repsonsible for the two foliations. Neither is related to accumulated finite compressive strain, but are instead related to very high strain rates.

STREAM DISCHARGES FROM ALASKA RANGE GLACIERS

(C.F. Raymond, Geophysics, UW, Seattle, WA, collaborative with W.D. Harrison, Geophysical Institute, UA)

In order to document changes in stream discharges associated with changes in basal sliding, we are recording stream stage, water conductivity, and turbidity every half hour over nearly full melt seasons from Fels and Black Rapids Glaciers in the Alaska Range. Information about the seasonal pattern,

characteristic weather-induced events, isolated turbidity events, and a strong diurnal cycle give information about properties of the basal hydraulic system. The stream events are in all cases correlated with changes in velocity and strain rate on the glaciers (observed by Will Harrison) and have characteristics that show some similarities but distinct differences in comparison to the pre-surge "mini-surge" sequences of Variegated Glacier.

BOUDINAGE IN ICE

(J. Cunningham, Geophysics, UW, Seattle, WA)

The potential for boudinage of vertically compressed stratigraphic layering in ice sheets has been examined, based on the theory of boudinage in non-Newtonian materials (R.B. Smith). If there are short scale variations in shiftness for example, caused by differences in impurities or texture, then there could be non-homogeneous straining of layers and disruption of stratigraphic sequences. Preliminary assessment of avaiable information about rheological variation in ice cores and expected finite vertical strain in old ice at depth indicate that initial variations in layer thickness may be amplified by more than an order of magnitude at a horizontal scale of about five times the layer thickness.

TIME SCALE FOR ADVANCE AND RETREAT OF GLACIERS

(C. Raymond, E. Waddington, M. Schwitter, Geophysics Program, UW, Seattle, WA)

The times required for a glacier to fully adjust to a climate change appear on theoretical grounds to be controlled by the time required to change its volume at the rate allowed by the new mass balance. The volume change is related to the longitudinal profile in ice thickness change and in particular, how the large changes near the terminus decay back up glacier to low values in the accumulation area. This decay pattern is being quantitatively investigated using existing data from a number of glaciers in the North American Cordillera and the Alps.

BASAL HYDRAULICS OF SOUTH CASCADE GLACIER, WA

(Andrew G. Fountain, ICP-USGS, Tacoma, WA)

During the summer of 1987, 18 boreholes were drilled to the bed of South Cascade Glacier. Eleven holes connected with the sub-glacial hydraulic system and 10 were monitored using pressure transducers. Also dye-tracers were injected into crevasses and boreholes to determine travel-time of the water and character of the system. The three major streams that emptied the glacier were monitored for discharge, conductivity and in one case, turbidity. Preliminary results indicate that the boreholes do not connect directly to conduits or cavities at the bed. Dye injections showed rapid travel times indicating that passage-ways do exit. Taken together these results suggest a basal flow model that combines features of a conduit system and less permeable media.

OUTBURST FLOODS OF MT RAINIER

(Carolyn Driedger, D-USGS and Andrew Fountain, ICP-USGS)

A study was initiated in 1987 to examine the causes and results of outburst floods on Mt Rainier National Park in Washington State. These intermittent floods have plagued the park since its inception by destroying road and trail bridges, and overrunning camp and picnic grounds. These floods are also linked to and may cause debris flows that do much of the damage. The project entails monitoring two streams from glaciers that have shown a history of floods and one stream that has not shown any outburst floods as a control. No floods were measured during the summer of 1987 on the selected streams, however an unmonitored stream had four large floods. The project will continue in the summer of 1988.

ICE MOTION SURVEY AT AGASSIZ ICE CAP, ELLESMERE ISLAND, ARCTIC CANADA

(E.D. Waddington and Magnus M. Magnusson, Geophysics Program, UW, Seattle, WA)

A strain network of 110 markers was established in May 1987 enclosing the dome on which Polar Continental Shelf Project and Geological Survey of Canada have drilled three coreholes to bedrock. The strain net also encloses about 5 km of the flowline through a fourth corehole located about 1 km off the dome. The expected strain rates and velocities are small (10^{-4} yr^{-1} and 2 m yr^{-1} respectively); a topographic map is in preparation based on the initial survey. Following the resurvey in 1989, velocities and strain rates will be determined. These data will provide boundary conditions for detailed flow calculations required to derive details of the climate signal from the corehole off the dome. In addition, the data set will permit testing of finite element ice flow models.

MICROCLIMATE STUDIES AT AGASSIZ ICE CAP, ELLESMERE ISLAND, ARCTIC CANADA

(E.D. Waddington and Magnus M. Magnusson, Geophysics Program, UW, Seattle, WA)

Temperatures measured by David Fisher of Geological Survey of Canada in three boreholes on and near a dome at Agassiz Ice Cap, Ellesmere Island, Arctic Canada, differ by several degrees at 10 m depth, although the site is in a cold dry snow zone, and the surface slopes and aspect, mass balance, albedo and melt percent are comparable, or should create negligible differences in firn temperature at the three sites. Inversion conditions may contribute to the differences, but are unlikely to explain the effect completely. Windier conditions on the dome itself are thought by Fisher to increase the firn temperature there. Viscous heating of air

pumped through the porous firn in response to turbulent pressure fluctuations at the snow surface can warm the firn. Therefore, to delineate the area of anomalous temperatures, 10-m temperatures were measured on a 5 km line of 12 sites crossing the dome. Temperatures continued to decrease with lowering elevation beyond the zone of known wind scouring, and the maximum 10-m temperature is not located at the summit. Initial experiments to measure the turbulent power spectrum of the wind were carried out.

USA - ECUADOR

PROGLACIAL STREAM ELECTROCHEMISTRY, COTOPAXI VOLCANO, ECUADOR
(R.C. Metcalf, MCR Scientific)
pH, conductivity, and water temperature profiles were measured in July 1987 for two proglacial streams on the northern slopes of Cotopaxi, a heavily glaciated volcano in Ecuador. The two streams draining glaciers closest to the east and west of the Jose Rivás Hut were sampled at 4900–4700 m and 4750–4400 m elevation, from their termini to 400 m downstream. Despite the presence of sufficient fumarolic emissions to asphyxiate several climbers recently in the summit crater, ice melt from these glaciers has among the lowest solute contents yet sampled outside the polar regions. The resulting low magnitude stream conductivity signal offers hope for future attempts to monitor volcanic activity by continuous stream conductivity measurements, in concert with standard geophysical techniques. The nearby town of Latacunga (pop. 29,000) has been devastated by Cotopaxi's eruptions three times, most recently in 1877. Cotopaxi's glaciers have retreated rapidly since 1976, with hazardous implications for inexperienced climbers expecting an easy snow slog to the 5897 m summit.

Andrew Fountain

ANNUAL GENERAL MEETING 1987

MINUTES OF THE ANNUAL GENERAL MEETING OF THE INTERNATIONAL GLACIOLOGICAL SOCIETY

11th September in the Lecture Room of Weserforum, Columbus Center, Bremerhaven, Federal Republic of Germany

The President, Dr Hans Röthlisberger, was in the Chair. 43 members from 15 countries were present.

1. The Minutes of the 1986 Annual General Meeting, published in *ICE* No.82, p.19-20, were approved and signed by the Chairman.

2. The President gave his report for 1986-87. The last AGM was appropriately held in Cambridge, England, after celebrating the 50th Anniversary of the Society. Now we are assembled once more outside Great Britain in accordance with a gradually developed tradition to give IGS members from other areas a chance to attend the meeting in greater numbers. During the 51st year of the Society its main activities have been carried on along the same lines as given in detail in last year's report, so that it is sufficient to refer briefly to the changes.

Our membership has increased from around 830 to 905. Library subscribers number 570, an increase of 20. (It seems that the Golden Anniversary has done us some good.) Saudi Arabia is to be added to the list of countries with members, because one of our U.S. members is now working at a University there.

Three issues of the *Journal* were published during the current year. Publication time (that is the time between receipt of the revised manuscript and publication date) has now dropped below the target of 8 months, i.e. to 6.7 and 7.2 months for Nos.113 and 114, respectively – an average of 7 months. These figures do not include the time spent on work with the *original* submission on refereeing and editing revisions; it is important for editors, reviewers and authors alike to be aware that it may be their fault if it takes a long time from the submission of the original manuscript to the publication date.

As the back-log of old articles is now cleared away, more pages can be devoted to new articles, thanks to reduced costs and the productive staff in Cambridge. Longer articles can be considered for publication. The Society depends now on the members and authors from outside to send in new manuscripts. Please help to spread the news that the *Journal* has become a "fast publication".

Steps have also been undertaken to improve the printing. Future issues should show the same quality as the *Annals*, as the Secretary General has arranged for the *Journal* to be printed by Lockem Druk in the Netherlands, beginning with No.115 and the special anniversary issue. Updating the equipment for producing the *Journal* and *Annals* will also help to improve the printing quality further.

Volume 9 of the *Annals*, the Proceedings of the Second Symposium on Remote Sensing in Glaciology held in Cambridge, was mailed only two weeks after the 9-month deadline that is the target for *Annals* volumes. Eric Richardson was the House Editor for Vol.9, as he had been for Vol.8. He fell seriously ill shortly after the Symposium and died a few months later. Our Secretary General lost her husband, and numerous people from within the Society and closely connected to it, mourned over the loss of a dear friend who had, before becoming one of the House Editors, for many years contributed behind the scenes to the smooth operation of the Society's business. Thanks to Hilda Richardson, who helped during the latter stages of Vol.9, Dr Ray Adie, House Editor of the *Journal*, Rosemary Graham, the new House Editor for *Annals*, and several others, Vol.9 came out almost on time. The option to include illustrations in colour was offered for the first time. Authors of the respective articles have expressed their great satisfaction with the quality of the printing.

ICE edited by the Secretary General and Newsletters from her went out regularly from the Headquarter office. In the year 1987, all three issues of *ICE* have been prepared on schedule – the third issue is in press and will appear in your mailbox before the end of the year.

As part of last year's Anniversary Celebrations, the 51st year began with the Golden Jubilee Tour, the Post-Symposium excursion after Cambridge. The event is thoroughly described by Lorne Gold in *ICE* No.82, amply illustrated with photographs by him and K. Steffen. Unfortunately the 50th Anniversary Celebration of the Swiss Federal Institute for Snow and Avalanche Research and an International Symposium on Avalanche Formation, Movement and Effects which was co-sponsored by IGS, took place from 14–19 September in Davos during the same week as the IGS Tour, owing to tight schedules of important participants outside the Glaciological Community.

An IGS Symposium on Ice-Core Analysis was held in Bern, Switzerland, 30 March – 3 April, including the Annual Banquet on 2 April. An illustrated report of these events had already been published by the secretary General in *ICE* No.84. During the current week IGS has co-sponsored FISAG, the Fourth International Symposium on Antarctic Glaciology of the Scientific Committee on Antarctic Research (SCAR) here in Bremerhaven.

For future IGS events, I refer to the circulars already received by the members of IGS, namely the second circulars for the Symposium on Ice Dynamics, 14–20 February 1988 in Hobart, Australia, and for the Symposium on Snow and Glacier Research Relating to Human Living Conditions 4–9 September in Lom, Norway. A first circular went out on the Symposium on Ice and Climate to be held 21–25 August 1989 in Seattle, WA, U.S.A. Further meetings are in preparation.

The clerical and secretarial staff consisted of Pat Lander, Beverley Baker, Linda Gorman, Sally Stonehouse and Mary Parker (all part-time, except Linda). As House Editors we now have Ray Adie for the *Journal*, Rosemary Graham for *Annals* and Sylva Gethin for reference editing.

I want to thank the Secretary General and her staff for the good work they did during the year. Further thanks go to the Scientific Editors and the Referees, and to all those who have acted through the year in the Council and on Committees of the Society. With that I close the President's report.

The retiring President, Prof. H. Röthlisberger, who had three years before in his acceptance spech in Sapporo referred to the not-too-distant future, when presidents will no longer be older than the Society itself, invited the incoming President, Dr S. Colbeck, to address the meeting.

3. The Treasurer, Dr J.A. Heap, submitted a report:

"I regret that, once again, I cannot be with you to present my report.

The general state of the Society's finances is good. As you will see from the audited accounts for 1986, there was a surplus on the General Income and Expenditure Account of £5,272 following a deficit in 1982 of £2,120 and surpluses in the three years 1983-85 of £6,136, £3,831 and £4,785 respectively.

Over the last five years the Accumulated Fund, an indicator of the general state of the Society's finances, has moved from showing a deficit of £13,251 in 1982 to a surplus of £13,155 in 1986. The serious situation that faced the Society in 1982 has now been rectified. The key to maintaining this situation involves a cautious attitude towards raising income from members and libraries and continuing efforts to increase the productivity of the Society through new technology.

These accounts show no marked changes over the pattern which has developed during the previous three years. The Society's operation as a publisher remains viable, as long as every effort is made to keep costs under tight control.

Lastly, I recommend that the Council adopt the audited accounts for 1986."

4. Election of Auditors for the 1987 accounts. B. Stauffer proposed and K. Hutter seconded that Messrs Peters, Elworthy and Moore of Cambridge be elected auditors for the 1987 accounts. This was carried unanimously.

5. Elections to the Council 1987-90. After circulation to all members of the Society of the Council's suggested list of nominees, no further nominations had been received The following people were therefore elected unanimously:

President:	S.C. Colbeck
Vice-Presidents (2)	G.K.C. Clarke
	P. Schwerdtfeger
Elective Members (4)	C. Hammer
	M. Kuhn
	E.L. Lewis
	H.J. Zwally

BRITISH BRANCH MEETING

24–25 September 1987, Edinburgh

The Annual Conference of the British Branch took place in the Pollock Halls of Residence, Edinburgh on 24–25 September 1987. The meeting was organised by members of the Geography and Geology Departments of the University, and included a field trip up Arthur's Seat and into the local Grampian Hills. Hal Lister enlivened the Annual Dinner with an impromptu witty speech.

At the A.G.M. of the British Branch, the following elections were made:

President	1987-89	Dr J.G. Paren, B.A.S., Cambridge
Vice President	1987-89	Prof. G.S. Boulton, Geology, Edinburgh
Secretary/Treasurer	1987-89	E.W. Wolff, B.A.S. Cambridge

The retiring President, Dr D.N. Collins (Manchester) and Secretary/Treasurer, Dr J.A. Dowdeswell (Aberystwyth) were thanked for their contributions to the life of the British Branch. The treasurer reported a healthy bank balance and David Collins agreed to host the 1988 meeting.

The conference covered many aspects of

research in glaciology: dynamics, ice core studies, modelling, glacial geomorphology, hydrology and remote sensing. The meeting included a free-ranging discussion led by Prof. G.S. Boulton on the advantages of focussing U.K. glaciological research into a major national programme, preferably in the Antarctic.

The following papers were presented:

A. Jenkins and C.S.M. Doake (B.A.S.)
Flowline measurements on the Ronne Ice Shelf, Antarctica.

A.M. Smith (B.A.S.)
Tiltmeter observations from the Doake Ice Rumples, Antarctica.

D. Mantripp (B.A.S.)
Recent developments in Antarctic satellite imagery.

D.G. Vaughan (B.A.S.)
Futher investigations of the grounding zone of the Rutford Ice Stream.

R.M. Frolich (B.A.S.)
Force balance of the Rutford Ice Stream, Antarctica: relative importance of lateral and vertical shear stresses.

D.A. Peel (B.A.S.)
Ice core and climate in the Antarctic Peninsula.

D.E. Sugden and T. Payne (Edinburgh)
Modelling ice sheet behaviour in the Antarctic Peninsula.

A. Russell (Aberdeen)
Geomorphological effects of a recent Jökulhlaup in West Greenalnd.

E.M. Morris (B.A.S.)
Turbulent transfer over snow and ice surfaces.

P.W.F. Gribbon (St Andrews)
Thermoconvective flow in cryoconite holes.

R. Howe (Birmingham)
Observations of the ice $1h - ice\ XI$ transition by dielectric measurements.

R. Souchez (Brussels)
Freezing rate determination from the isotopic composition of ice.

J.C. Moore (B.A.S.)
Dielectric variability of a 130 m ice core: implications for radio-echo sounding.

R. Mulvaney, A.P. Reid and D.A. Peel (B.A.S.)
High resolution anion profile of an ice core from Dolleman Island, Antarctica.

E. Wolff and R. Mulvaney (B.A.S.)
Sulphuric acid at triple-grain boundaries in Antarctic ice.

J. Raper (Queen Mary College, London)
Landform/sediment relationships in British glacial valleys: the case of the Taff, S. Wales.

W.B. Whalley (Belfast), J.E. Gordon (Nature Conservancy) and A.F. Gellatly (Plymouth Polytech.)
Plateau ice caps in North Norway: their present state and significance.

D. van der Wateren (Amsterdam)
Geological and glaciological controls on the formation of push moraines in western Europe.

J. Hart (East Anglia)
Glaciotectonic deformation.

C.R. Fenn, S. Fraser-clark and P.J. Gogarty (Worcester Higher Education College)
Overflow and outburst events from Bas Glacier d'Arolla, 15–18 July 1987.

J. Warburton (Southampton)
Proglaical river channel change in response to a glacial flood event, Bas Glacier d'Arolla.

J. Maizels (Aberdeen)
A field test of palaeohydraulic equations based on sediment transport thresholds in active meltwater streams.

D. Collins (Manchester)
Climatic variations, glacier mass balance and runoff from alpine glaciers in the Swiss Alps 1920–1985.

R. J. Braithwaite (Geological Survey, Greenland)
Recent studies of glacier hydrology in Greenland.

G.S. Boulton and R.C.A. Hindmarsh (Edinburgh)
Subglacial channel development on soft beds, and the origin of tunnel valleys.

The 1988 Branch Meeting will be held in Manchester, and be organised by Dr D.N. Collins. Further details will be circulated in 1988.

J.G. Paren

NORTHEAST NORTH AMERICAN BRANCH MEETING

27–29 March 1987, Lake Placid, NY, U.S.A.

The NENA IGS held their biennial gathering along the shores of frozen Lake Placid, the site of the 1980 Olympics, in the heart of the Adirondack Mountains of northern New York State, U.S.A.

The meeting had two sessions: Friday night (8.30–11.00 pm); Saturday morning (8.30–11.30 am) and consisted of 17 papers on a diverse variety of topics. Saturday afternoon was open and roughly half of the participants took advantage of the warm spring skiing conditions. The other half relaxed in the comfortable cabins of the resort or visited the village of Lake Placid including the Olympic sports facilities. On Saturday evening, a cocktail hour including a hosted bar and table of appetizers substituted for dinner for many of the participants. Later in the evening Steve Ackley (CCREL) narrated a video tape showing the lifestyle aboard the funded and comfortable German icebreaker *Polarstern* during the June–September 1986 Antarctic

expedition into the Weddell Sea. Cameron Wake (Laurier University) gave a stunning slide presentation of the Karakoram Mountains of Pakistan. The photographs were taken during the 1986 Pakistan Canada – Karakoram Expedition.

Steve Ackley of CRREL made all the arrangements for the conference facilities including lodging, wrote and mailed the announcements as well as put together the conference schedule. The flexibility shown by the presider and participants resulted in a smooth and informal meeting enjoyed by everyone.

The next meeting will be held in two years at an Eastern Canada site. Details will follow as the meeting approaches.

MEETING AGENDA

Friday evening

G. Young (IWD/EC)
Ablation and movement studies on a Karakoram Glacier.

C. Wake (Laurier Univ)
An overview of snow accumulation studies in the central Karakoram.

J. Kasper (Laurier Univ)
Ice margin behavior during the filling and draining of an ice-dammed lake.

A. Fountain (ICP-USGS)
Basal hydrology of South Cascade Glacier.

M. Spenser (U. New Hampshire)
Chemistry of fresh snow from Mt Everest.

R. Bindschadler (NASA/G)
West Antarctic glaciology and remote sensing applications.

L. Arsenault (CRRS)
Remote sensing studies on snow and ice.

W. Hibler (Dartmouth C.)
Arctic ice – ocean model.

Saturday morning

E. Whalley (NRC)
The O–D distance in ice I.

E. Whalley (NRC)
Recent work on high density amorphous ice.

S. Colbeck (CRREL)
Ski friction.

L. Gold
Habbakuk – building ships of ice.

W. Nixon (Dartmouth C.)
Fracture toughness of ice.

W. Nixon (Dartmouth C.)
Splitting of icebergs.

P. McComber and J. Druez (U. Quebec C)
An analysis of some ice accretion measurements on HydroQuebec test line at Mt Valin.

H. Shen (Clarkson C.)
On wave-generated ice floe collisions.

H.T. Shen (Clarkson C.)
Enrichment of sediment concentration in coastal ice covers.

Andrew Fountain

JOURNAL OF GLACIOLOGY

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

J E HAY AND B B FITZHARRIS:
A comparison of the energy-balance and bulk aerodynamic approaches to estimating glacier melt.

C F RAYMOND AND W D HARRISON:
Evolution of Variegated Glacier, Alaska, U.S.A., prior to its surge.

H CONWAY AND J ABRAHAMSON:
Snow-slope stability – a probabilistic approach.

B L HANSEN AND N S GUNDESTRUP:
Resurvey of bore hole at Dye 3, south Greenland.

M POURCHET, J F PINGLOT, L REYNAUD AND G HOLDSWORTH:
Identification of Chernobyl fall-out as a new reference level in Northern Hemisphere glaciers.

P SCHAERER:
The yield of avalanche snow at Rogers Pass, Canada.

D K PEROVICH AND A HIRAI:
Microcomputer-based image-processing system.

L A RASMUSSEN:
Bed topography and mass-balance distribution of Columbia Glacier, Alaska, U.S.A., determined from sequential aerial photography.

S Z SEABERG, J Z SEABERG, R L HOOKE AND D W WIBERG:
Character of the englacial and subglacial drainage system in the lower part of the ablation area of Storglaciären, Sweden, as revealed by dye-trace studies.

R L HOOKE, S B MILLER AND J KOHLER:
Character of the englacial and subglacial drainage system in the upper part of the ablation area of Storglaciären, Sweden.

ANNALS OF GLACIOLOGY

The following papers have been published in Volume 10, Proceedings of the Symposium on Ice Core Analysis held at the University of Bern, Switzerland, 30 March – 3 April 1987.

R B ALLEY AND B R KOCI:
Ice-core analysis at Site A, Greenland: preliminary results.

C F BOUTRON, C C PATTERSON, C LORIUS, V N PETROV AND N I BARKOV:

Atmospheric lead in Antarctic ice during the last climatic cycle.

H B CLAUSEN, N S GUNDESTRUP, S J JOHNSEN, R BINDSCHADLER AND J ZWALLY:
Glaciological investigations in the Crête area, central Greenland: a search for a new deep-drilling site.

H B CLAUSEN AND C U HAMMER:
The Laki and Tambora eruptions as revealed in Greenland ice cores from 11 locations.

H B CLAUSEN AND B STAUFFER:
Analyses of two ice cores drilled at the ice-sheet margin in West Greenland.

D M ETHERIDGE, G I PEARMAN AND F DE SILVA:
Atmospheric trace-gas variations as revealed by air trapped in an ice core from Law Dome, Antarctica.

D A FISHER AND R M KOERNER:
The effects of wind on $\delta(^{18}O)$ and accumulation give an inferred record of seasonal δ amplitude from the Agassiz Ice Cap, Ellesmere Island, Canada.

Y FUJII AND O WATANABE:
Microparticle concentration and electrical conductivity of a 700 m ice core from Mizuho Station, Antarctica.

W GRAF, O REINWARTH, H MOSER AND W STICHLER:
Investigation of the ^{18}O content of a 100 m ice core from the Ronne Ice Shelf, Antarctica.

W HAEBERLI, H GAGGELER, U BALTENSPERGER, D JOST AND U SCHOTTERER:
The signal from the Chernobyl accident in high-altitude firn areas of the Swiss Alps.

A HIGASHI, M NAKAWO, H NARITA, Y FUJII, F NISHIO AND O WATANABE:
Preliminary results of analyses of 700 m ice cores retrieved at Mizuho Station, Antarctica.

G HOLDSWORTH, H R KROUSE AND E PEAKE:
Trace-acid ion content of shallow snow and ice cores from mountain sites in western Canada.

M O JEFFRIES AND H R KROUSE:
Salinity and isotope analysis of some multi-year landfast sea-ice cores, northern Ellesmere Island, Canada.

M O JEFFRIES, W M SACKINGER, H R KROUSE AND H V SERSON:
Water circulation and ice accretion beneath Ward Hunt Ice Shelf (northern Ellesmere Island, Canada), deduced from salinity and isotope analysis of ice cores.

M A KHALIL AND R A RASMUSSEN:
Nitrous oxide: trends and global mass balance over the last 3000 years.

S KIRCHNER AND R J DELMAS:
A 1000 year glaciochemical study at the South Pole.

R M KOERNER, J C BOURGEOIS AND D A FISHER:
Pollen analysis and discussion of time-scales in Canadian ice cores.

M A LANGE:
A computer-controlled system for ice-fabric analysis on a Rigsby stage.

M A LANGE:
Basic properties of Antarctic sea ice as revealed by textural analysis of ice cores.

C C LANGWAY, JR, H B CLAUSEN AND C U HAMMER:
An inter-hemispheric volcanic time-marker in ice cores from Greenland and Antarctica.

C C LANGWAY, JR, H SHOJI AND N AZUMA:
Crystal size and orientation patterns in the Wisconsin-age ice from Dye 3, Greenland.

M LEGRAND AND R J DELMAS:
Soluble impurities in four Antarctic ice cores over the last 30 000 years.

R MULVANEY AND D A PEEL:
Anions and cations in ice cores from Dolleman Island and the Palmer Land plateau, Antarctic Peninsula.

M NAKAWO, M NAGOSHI AND S MAE:
A stratigraphic record of an ice core from the Yamato Mountains meteorite ice field, Antarctica.

D A PEEL, R MULVANEY AND B M DAVISON:
Stable-isotope / air-temperature relationships in ice cores from Dolleman Island and the Palmer Land plateau, Antarctic Peninsula.

P PIMIENTA, P DUVAL AND V Ya LIPENKOV:
Mechanical behavior of ice along the 2040 m Vostok core, Antarctica.

J SCHWANDER, B STAUFFER AND A SIGG:
Air mixing in firn and the age of the air at pore close-off.

H SHOJI AND C C LANGWAY, JR:
Flow-law parameters of the Dye 3, Greenland, deep ice core.

U SIEGENTHALER, H FRIEDLI, H LOETSCHER, E MOOR, A NEFTEL, H OESCHGER AND B STAUFFER:
Stable-isotope ratios and concentration of CO_2 in air from polar ice cores.

A SIGG AND A NEFTEL:
Seasonal variations in hydrogen peroxide in polar ice cores.

R SOUCHEZ, R LORRAIN, J L TISON AND J JOUZEL:
Co-isotopic signature of two mechanisms of basal-ice formation in Arctic outlet glaciers.

T STAFFELBACH, B STAUFFER AND H OESCHGER:
A detailed analysis of the rapid changes in ice-core parameters during the last ice age.

J P STEFFENSEN:
Analysis of the seasonal variation in dust, Cl^-, NO_3^-, and SO_4^{2-} in two central Greenland firn cores.

L G THOMPSON, WU XIAOLING, E MOSLEY-THOMPSON AND XIE ZICHU:
Climatic records from the Dunde ice cap, China.

D WAGENBACH, K O MUNNICH, U SCHOTTERER AND H OESCHGER:
The anthropogenic impact on snow chemistry at Colle Gnifetti, Swiss Alps.

O WATANABE, Y FUJII AND K SATOW:
Depositional regime of the katabatic slope from Mizuho plateau to the coast, East Antarctica.

E W WOLFF AND D A PEEL:
Concentrations of cadmium, copper, lead and zinc in snow from near Dye 3 in south Greenland.

GLACIOLOGICAL DIARY

** IGS Symposia
* Co-sponsored by IGS

1988

21-25 March
Thirteenth General Assembly of the European Geophysical Society, Bologna, Italy. (Dr A.K. Richter, MPI für Aeronomie, D-3411 Katlenburg-Lindau, Federal Republic of Germany)

11-15 April
Sixth International Congress on Numerical methods in geomechanics, Innsbruck, Austria. (G.A. Swoboda, University of Innsbruck, Technikerstr. 13, A-6020 Innsbruck, Austria)

24-26 May
Workshop on Ground probing radar, Geological Survey of Canada, Ottawa, Canada. (Leonard S. Collett, Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, Canada K1A 0E8)

4-8 July
Sixth International Congress on Protection of habitat from floods, debris flows and avalanches, Graz, Styria, Austria. (INTERPRAEVENT 1988, Postfach 43, A-8010 Graz, Austria)

25 July - 5 August
Glaciology and glacier hydrology – field training course, Place Glacier, coastal mountains of British Columbia. To be given by Dr Gunnar Ostrem from the Norwegian Water Resources and Energy Administration, presented in association with the National Hydrology Research Institute, Saskatoon, Saskatchewan and Simon Fraser University, British Columbia. (Freddie Frankling, Geotechnical Science Laboratories, Dept. of Geography, Carleton University, Ottawa, Ontario, Canada K1S 5B6)

2-5 August
Fifth International Conference on Permafrost, Trondheim, Norway. (c/o The Norwegian Institute of Technology, Studies Administration, N-7034 Trondheim-NTH, Norway.)

2 August
(in conjunction with the above conference) Workshop on Permafrost data and information. (R.G. Barry, Director, WDC-A for Glaciology, Boulder, Colorado, U.S.A.)

23-27 August
Ninth International Symposium on Ice, Hokkaido University, Sapporo, Japan. (Hiroshi Saeki, Department of Civil Engineering, Hokkaido University, Kita-13, Nishi-8, Kita-ku, Sapporo, 060, Japan)

4-9 September
** Symposium on Snow and glacier research relating to human living conditions. Lom, Norway. (Secretary General, IGS, Lensfield Road, Cambridge CB2 1ER, UK)

13-16 September
Eighth International Conference on Geoscience and remote sensing, Edinburgh, Scotland. (Dr J.A.T. Young, Department of Geography, University of Edinburgh, Drummond Street, Edinburgh EH8 9XP, Scotland, UK)

12-15 October
International Snow Science Workshop, Whistler, Canada. (I.S.S.W. '88 Committee, P.O. Box 67, Whistler, B.C., Canada V0N 1B0)

12-15 October
Workshop on Ice core drilling, Grenoble, France. (Mrs D. Beaudoing, Laboratoire de Glaciologie et Géophysique de l'Environnement, B.P. 96, 38402 St Martin d'Hères Cedex, France)

24-26 October
Fiftieth Anniversary Scientific Meeting of the Japanese Society of Snow and Ice, Tokyo, Japan. (Dr Kou Kusunoki, Committee for 1988 Meeting, Japanese Society of Snow and Ice, 308 Bancho Heim, 1-2, Nibancho, Chiyoda-ku, Tokyo 102, Japan)

1989

13-17 March
Fourteenth General Assembly of the European Geophysical Society, Barcelona, Spain. (E.G.S. Office, c/o MPI für Aeronomie, D-3411 Katlenburg-Lindau, Federal Republic of Germany)

20-23 March
Fifth Conference of the European Union of Geosciences, Strasbourg, France. (Jan Høst, Geological Survey of Norway, P.O. Box 3006 – Lade, N – 7002 Trondheim, Norway)

9-19 July
28th International Geological Congress, Washington, D.C., U.S.A. (B.B. Hanshaw, Secretary General, 28th International Geological Congress, P.O. Box 1001, Herndon, VA 22070-1001, U.S.A.)

21-25 August
23rd IAHR Biennial Congress, Ottawa, Ontario, Canada. (T.M. Dick, NWRI, CCIW, P.O.Box 5050, 867 Lakeshore Road, Burlington, Ontario, L7R 4A6, Canada)

21-25 August
** Symposium on Ice and Climate, Seattle, Washington, U.S.A. (Secretary General, IGS, Lensfield Road, Cambridge CB2 1ER, UK)

1990

August
** Symposium on Ice–Ocean Dynamics and Mechanics, Hanover, N.H., U.S.A. (Secretary General, IGS, Lensfield Road, Cambridge CB2 1ER, UK)

NEWS

APPOINTMENTS

Wilfried Haeberli has now taken over Hans Röthlisberger's position in VAW, ETH, Zürich, Switzerland.

Peter Wadhams has been appointed Director of the Scott Polar Research Institute, University of Cambridge, England.

NEW MEMBERS

Julie Brigham-Grette, Dept. of Geology and Geography, University of Massachusetts, Amherst, MA 01003, U.S.A.

Barbara A. Burns, Alfred-Wegener-Institut, Columbus Center, 2850 Bremerhaven, Federal Republic of Germany.

Chris D. Clark, Grant Institute of Geology, University of Edinburgh, West Mains Road, Edinburgh EH9 3JW, U.K.

David M. Cole, U.S. Army CRREL, 72 Lyme Road, Hanover, NH 03755, U.S.A.

Marianne Cromack, Department of Geography, University College of Wales, Llandinam Building, Aberystwyth, Dyfed SY23 3DB, U.K.

Peter L. Croot, 82 Passmore Hill, Dunedin, New Zealand.

M.D. Garbutt, Department of Geography, University of Cambridge, Downing Place, Cambridge CB2 3EN, U.K.

Mikhail G. Grosswald, Institute of Geography, U.S.S.R. Academy of Sciences, 29 Staromonetny Street, 109017 Moscow, U.S.S.R.

N.W.J. Hazelton, 17 Edward Street, Rochester, Victoria 3561, Australia.

Josef Hopf, Wildbach-und Lawinenverbauung, Liebeneggstrasse 11, 6010 Innsbruck, Austria.

Philippe Huybrechts, J. Wytsmanstraat 44/9, 1050 Brussels, Belgium.

Sepp Kipfstuhl, Frettenshofen 18, 8437 Freystadt, Federal Republic of Germany.

Anne J. Letréguilly, Obere Bürger 20, 2850 Bremerhaven, Federal Republic of Germany.

William W. Locke, Department of Earth Sciences, Montana State University, Bozeman, Montana 59717, U.S.A.

Baerbel K. Lucchitta, U.S. Geological Survey, 2255 North Gemini Drive, Flagstaff, AZ 86001, U.S.A.

George Musil, Glaciology Section, Earth Sciences Building, University of Melbourne, Parkville, Victoria 3052, Australia.

Veijo A. Pohjola, Karlsrogatan 15 (209), 752 38 Uppsala, Sweden.

Catherine B. Ritz, Laboratoire de Glaciologie et Géophysique de l'Environnement, BP 96, 38402 St Martin d'Hères Cédex, France.

Horst Schaffhauser, Am Schiessbühel 20, 8112 Gratwein, Austria.

Franz Thyssen, Am Haug 62, 4405 Nottuln, Federal Republic of Germany.

INTERNATIONAL GLACIOLOGICAL SOCIETY

Founded by G. Seligman

c/o SCOTT POLAR RESEARCH INSTITUTE, Lensfield Road, Cambridge CB2 1ER, England
Secretary General: H. Richardson

COUNCIL MEMBERS

			Date first elected to the Council (in present term of office)
PRESIDENT	S.C. Colbeck	1987-90	1984
VICE-PRESIDENTS	G.K.C. Clarke	1987-90	1987
	H. Kohnen	1985-88	1984
	P. Schwerdtfeger	1984-87	1984
IMMEDIATE PAST PRESIDENT	H. Röthlisberger	1987-90	1978
TREASURER	J.A. Heap	1986-89	1980
ELECTIVE MEMBERS	* K. Higuchi	1985-88	1985
	* C. Jaccard	1985-88	1985
	* Shi Yafeng	1985-88	1985
	* B. Wold	1985-88	1985
	* R. Hooke	1986-89	1986
	* N. Maeno	1986-89	1986
	* R. Perla	1986-89	1986
	* D. Sugden	1986-89	1986
	* C. Hammer	1987-90	1987
	M. Kuhn	1987-90	1987
	* E.L. Lewis	1987-90	1987
	* H.J. Zwally	1987-90	1987

* first term of service on the Council

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INTERNATIONAL GLACIOLOGICAL SOCIETY

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Editor: H. Richardson
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This news bulletin is issued to members of the International Glaciological Society and is published three times a year. Contributions should be sent to the Secretary General, International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, England.

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

Sterling £9.00

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