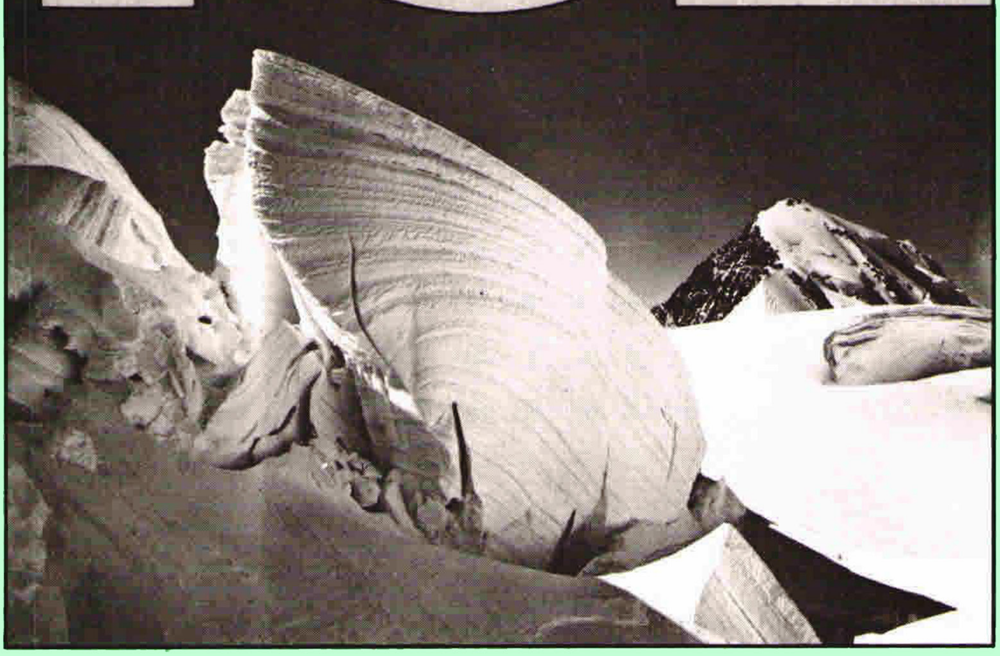
Number 98 1st Issue 1992

ICE



NEWS BULLETIN OF THE INTERNATIONAL GLACIOLOGICAL SOCIETY

Scientific Committee on
Antarctic Research (SCAR)

FIFTH INTERNATIONAL SYMPOSIUM ON ANTARCTIC GLACIOLOGY (VISAG)

Cambridge, UK
5-10 September 1993

Co-sponsored by:
International Glaciological Society (IGS)
International Commission on Snow and Ice (ICSI)

Proceedings to be published by the IGS in
ANNALS OF GLACIOLOGY Volume 20

ISSN 0019–1043

ICE

NEWS BULLLETIN OF THE INTERNATIONAL GLACIOLOGICAL SOCIETY

Number 98 1st issue 1992

CONTENTS

COVER PICTURE: Sérac on the Ghiacciaio del Lys, Monte Rosa, Italy. Photograph taken by Foto Guindani, Gressoney St. Jean, and used for a postcard for the participants at the VIth meeting of the Comitato Glaciologico Italiano in Gressoney, Valle d'Aosta, 26–28 September 1991.

ITALY

For abbreviations, see end of this report

Glacier fluctuations

(E. Armando, C. Smiraglia, G. Zanon, CGI)
A large sample group of the approximately 1400 Italian glaciers is monitored every year under the coordination of the Comitato Glaciologico Italiano (CGI) in Turin. CAI and CAI-SAT collaborate in this activity. Data on glacier snout fluctuations have been published in the *Bollettino del CGI* on a regular basis since 1925, and in *Geografia Fisica e Dinamica Quaternaria* since 1977. From 1967 onwards data on Italian glaciers have been published in *Fluctuations of Glaciers*, Vols I-V, of the Permanent Service on the Fluctuations of Glaciers (PSFG), now World Glacier Monitoring Service (WGMS).

The results of the last three years' monitoring are as follows:

Glaciers	*1988*	*1989*	*1990*
in retreat	92	106	123
in advance	26	11	9
stationary	13	5	9

After approximately 40 years' uninterrupted retreat, the Italian glaciers have been going through a period of modest advance since the mid-1960s, with the maximum number of advancing snouts recorded in 1980 (87% of glaciers with variations measured). This stage can be considered to have virtually come to an end by 1985, when a new period of strong retreat began, affecting every sector of the Italian Alps without exception.

GLACIER MASS BALANCE

Caresèr Glacier

(G. Zanon, DGUP)
The Caresèr Glacier is located on the south-eastern slope of the Ortles-Cevedale group (Central Alps), in the Noce-Adige Basin, and may be considered representative of the glaciated areas of the transitional belt between the continental-type Alpine climatic environment to the north of the massif, and the Mediterranean region to the south. With a current surface area of just under 4 km^2 the Caresèr is a mountain glacier (cirque). The glacial stream is dammed at an altitude of 2600 m, forming a reservoir of $16 \times 10^6 m^3$. Climatological data are now recorded by an automatic station set up in 1990 on the dam (F. Buffa, PAT SAPOI UI) and by a series of totalisers on the surface of the glacier itself.

Mass-balance research using direct glaciological measurements has been carried out since 1966–67. The mean balance between 1966–67 and 1990–91 was –580 mm Weq (ELA = 3215 m); however, whilst the balance was almost in equilibrium at –130 mm Weq (ELA = 3100 m) up to 1979–80, it became –1080 mm Weq (ELA = 3370 m) during the 1980s. The value of –1730 mm W eq (ELA = 3462 m) for 1990–91 was the largest negative number for the entire observation period.

The direct glaciological method was calibrated with good results by a comparison of aerial surveys effected in 1967, 1980 and 1990. A comparison between 1967 and 1990, the period of research on the balance, shows that the glacier area has decreased by 18%, with a loss in volume of $66.0630 \times 10^6 m^3$ Weq.

Data on Caresèr Glacier balance has been published in *Fluctuations of Glaciers* of the PSFG and WGMS, and in *Mass Balance Bulletin* of the WGMS.

Sforzellina Glacier

(C. Smiraglia, ISUUP)
The Sforzellina is a small cirque glacier (0.42 km^2) situated in the Gavia Valley (Ortles-Cevedale group). A mass-balance programme research using 20 ablation stakes was launched in 1986–87. The balance has always been negative, with a mean for the 1986–87/1989–90 period of –910 mm water equivalent. Surface speed measurements have also been effected, with values between 1.3 and 6.7 m a^{-1}. Thickness, evaluated using geoelectric surveys, turned out to be between 13 and 35 m.

Research programmes in other areas

A new research programme on the mass and hydrological balances of the Fontana Bianca Glacier (Val d'Ultimo, Ortles-Cevedale group) was launched in 1991–92 (P. Valentini, PAB UI PSV, in collaboration with G. Kaser of the Institut für Meteorologie und Geophysik of the University of Innsbruck). Accumulation and ablation surveys have been carried out since 1990 on the Forni Glacier (Ortles-Cevedale group), the largest Italian glacial system (13 km^2 surface area) (C. Smiraglia, ISUUP). Research on various parameters is also in progress on the Adamello and Brenta groups glaciers (CAI-SAT). A research programme is planned to begin in 1992 on the Ciardoney Glacier in the Gran Paradiso group (L. Mercalli, CGI) to be carried out in comparison with similar studies on one glacier on the French side of the group and one in the Pyrenees.

Glacial climatology

(S. Belloni, M. Pelfini, DSTUM; C. Smiraglia, ISUUP)
The pluviometric parameters of 42 meteorological stations in the Adda Basin between 1921 and 1970 were examined in detail (regimens, graphs indicating possible pluviometric developments, regimens of days of storms, seasonal rainfall polygons, distribution of accumulated frequencies of quantities per day, and days of consecutive rainfall or no rainfall).

Data on regimens for snow-cover thickness and snow permanence for 110 stations in Lombardy were analysed by computer.

Annual and seasonal temperatures, snowfall, and snow-cover permanence regimens were studied for certain sample stations in relation to interpretation of snout fluctuations of glaciers in the Italian Alps. In particular, concerning the Sondrio station, the delay between climatic changes and the response times of the Sforzellina and Dosegù Glaciers (Ortles-Cevedale group) were evaluated.

Environmental glaciology

(G. Rossi, CRIS SI ENEL)

The CRIS SI of the Venice ENEL has two separate scientific programmes in progress, mainly centred on climatic–environmental research in intensely glaciated Alpine areas. The first of these is studying the regimen of two basins in the Italian Alps, regarding the effects of short- and medium-term climatic fluctuations. One of these areas is the upper Valle della Mare (Cevedale group), where research, which has been in progress on the Caresèr Glacier for over 25 years in collaboration with the CGI and the DGUP, will be joined during 1992 by similar surveys on the La Mare Glacier. The other area includes the glacial systems at the head of the Gressoney Valley (Monte Rosa group), i.e. the Lys, Indren and Felik Glaciers.

The second project involves taking part in the ALPTRAC international programme, with CRIS SI working with the ENEL Servizio Ambiente and CNR Laboratorio di Cosmogeofisica of Turin. This group project involves setting up and monitoring the instruments of two automatic stations on the Caresèr Glacier (3100 m) and Colle Vincent (4090 m), respectively, as well as taking direct samples from the snow cover during the spring. The snow samples, taken in layers 5–10 cm thick, are chemically analysed to calculate concentrations of main cations and anions. Even individual snowfalls can be recognised, as snow cover thicknesses are recorded by ultrasonic distance measuring equipment. Special mathematical models for simulating the large-scale movement of air masses allow reconstruction of the paths followed by the storms which transported the identified chemicals.

Natural calamities

(G. Mortara, CNR IRPI)

Research in this subject dealt with those aspects concerned with hydrogeological protection which thus have a strong applicational character. Within this perspective, the consequences of the recent advance of the Miage Glacier (Monte Bianco group) were analysed, several sections of which have now moved beyond the historic moraines of the Little Ice Age and now threaten to cut off the Val Veni road (upper Val d'Aosta).

The unexpected collapse of the Upper Coolidge Glacier (Monviso group) in 1989 provided an occasion to study a phenomenon which was exceptional for both size and detachment mechanism.

Recently acquired knowledge of these two glaciers and the repeated emptying of Lake Locce (Monte Rosa group) suggested that it would be worth extending analysis of these types of instability, connected with past and present glacier activity, to every part of the Italian Alps.

Remote sensing

(R. Rabagliati, R. Serandrei Barbero, CNR ISDGM; A. Della Ventura, A. Rampini, CNR IFCTR)

Long-term teamwork between computer physicists and geologists has enabled a software procedure to be developed for monitoring the surfaces of Alpine glaciers by interpreting digital images recorded by the Multispectral Scanner (MSS) and Thematic Mapper (TM) on board the Landsat satellites. This technique offers integration of current field glaciological observations with large-scale synoptic information, comparable in time because the data is acquired by means of an identical technique.

The system uses a simple, low-cost method which combines statistical and structural information. An initial classification stage uses statistical parameters computed on areas of known composition to identify different types of land cover (snow, ice, other). In the second stage, previously classified pixels are assigned to the glaciers and their different sectors, such as accumulation and ablation areas. The procedure was systematically applied to the Breonie, Aurine and Pusteresi (Central and Eastern Alps) Glaciers for quantitative, synoptic information on a biennial scale for 89 glaciers in the Italian Alps.

Antarctic research

(C. Baroni, MCSNB; M. Frezzotti, ENEA; A. Lozej, G. Orombelli, I. Tabacco, DSTUM; M. Meneghel, G. Zanon, DGUP; C. Smiraglia, ISUUP)

The Programma Nazionale di Ricerche in Artartide (PNRA) was launched in 1985, since when seven expeditions have been organised to Terra Nova Bay (northern Victoria Land), where Italy has set up a permanent summer base. Glaciological research dealt with the mass balance of small local glaciers, outlet glacier and ice shelf accumulation and ablation measurements, topographical surveys of glacier snouts, surface speed measurements, snow stratigraphy, and the collection of snow and ice samples for chemical isotope and structural analysis. Geophysical surveys using radio-echo sounding (RES) techniques were also conducted on glaciers and frozen lakes. Satellite images and aerial photographs were analysed with the help of ground checks to evaluate the velocity and fluctuation over time of floating tongues and ice shelves, and ice discharge estimates were carried out for the largest outlet glaciers in the region. The velocity measured over more than 100 spots for the largest of these, the David Glacier, ranges between 200 and 900 $m\,a^{-1}$, from the grounding line to the ice cliff.

Geomorphological surveys reconstructed the extent of the ice during the last glacial maximum (LGM), documented by sediment (Terra Nova Drift) younger than 25.620 $\pm$ 230 ^{14}C yrs BP and older than 7505 $\pm$ 230 ^{14}C yrs BP. In addition, at least two phases of minor glacier advance during the late Holocene were identified, the second of which was later than the 13th century.

SNOW AND AVALANCHES

Experimentation of automatic stations in remote high-altitude areas

(A. Cagnati, A. Luchetta, M. Valt, CSVDI)

A network of high-altitude automatic stations was set up to acquire data on snow cover, snowfall, snow temperature, wind direction and speed, solar radiation and humidity in real time. The network comprises 16 stations, covering a mountainous surface area of 5400 km^2. Experimental work is in progress on new sensors, such as an ultrasonic snow gauge and vibrating wire totaliser rain gauge. Data acquisition is currently effected by radio, but a new acquisition system using the Meteosat geostationary satellite will go into service in winter 1992.

Studies on effect of climatic fluctuations on snow cover

(A. Cagnati, A. Luchetta, M. Valt, CSVDI)
A research programme was set up to reveal the influence of climatic fluctuations on the duration and extent of snow cover by recovering a body of historic data of differing origins, reconstructing the missing data and identifying trends using a variety of methods. Some processing has already been carried out for Arabba, a station at 1612 m in the Dolomites, on a 65-year series. The results, which partly contradict other studies, demonstrate the need for further research on climatic fluctuations using historic mountain station series in which anthropogenic effects have less influence.

Study and classification of snow cover using active microwave sensors

(M. Antoninetti, CNR IGL)
The Agenzia Spaziale Italiana marked the occasion of the launch of the first European satellite for studying terrestrial resources, the ERS-1, with a series of radar aerial images with characteristics similar to those which will be available in the near future. The areas chosen include one suitable for the study of ice and snow-related problems. The area covers some 18.8 km^2, taking in the Marmolada Glacier and upper Cordevole Basin. Images are made using a SAR radar operating in bands X and C, whilst simultaneously effecting a series of ground measurements to calibrate the data recorded in the radar images.

Slow movements in snow cover

(F. Sommavilla, CSVDI)
Research on slow movements in snow cover was begun for more accurate evaluation of stress from snow cover on stabilisation works, so that the size of the latter can be calculated correctly. The slip and creep values for determining slip factors in particular were measured by setting up suitable instrumentation in experimental fields. Future developments include the use of automatic systems for continuously monitoring experimental fields. This research is financed by the Associazione Interregionale Neve e Valanghe (AINEVA) and coordinated by CSVDI.

Avalanche prevention

(P. Valentini, PAB UI SPV)
A network of monitoring stations in the Province of Bolzano-Bozen (Alto Adige-Süd Tirol) collects and processes meteorological and nivometric data and publishes an avalanche-warning bulletin three times a week. It also compiles and manages an avalanche inventory and draws up maps of risk areas using photo-interpretation and historical and geomorphological surveys. Local avalanche teams are kept informed and avalanche appraisals are prepared for ski resorts, populated areas and communication networks.

(M. De Carli and others, PAT SCV UNV)
Amongst the responsibilities of this office, which covers the Province of Trento, is the collection of nivometric and meteorological information using a network of 30 manual and 4 automatic stations, together with a station for studying wind transport of snow. The office also coordinates local avalanche teams, set up by town councils in the Province for advising mayors on preventative and public safety measures against avalanches. Bulletins are issued three times a week to these local teams, summarising data collected and giving information on weather and snow developments.

An avalanche inventory is kept, maps of probable avalanche locations (CLPV) drawn up and a consultancy service is provided for technical teams regarding defence and the execution of plans for risk areas, in order to prepare district urban planning projects.

GLACIAL AND PERIGLACIAL GEOMORPHOLOGY

Holocene glacier fluctuations

(M. Pelfini, DSTUM)
Systematic research is nearing completion on Holocene glacier fluctuations in the Ortles-Cevedale group (Lombard flank). Direct surveys were carried out in the upper Valtellina tributary valleys to reconstruct maximum expansion in the Holocene and the retreat between the Little Ice Age and today. Morainic deposits were dated, where possible, using lichenometry, buried soils (^{14}C dating) and historical, cartographic and iconographic surveys. Research was also carried out on newly formed moraines dating from the recent phase of glacier advance between 1965 and 1985.

Paleoenvironmental reconstructions and geomorphological mapping

(B. Baroni, MCSNB; A. Carton, IGUM)
A detailed geomorphological survey is being conducted in glaciated areas of the Adamello-Presanella group (Central Alps). Large-scale geomorphological maps have been drawn up of the Avio, Miller, Narcanello Valleys and Conca Baitone, and a map of upper Genova Valley is in the final stages of completion.

Research was conducted in the same group to identify the Holocene fluctuations of certain glaciers. Neoglacial advance of the Pisgana Glacier, in particular, was identified as having taken place between 3350–3386 and 2706–2707 BP inclusive. An advance in the Genova Valley in the years 6299–5519 BP was identified, as well as another advance that can be traced to the Middle and Little Ice Ages. Iconographic information and dendrochronological surveys enabled some moraines in the same valley to be dated, and two lichenometric graphs were constructed for *Rhyzocarpon geographicum* and *Aspicilia cinerea* for the period 1864–1915. The growth rates were 0.5 mm a^{-1} and 1.7 mm a^{-1}, respectively. Dendrochronological surveys were also used to evaluate the larch settlement period for this area as approximately 15 years.

Glacial morphology of the Maritime Alps

(P. R. Federici, F. Rapetti, S. Vittorini, DSTUP)
Detailed morphological studies are in progress on the preparation of a series of geomorphological maps of the Argentera massif (Maritime Alps) and neighbouring areas. The presence of eight existing glaciers should permit reconstruction of morphoclimatic events between the penultimate glaciation and historic times. The study is accompanied by climatological investigations of original material.

Traces of glacial and periglacial modelling in the Apennines and Pindus

(F. Boenzi, F. Palmentola, G. Mastronuzzi, P. Sansò, DGGB)

As part of programme research activities being carried out in collaboration with the Centro di Geomorfologia Integrata per l'Area del Mediterraneo, studies are in progress on the traces of glacial and periglacial modelling which can be recognized in the Southern Apennines and the Pindus range in Greece. In the Apennines, research was carried out on the Matese massif, Monte Cervati, Monte Sirino, the Pollino massif and Sila, etc. In Greece, the Smolikas and Timfli massifs in Epirus have been examined so far.

At this moment in time, there is a fair degree of knowledge on the progress of Würmian glaciation in the Southern Apennines, whilst new information on the Pindus range is beginning to emerge. The final objective of this research is to correlate the three great Mediterranean peninsulas — Balkan, Italian and Iberian — from this point of view.

Rock glaciers in the Italian Alps

(A. Carton, IGUM; F. Dramis, DSTUC; C. Smiraglia, ISUUP)

A systematic study was conducted on the existence, consistency and distribution of rock glaciers in the Italian Alps, by analysis of aerial photographs and ground surveys. About 1000 forms were identified over a total surface area of approximately 20 000 km^2; of these, 131 (13%) are active, 449 (45%) inactive and 215 (21%) of uncertain activity; the remaining 21% are forms that could not be identified with certainty. The identified rock glaciers are more numerous in areas characterised by crystalline and metamorphic rocks, and were also found in prevalently north-facing sites.

The decrease in altitude of many parameters, proceeding from west to east, suggests a connection between the rock glaciers themselves and the general climatic characteristics of the south side of the Alpine range. The different altimetric distribution of certain parameters for active and inactive forms can be explained by the rise with altitude of the mean annual isotherm $-2°C$ between the past and today.

Active rock glaciers

(S. Belloni, M. Pelfini, DSTUM; C. Smiraglia, ISUUP)

130 of the approximately 1000 rock glaciers observed in the Italian Alps may be considered active (see above). This interpretation is confirmed by ground surveys carried out in the most important massifs, above all the Ortles-Cevedale group (Central Alps).

A statistical analysis of the morphometric and morphological aspects of these active rock glaciers was carried out and the "average" characteristics of these forms determined for the Italian Alps. The surface area is fairly limited, individual forms prevalently covering less than 0.06 km^2. The altimetric zone across which rock glaciers extend ranges between 2400 and 2800 m (snout level) and 2800–3000 m (maximum altitude). The maximum length and width prevalently fall in the 200–600 m and 200–300 m ranges, respectively. They are mainly north facing, especially the larger forms and those with lower-altitude snouts.

A very significant correlation between the minimum altitude of the active rock glaciers and the mean annual isotherm of $-2°C$ was identified, using climatic parameters from six Alpine stations at altitudes between 1236 and 2340 m.

Active rock glaciers in Val Pisella

(C. Smiraglia, ISUUP)

There are many south-facing rock glaciers in the Val Pisella (Valfurva, Ortles-Cevedale group), some of which are considered active, according to morphological and vegetation criteria; their snouts' altitudes range between 2825 and 3000 m. Surveys have been in progress since 1986 on the surface speed and internal structure of one of these rock glaciers, using 50 surface reference points. The highest speed (40 $cm\,a^{-1}$) is recorded in the centre part, whilst it gradually decreases towards the valley and on the sides, falling to zero at the snout. Vector analysis shows flow lines parallel to the longitudinal axis of the rock glacier in its upper portion, diverging in the lower sector where they are arranged transversally.

Southernmost limit of rock glaciers in the Central Apennines

(F. Dramis, DSTUC; A. Kotarba, Instytut Geografii, Polskiej Akademii Nauk, Krakow)

A systematic survey was conducted on the Central Apennines periglacial area with particular attention to the influence of periglacial environmental conditions on morphological evolution. The Maiella group rock glaciers, characterised by very recent forms and in certain cases by the presence of internal ice, were taken into consideration. A geophysical back-up survey is envisaged regarding the latter.

Mountain permafrost and climate

(F. Dramis, DSTUC; Cheng Guodong, Institute of Glaciology and Geocryology, Lanzhou)

As part of the activities of the IPA Mountain Permafrost Working Group, a study was prepared, updated to 1991, dealing with problems concerning relations between climatic conditions and mountain permafrost on a global scale.

Submitted by Giorgio Zanon

Abbreviations used in the text:

CSVDI:	Centro Sperimentale Valanghe e Difesa Idrogeologica, Arabba (Belluno).
CAI:	Club Alpino Italiano; CAI-SAT: Società Alpinisti Tridentini (Sezione di Trento del CAI).
CGI:	Comitato Glaciologico Italiano, Torino.
ENEA:	Comitato Nazionale per la Ricerca e lo Sviluppo dell'Energia Nucleare e delle Energie Alternative, Roma.
CNR IFCTR:	Consiglio Nazionale delle Ricerche, Istituto di Fisica Cosmica e Tecnologie Relative, Milano.
CNR IGL:	Consiglio Nazionale delle Ricerche, Istituto di Geofisica della Litosfera, Milano.
CNR IRPI:	Consiglio Nazionale delle Ricerche, Istituto di Ricerca per la Protezione Idrogeologica nel Bacino Padano, Torino.
CNR ISDGM:	Consiglio Nazionale delle Ricerche, Istituto per lo Studio della Dinamica delle Grandi Masse, Venezia.
DGUP:	Dipartimento di Geografia, Università di Padova.

DGGUB:	Dipartimento di Geologia e Geofisica, Università di Bari.
DSTUC:	Dipartimento di Scienze della Terra, Università di Camerino.
DSTUM:	Dipartimento di Scienze della Terra, Università di Milano.
DSTUP:	Dipartimento di Scienze della Terra, Università di Pisa.
ENEL CRIS SI:	Ente Nazionale per l'Energia Elettrica, Centro Ricerca Idraulica e Strutturale, Servizio Idrologico, Venezia.
IGUM:	Istituto di Geologia, Università di Modena.
ISUUP:	Istituto di Scienze Umane, Università D'Annunzio, Pescara.
MCSNB:	Museo Civico di Scienze Naturali, Brescia.
PAB UI SPV:	Provincia Autonoma di Bolzano, Ufficio Idrografico, Servizio Prevenzione Valanghe.
PAR SAPOI UI:	Provincia Autonoma di Trento, Servizio Acque Pubbliche e Opere Idrauliche, Ufficio Idrografico.
PAT SCP UNV:	Provincia Autonoma di Trento, Servizio Calamità Pubbliche, Ufficio Neve e Valanghe.
PSFG:	Permanent Service on the Fluctuations of Glaciers.
WGMS:	World Glacier Monitoring Service.

JAPAN

ICE AND SNOW

Distribution and crystal growth studies of air-hydrate in a polar ice sheet

(T. Uchida, T. Hondoh and S. Mae, Faculty of Engineering, Hokkaido University)

Observation of air-hydrate crystals with a microscope was made on Vostok ice cores, Antarctica, which retain a significant number of air-hydrates even about 6 years after being recovered from the ice sheet. The smaller number and the larger mean volume of hydrate crystals were observed in ice of the last interglacial stage compared with those from glacial stages. The distribution of the concentration and the mean volume of air-hydrate crystals are explained by changes in climatic conditions. Depth variation of the air-hydrate volume was, on the other hand, explained in terms of the ratio of air molecules included in the crystal to the total number of water molecule cages, each of which can include at most one air molecule.

Experiments on the growth processes of air-hydrate crystals from air bubbles included in the deep Vostok ice cores were carried out under high hydrostatic pressures. The transformation from a bubble to an air-hydrate crystal occurred when the annealing pressure was higher than the theroetical dissociation pressure of air-hydrate. Two transition types from a bubble to an air-hydrate were observed under different annealing conditions. The measurements of each crystal growth rate showed that the rate was proportional to the excess pressure over the dissociation pressure of air-hydrate. These results allow us to consider that the crystal growth processes of air-hydrate in ice are interpreted by assuming two rate-determining processes: the construction of the clathrate structure on the crystal surface, and the supply of water molecules to the interface between the bubble and the air-hydrate.

These studies on air-hydrate crystals in polar ice have been continued in collaboration with P. Duval (Laboratoire de Glaciologie et Géophysique de l'Environnement, Grenoble) and V. Ya. Lipenkov (Arctic and Antarctic Research Institute, St Petersburg).

Interannual variation of snow cover in northern Japan Alps

(T. Ohata, K. Seko and Y. Fujiyoshi, Water Research Institute, Nagoya University)

Tateyama Mountains are one of the most snowy mountain ranges in Japan, where winter accumulation exceeds 9 m in depth. There are perennial snow patches, such as "Hamaguri-yuki" which has been continuously surveyed for more than 25 years.

The present project is being conducted to investigate the variability of the mountain snow cover and perennial snow patches, and its relation to atmospheric circulation. The snowfalls mainly occur due to a cold surge from the Siberian high pressure on the continent and the passage of low pressure systems along the Japanese islands during winter. The dependency of snowfall to air pressure systems is complicated, and the main task of the present study was focused on obtaining basic snowfall and snow accumulation data.

Five automatic snow-depth gauges are set along the mountain slopes to obtain snow accumulation and precipitation flux and one RHI radar is set in the foothills of the mountain range to observe the areal precipitation flux directly. In situ measurements of the snow cover are made several times during the winter season.

Intensive observation began in 1990, and will continue to 1992 and later. With use of the past long-term point measurement of snow in addition to the observed data, we may be able to discuss such problems as the possible variation of mountain snow cover due to climate warming, and interpretation of past variation of snow and ice masses in this region.

Measurement of viscosity of slush

(S. Kobayashi and K. Izumi, Research Institute for Hazards in Snowy Areas, Niigata University)

Recently slush-flow disasters occurred in small rivers in Honshu, Japan, and some people were killed. The biggest disaster ever caused by a slush flow was that at Ohozikari, Aomori Prefecture, on 22 March 1945, when 88 people were killed and 20 houses crushed.

In order to elucidate the mechanism of slush flows, measurements of the viscosity of snow–water mixtures (slush) were carried out in a cold room (0°C) by two methods: (1) with the use of a cylindrical viscometer, and (2) with measurement of slush flows along an inclined smooth surface. The results obtained from these experiments showed that the viscosity of slush decreased with an increasing shear rate. A fluid with this behaviour is known as a "pseudoplastic".

GLACIERS

Greenland

(T. Kameda, Physics Section, Kitami Institute of Technology)

Shallow ice corings were carried out at a site (66°51.9′ N, 46°15.9′ W; 2030 m a.s.l.) from May to June 1989 by the Japanese Arctic Glaciological Expedition 1989 (JAGE 89). This research site is located about 180 km east from Søndre Stromfjord, West Greenland, called Site-J. The JAGE 89 project was organized by the Arctic Research Committee (Chairman, Professor S. Kobayashi, Research Institute for Hazards in Snowy Areas, Niigata University) of the Japanese Society of Snow and Ice, and principal investigator of the project was Professor O. Watanabe (National Institute of Polar Research). Two ice cores, 206.6 and 101.5 m in depth, were recovered by JAGE 89 field members: Y. Fuijii (National Institute of Polar Research), H. Narita (Institute of Low Temperature Science, Hokkaido University), F. Nishio (Earth and Planetary Science, Hokkaido University of Education), H. Shoji (Department of Earth Science, Toyama University), K. Kamiyama (Geophysical Research Station, Kyoto University), T. Kameda (Physics Section, Kitami Institute of Technology), Y. Tanaka (Geosystems Inc., Tokyo) and M. Miyahara (Geo Tecs Co. Ltd, Nagoya).

Dating of the ice core was carried out by several different methods; seasonal cycle of the ECM and stratigraphy record (F. Nishio), interpretation of the pH and EC signals (Y. Fujii and K. Kamiyama), tritium concentration profile (K. Izumi, Research Institute for Hazards in Snowy Areas, Niigata University), $\delta^{18}O$ (O. Watanabe), and the density–depth profile (T. Kameda and H. Shoji). Annual mean accumulation rate at Site-J was found to be 0.39 m a^{-1} water equivalent during 1783–1988 AD and also during 1963–88 AD. The bottom of an ice core (206.6 m in depth) was dated at 1540 ± 10 AD.

Concentration of major soluble species (Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, NO_3^-, SO_4^{2-}), electrical conductivity, pH and a number of insoluble species of melted samples were measured continuously at the National Institute of Polar Research. Structural analyses of the ice core were studied by H. Narita, H. Shoji, A. Mitani (Department of Earth Science, Toyama University) and T. Kameda. The possibility for quantitative reconstruction of past summer temperatures from melt features in the ice core was studied by T. Kameda. Relatively cool summer periods were recognized by this analysis, and these periods may correspond to the Little Ice Age. Mechanical testing of the sample ice was studied by H. Shoji. It was found that melt layers are slightly softer than normal glacier ice which was made by firn compaction. CH_4 concentration of air bubbles in the ice core was measured by T. Nakazawa and T. Machida (Center for Atmospheric and Oceanic Sciences, Tohoku University). A detailed profile of past CH_4 concentration was obtained. Organic acids, aldehydes and lipid class components in ice samples were detected by capillary gas chromatography (GC) and GC-mass spectrometry (by K. Kawamura, Department of Chemistry, Tokyo Metropolitan University). MSA (methanesulfonic acid) and major soluble species were measured by K. Suzuki (Department of Geography, Tokyo Metropolitan University).

Recent glacier variations in the southern Patagonia Icefield, as revealed by Landsat and other remote-sensing data

(M. Aniya, Institute of Geoscience, University of Tsukuba, and R. Naruse, Institute of Low Temperature Science, Hokkaido University)

A systematic study of the recent glacier variations in the southern Patagonia Icefield (SPI), located near the southern end of the Andes, has been in progress since 1990, utilizing remote-sensing data, primarily Landsat TM and MSS and aerial photographs. For the northern one-third of the SPI, cloudless images of 1976 Landsat MSS and 1986 Landsat TM are available, while for the southern two-thirds, the only usable Landsat data are the 1986 TM due to extremely inclement weather conditions. As a result, we employed aerial photographs taken during the 1970s by Argentine and Chilean agencies and digitized them for digital superimposition onto the Landsat TM data.

During a 10-year period between 1976 and 1986 , Brüggen (or Pio XI) Glacier, located on the western side of the SPI, had advanced 300–1400 m at the northern tongue, while the southern tongue retreated up to 600 m. This glacier is noted for an unusual advance of up to 9 km between 1947 and 1976. Jorge Montt Glacier, the northernmost one in the SPI, had receded modestly, about 400 m, in the 10-year period. O'Higgins Glacier, located on the eastern side of the SPI, showed a very rapid recession with a maximum of 2300 m in10 years. This glacier had retreated about 10 km since 1947, which contrasts dramatically with Brüggen Glacier because both are located at similar latitudes and only about 60 km apart in an east–west direction. For the variation of Viedma Glacier, we had to use aerial photographs because there is cloud cover, although thin, over this glacier in the TM image. A comparison of the 1968 and 1981 aerial photographs indicates very slight change at the snout.

For the glaciers located in the southern two-thirds of the SPI, we had to employ aerial potographs of various dates for the comparison with the 1986 Landsat TM. For Upsala glaciers, there are several dates of remote-sensing data available. A comparison with the 1970 photograph and TM image (16 years) revealed that the glacier had retreated a maximum of 4.4 km near the eastern margin. However, it had advanced between 1970 and 1977 (Salyut-6 image) a maximum of 400 m near the center. It has been in a trend of rapid recession since 1978. Moreno Glacier, noted for repeated damming-up of the channel by advancing and reaching the opposite bank, showed oscillation of the snout, whose magnitude is up on the order of 500 m during the last 40 years. Tyndall Glacier, the southernmost major outlet glacier, had receded between 1975 and 1986 (11 years) on the order of 700 m at the snout. The surface lowering is estimated at about 140 m from 1947 to 1990 at the left bank about 15 km up from the snout.

SEA ICE

Air–sea ice–ocean interaction study in the Antarctic Climate Research Program

(T. Takizawa, Institute of Low Temperature Science, Hokkaido University)

Oceanographic observations were conducted off Queen Maud to Enderby lands, Antarctica, in the summers of 1990-91 and 1991–92. Meanwhile, year-round variations in water structure under the fast ice in Lützow-Holm Bay were investigated in 1990 and 1991. The purposes of the study were to evaluate: (1) roles of the Circumpolar Deep Water (CDW) for sea and sea-ice processes, (2) seasonal and spatial change of the mixing layer depth, (3) heat flux from ocean to air, (4) influence of sea-ice processes on the water structure of ice-covered sea. This study also focused on the evolution of coastal polynya off Lützow-Holm Bay.

Routine measurements of temperature profile down to about 500 m depth of the polynya were carried out by an air-deployed XBT. Two unmanned meteorological stations were set up on the fast ice in Lützow-Holm Bay. An oceanographic ARGOS buoy was deployed at one station. This buoy measures the water temperature and conductivity at six layers down to 300 m depth, and is still working. In addition, a current meter was moored beside the buoy throughout 1990 at a depth of 300 m. Current observations during several months were made near Syowa Station in 1991.

Preliminary analyses show that CDW existed near the bottom of the central trough in Lützow-Holm Bay and its inflow from the open ocean seemed to occur intermittently. A blob of warmer water was occasionally found in the surface layer. This would be due to the irregular intrusion of the offshore warm water. In spring a cold and oxygen-rich water was observed at the depth of about 300 m on the slope of the trough. This water is reasonably interpreted as a product of sea-ice processes during winter.

Sea-ice observation in the Arctic Ocean

(H. Nakamura, National Research Institute for Earth Science and Disaster Prevention)
Measurements of thickness and thermal conductivity of sea ice were carried out in August 1991 under the program of Polar Star International Arctic Ocean Expedition (IAOE-91) in the Arctic Ocean near Spitsbergen, Norway. Ice thickness was measured in the sea from 80° N, 30° E to 85° N, 35° E, putting a rule on the side of the sea ice which was broken by the bow of the icebreaker, at a sailing speed of about 4 kt. Thermal conductivity was measured on the sea ice which was collected from the point 85° N, 40° E. Results obtained from this observation will be applied as the initial conditions to the computer simulation on the air–sea interactions.

Submitted by R. Naruse

USA – WESTERN

POLAR ICE CAPS

Ice Radar

(S. Hodge, Ice and Climate Project, US Geological Survey, Tacoma, WA)
ICP is carrying out both surface and airborne radar measurements of ice thickness in both Greenland and Antarctica. In Greenland these efforts were fundamental in determining the GISP-2 site. In Antarctica, last year's field programs have shown internal ice horizons with large undulations that do not appear to be related to the bed topography. These field studies are continuing this year.

Numerical ice flow and temperature modelling of central Greenland

(J. Firestone, Geophysics, University of Washington, Seattle, WA, Christine Schott, University of Copenhagen, E. Waddington and C. Raymond, Geophysics, University of Washington, Seattle, WA)
A finite element model solving for time-dependent temperature patterns in a vertical plane has been developed. Results show that the basal temperatures at the GRIP and GISP2 coring sites at Summit remained below the melting point during the last glacial cycle if the geothermal heat flux is less than 56 $mW\,m^{-2}$.

Calculations of the ice flow pattern on the GRIP-GISP2 flowline combined with estimates of the mass balance history have provided preliminary time scales for both cores. Ice older than 150 Kyr with stratigraphy undisturbed by basal topography may be found at both sites.

Development of a coupled time-dependent ice flow and temperature model is nearly complete. This model will permit future refinements of the time scales and studies of ice rheology and fabric development there.

Strain net at Agassiz Ice Cap, Ellesmere Island: an integrated approach from survey data to ice flow models

(E. Waddington and A. Rasmussen, Geophysics, University of Washington, Seattle, WA)
The 1987 strain net of 110 markers was resurveyed in 1989. Due to longitudinal stress gradients, the ice flow direction deviates up to 150° from the local slope when averaged over up to one ice depth.

We have developed a computer program package called UVWXYZ based largely on widely available FORTRAN matrix solver routines to analyze ice motion from field observations (angles, distances, and satellite positions) through to calculation of flowline positions and surface strain patterns along the flowlines, i.e. bridging the gap between surveying and ice flow modelling. All marker positions and velocities can be determined simultaneously in a least-squares sense along with full error estimates. This allows us to use all data from arbitrary times without reduction to epoch. We then use these error estimates as weights while finding the parameters of a smooth vector surface that best fits the velocity solution at the discrete marker positions in a least-squares sense. We impose constraints derived from vorticity and divergence considerations to couple the velocity components in the vector field. This smooth vector surface, which is defined and differentiable everywhere, permits determination of the flowlines, velocities, and strain patterns needed for ice flow model data and tests.

Geophysics and ice coring on Dyer Plateau Antarctic Peninsula

(C. Raymond and B. Weertman, Geophysics, University of Washington, Seattle, WA)
A cooperative project involving the British Antarctic Survey, Ohio State University, the Polar Ice Coring Office, and the University of Washington is aimed at gathering paleoclimate information from Dyer Plateau, Antarctic Peninsula. During the 1990 field season, we did geophysical measurements in a 24 km by 10 km area surrounding a core site on the flow divide. Measurements include: (1) extensive radio-echo sounding traverses with a new light-weight digitally recording, profiling system that can detect internal a layering; (2) initial survey of a 100 marker strain grid; and (3) insertion of markers in a core hole for vertical strain measurement.

The internal layer geometry shows a complex response to the rugged basal topography and spatial gradients in mass balance. Current research is directed toward mapping of internal layers, prediction of internal layer geometry under steady state conditions using finite-element flow models, and detection of evidence for past changes in the ice-sheet flow regime. Measurement of the surface and vertical strain-rate patterns will require remeasurement during a later field season. These measurements will provide tests for the flow modeling and aid in the interpretation of the core stratigraphy.

Radar studies of basal conditions and internal layering on West Antarctic ice streams

(R.W. Jacobel, St. Olaf College, Northfield, MN) Work has continued on analyzing our surface-based radar data acquired with colleagues in the U.S. Geological Survey on ice streams B and C. We have developed techniques for producing hard-copy color displays which clearly depict the dramatic folding and contortions of the internal layering in these ice streams. These folds can be followed from one profile to another, and from these we have produced maps of internal surfaces, as well as maps of the bed and associated roughness features. While this folding depicts the strain history of the ice, it does not appear to have any simple relationship to the bed topography, or to strain-rate measurements at the surface, and we are currently working to interpret and understand these features in terms of ice stream dynamics.

We have made modifications to the St. Olaf radar system for future work on the ice streams which enable it to acquire larger volumes of digital data more rapidly, and thus increase the range and data density for profiling. The new system was tested in studies on South Cascade Glacier, Washington, USA this past summer with A. Fountain of the USGS. Initial results from these surface-based profiles show that the radar can depict internal structures within the ice, and that it has confirmed the presence of water-filled conduits in areas where they were suspected from earlier borehole and dye studies.

Monitoring the dynamics of the Antarctic coastline with Landsat images

(B.K. Lucchitta, L.M. Bertolini, US Geological Survey, Flagstaff, AZ 86001, J.G. Ferrigno, and R.S. Williams, Jr., US Geological Survey, Reston, VA 22092)
The extent of advance or retreat of ice shelves and glacier tongues along the Antarctic coastline is known only for a few well-studied areas; yet to properly assess changes induced by global climatic variations, the entire coastline should be monitored. This problem is important because climate-induced changes in the area and volume of polar ice sheets may severely affect the Earth's densely populated coastal regions; melting of the West Antarctic ice sheet alone would cause a sea-level rise of 3.5 m.

An extensive set of Landsat images covering Antarctica was acquired in the early to middle 1970s. Recently, a program to obtain new Landsat images over the Antarctic coastal region was initiated by an international consortium of the Scientific Committee on Antarctic Research (SCAR). These later views of the scenes imaged earlier will permit the monitoring of coastal changes. Our pilot study showed that the images, after scanning, digitizing, and registration, can be manipulated by image-processing techniques, so that the extents of shelf ice, glaciers, and open water or seasonal ice can be compared, and the changes mapped and quantified. Our study also showed that many crevasse patterns in the floating part of outflow glaciers retain their identity over as much as 15 years, so that the patterns may be registered digitally by using a computer-interactive display or optically by using a stereoscope. From the registered points, the translational movement can be calculated, giving an extensive velocity profile of the glaciers. For example, 70 points on the Stancomb-Wills Glacier and Ice Tongue, eastern Weddell Sea, Queen Maud Land, yielded velocities ranging from $950\,m\,a^{-1}$ near the grounding line to $1200\,m\,a^{-1}$ at 100 km distance seaward from this line. The statistical error of the measurements along individual flowlines was determined to be 3 to 5%. This glacier and ice tongue have moved exceptionally fast. Similar measurements are possible for most outlet glaciers in Antarctica, and we have identified about 20 sets of presently available paired Landsat images for further analysis.

Monitoring coastline changes and obtaining a baseline of current glacier velocities will significantly improve our understanding of the present Antarctic environment and its sensitivity to future changes in global climate.

Ice sheet weather and climate

(U. Radok, University of Colorado, Boulder, CO, G. Wendler, University of Alaska, Fairbanks, AK, and H. Phillpot, University of Melbourne, Australia)
The meteorological processes that drive the Antarctic surface winds and their snow transport are being studied with the hour-to-hour observations made by automatic weather stations on the East Antarctic plateau south of Dumont d'Urville and Casey. Statistical relationships, established by Phillpot between the surface temperature and the elevation of the 500 hPa constant pressure level above the ice sheet surface, are being used to refine the large-scale pressure and wind fields over the ice sheet and to study their effects on the low-level flow and on the surface energy balance.

Borehole geophysical observations on Ice Stream B, Antarctica

(Division of Geological and Planetary Sciences, Caltech, Pasadena, CA)
In recent years, the development of the hot-water drilling technique for rapidly drilling deep boreholes through cold ice to the base of the Antarctic ice streams has opened the possibility of studying the controlling mechanism for fast-ice streaming flow. This technique has been successfully tested and fully implemented during the 1988/89 field season.

In the 1989/90 field season, six boreholes about 1060 m deep were drilled on Ice Stream B (83.5° S, 138.1° W).

Four till cores, one of them 3 m long, were extracted from the soft bed of the ice stream. The physical properties of these cores will be thoroughly tested. The till bed is at least 3.4 m thick. The distinction between basal sliding and till deformation could not be resolved unequivocally. The basal water pressure varies around the flotation level of 91.5 bar at which the water pressure at the bed is equal to the ice overburden pressure. Depending on the assumed till thickness, an electrical conductivity of the order of 30–50 μm is indicated. A salt injection experiment rendered the basal hydraulic conductivity. The basal water-flow velocity of $30\,m\,h^{-1}$, which is much higher than the hydraulic conductivity of the till matrix could accommodate, implies that the water is flowing through open channels at the ice-till interface.

Participants: H. Aschmann, M. Blume, J. Chadwock,

H. Conway, S. Duncan, H. Engelhardt, N. Humphrey, B. Kamb, T. Svitec, J. Zachariasen, NSF grant DPP 85-19083.

Runoff from cold glaciers and ice caps

(W.T. Pfeffer, INSTAAR, University of Colorado, Boulder, CO)
Work continues on the transient character of runoff from high Arctic glaciers and ice caps in response to predicted future changes in climate. Research is presently divided between modeling studies and field work. Models of grain-scale physical processes controlling water flow in initially subfreezing snow have been published, and a simulation model of regional scale runoff in a warming climate has been completed. Field work has been conducted in the Canadian Arctic and is continuing in Greenland. Laboratory experiments are in preparation and will be in progress by summer 1991.

Effects of errors in surface velocity measurements on estimates of basal velocity

(D. Bahr, INSTAAR, University of Colorado, Boulder, CO)
The effects of surface velocity observation errors on calculations of a glacier's bed velocities are being analyzed using a two-dimensional model constructed from ideas proposed by C. J. Van der Veen and I. M. Williams. A major goal of this study is to develop transfer functions for nonlinear rheologies which transform surface velocity perturbations to velocity perturbations at the bed. Such a function would allow calculations of uncertainties in bed velocities based upon known or estimated surface errors, and would also help to elucidate the magnitude and form of held perturbations which are detectable at the surface.

SNOW

Wind pumping in polar firn

(J. Cunningham, E. Waddington, R. Charlson, Geophysics, University of Washington, Seattle, WA, and G.K.C. Clarke, Geophysics, University of British Columbia, Vancouver, BC)
Air motion through polar firn can redistribute isotopic species, filter out aerosols such as sulphuric acid droplets (Cloud Condensation Nuclei) and possibly affect the temperature of the firn. Measurement of the decay of the air pressure spectral density with depth in the firn at Agassiz Ice Cap, Ellesmere Island, suggests that the heating effect due to viscous air flow in the porous firn is very small. A new, three-dimensional theory of wind pumping confirms this.

Dry deposition rates for sulphate aerosols have been reported to be 100 times higher than the amounts predicted by previous models that do not account for air flow in the snow. Since aerosols are effectively filtered from air that passes through snow, we have calculated the aerosol flux into the snow due to filtering of air moving through the firn by (a) pressure variation pumping (1 yr^{-1} to 1 s^{-1}) and (b) steady flow over topographic features such as sastrugi. Results suggest that these processes may account for most of the dry deposition sulphate in South Pole ice cores. The second mechanism dominates.

Remote sensing of snow

(E.G. Josberger, W.J. Campbell, Ice and Climate Project, US Geological Survey, Tacoma, WA)
As part of the joint USGS-NASA-USDA satellite passive microwave study of the snow pack in the Upper Colorado River Basin, ICP is investigating relationships between the satellite observations and the large scale hydrology of the basin, using the 8 year SMMR data set which will soon be expanded to include the DMSP SSMI observations. ICP is incorporating digital elevation data into both its large scale and mesoscale snow determinations. ICP is continuing its collection of internal snow-pack data, particularly grain size and density, at index sites across the entire basin. Finally, ICP is cooperating with the Nansen Remote Sensing Center, on a passive microwave study of the snow pack on the Hardangervitte plateau, Norway.

Climate processes on the Antarctic plateau

(S. Warren, T. Grenfell, R. Charlson, P. Grootes, Atmospheric Sciences, University of Washington, Seattle, WA)
A field project is planned for 1990-1991 at South Pole and Vostok to study (a) solar radiation spectrum, (b) bidirectional reflectance of snow, (c) thermal infrared spectrum (in collaboration with Murcrays of University of Denver), (d) mechanisms of aerosol deposition, and (e) oxygen isotopes, in individual snowfall events.

Temperature profiles and solar heating rates in Antarctic snow

(R. Brandt and S. Warren, Atmospheric Sciences, University of Washington, Seattle, WA)
A subsurface temperature maximum has sometimes been observed during the sunlit season on the Antarctic Plateau, and attributed to the "solid-state greenhouse effect". The variables controlling the strength of this effect were investigated by means of a spectral radiative-transfer model. The effect is expected to be small, at most a few tenths of a degree, in Antarctic snow.

Parameterization of snow albedo for climate models

(S. Marshall, University of Colorado, Boulder, CO, and S. Warren, Atmospheric Sciences, University of Washington, Seattle, WA)
The results of a physically based model for the spectral albedo of snow were parameterized into equations for snow albedo in two broad spectral bands (visible and near-infrared) for use by general circulation climate models. The parameterization is being installed in the NCAR Community Climate Model.

Wet snow avalanches

(H. Conway, Geophysics, University of Washington, Seattle, WA)
Measurements of strain-rate versus snow depth during rain show a wave of increased compaction rate that propagates into the snowpack. These waves apparently reflect mechanical effects of the penetrating water. Further measurements are required to determine whether this will provide a means for monitoring changes of snow stability.

Evidence of individual solar proton events in Antarctic snow

(A.M. Gisela, G. Dreschhoff and E.J. Zeller, Space Technology Center, University of Kansas, Lawrence, KS)
The high-resolution nitrate analyses of a snow sequence in Antarctica reveals clear evidence that the snow contains a chemical record of ionization from charged particles incident upon the upper atmosphere of the Earth. The Antarctic continent acts as a cold trap that effectively freezes out this signal and retains it in the stratigraphy of the ice shelves and the continental ice sheet. The signal measured results from the ionization of nitrogen and oxygen, the two primary constituents of the Earth's atmosphere, which subsequently react to form oxides of nitrogen. A large portion of the nitrogen oxides produced are ultimately oxidized to nitric acid and incorporated in snow crystals together with nitrates from tropospheric sources that also contribute to the general background. The nitrate concentration in a firn core was measured in Antarctica by ultraviolet spectrophotometry under tightly controlled experimental procedures. Based on uninterrupted, high-resolution sampling, variations in nitrate concentration were found to average about 53% (one standard deviation) of the mean concentration for the entire core. Short pulses of high nitrate concentration were found to show a variance of up to 11 standard deviations above the mean. At the series mean, the precision of analysis is better than 2%.

The firn core was drilled by hand to a depth of 21.7 m corresponding to 62 years and including more than 5 solar cycles. The time series that resulted from a total of 1393 individual analyses shows a statistically significant modulation of the background signal that is clearly traceable to solar activity. Several anomalously large concentration peaks were observed that have been dated and found to correlate with the major solar proton events of August 1972, July 1946, and the white-light flare of July 1928.

A nitrate signal of solar flares in snow from Greenland and Antarctica

(G. Dreschhoff, E. Zeller, and C. Laird, University of Kansas, Center for Research Inc., Lawrence, KS)
Nitrate concentrations in polar snow and firn were measured using an ultra-violet spectrophotometer at locations in both Antarctica and Greenland. All measurements were made in the field on samples collected in glaciological pits or from ice cores drilled by hand. In Antarctica, the high-resolution nitrate profile representing the years 1928 to 1988 showed peak concentrations up to 11 standard deviations above the mean. Several of the most prominent of these high peaks were determined to be the result of ionization from known solar proton events during which charged particles penetrated the middle and lower atmosphere (stratosphere). In July 1990, a shorter high-resolution nitrate profile covering about 20 years was acquired from an ice dome in northern Greenland near Thule. It is especially interesting because the snow deposited in the year 1989 shows a very pronounced increase throughout the year which we interpret as the result of ionization effects from the major solar proton events that occurred during that year.

Winter solute budget of Upper Lehman Creek Watershed, Great Basin National Park, Nevada

(R.C. Metcalf, MCR Scientific, Houston, TX and W.M. Brock, USNPS, Baker, NV)
A remote battery-powered, continuous electrochemical monitoring station was installed in December 1990 to monitor Lehman Creek's (2930 m) electrical conductivity and temperature throughout the winter. Preliminary results (from Spring, 1988) suggest that a 2 h sampling interval is sufficient to avoid signal aliasing in this watershed. Greater emphasis on quality control and quality assurance procedures than in other such studies insures the data quality for use in future NPS programs.

Reconnaissance electrochemistry of Mangatepopo Stream, Tongariro National Park, New Zealand

(R.C. Metcalf, MCR Scientific, Houston, TX)
The mid-winter electrochemistry of 2 spot samples collected between 1300–1400 m from Mangatepopo Stream on the 1967 m volcano, Mt. Tongariro (North Island), have been superficially examined. Conductivity varied from 500–800 $\times$ 10^{-4} S m at 1°C during July 1990. Ferromagnesian precipitates coated the stream bed from near the soda springs (1400 m) for a distance of over 1 km downstream (1300 m). At present, the chemical and thermal effects of vulcanism are only obvious at Red Crater, Te Mari Crater, and Ketetahi Hot Springs. The precipitates may form from downstream increases in pH (more alkaline) or dissolved oxygen. There is no quantitative information concerning the source of solutes in Mangatepopo Stream, whether they derive from the snow melt of the rather quiescent Mt Tongariro 1.5 km to the northeast (ash erupted from Red Crater in 1926), or the more active Mt Ngauruhoe (eruptions 1949, 1954, 1974, and 1975) 2 km to the southeast. Destructive lahars and avalanches are serious applied glaciological problems in Tongariro National Park.

Application of SSM/I data for snow cover and climate research

(R.L. Armstrong, NSIDC/CIRES, University of Colorado, Boulder, CO)
The capability to produce daily snow parameter products from the DMSP Special Sensor Microwave Imager (SSM/I) is being funded by NASA's Interdisciplinary Research Program. A data system is being developed which will produce, archive, and distribute validated snow-cover products for community use. Initial emphasis is on Northern Hemisphere snow extent. We are also exploring the potential of the SSM/I for mapping other snow cover properties such as snow water equivalent, snow depth, and dry/wet snow boundary.

Within this project we coordinate the activities of the SSM/I Products Working Team (SPWT) which is a multi-agency and multi-disciplinary working group focussing on the problems associated with extracting land surface (primarily vegetation, soil, and snow cover) information from SSM/I. Currently, emphasis is on developing optimal binning and gridding routines as well as the selection of one or more snow-cover algorithms for use in the production of standardized data sets. Regional test areas selected are the western United States and Central Europe. For the US, the relative accuracy of the algorithms will be tested by comparison with several validation data sets including snow-depth measurements from the National Weather Service and the Soil Conservation Service, as well as output from the prototype Air Force Global Weather Central (AFGWC) snow-depth model. Later in this project we will explore the combined research potential of the SSM/I derived snow-cover and sea ice products for climate dynamics and global/regional hydrology.

Monitoring global snow depth

(R.L. Armstrong and M. Hardman, NSIDC/CIRES, University of Colorado, Boulder, CO)
A new snow-depth model is being developed to replace the current model used by the U.S. Air Force Global Weather Central (AFGWC). The prototype model will provide a state-of-the-art integration of all snow cover data available at AFGWC in order to provide a daily global snow-cover product at a 40 km grid resolution. The basic data generated for each grid point include calculated average and maximum snow depth, ages in days of the total snow cover and days elapsed since the last snowfall, along with appropriate data source flags and summary diagnostics. The model represents the integration of surface and satellite observations. Surface measurements are from the World Meteorological Organization (WMO) synoptic data collection network. An improved surface-measurement-point to grid-point interpolation technique has been developed based on both distance and elevation weighting criteria as well as a spatial variance defined by snow cover climatology. The model uses passive microwave satellite data (DMSP-SSM/I) which provide global, all-weather, day/night, information on snow-cover extent. In addition, the potential to extract snow-depth information from passive microwave data is fully exploited. Because no single snow-depth algorithm is suitable for global application, individual surface-type algorithms are being developed.

Chemical hydrograph from Alpine snowpacks

(J. Melack, J. Dozier, University of California, Santa Barbara, CA, R. Bales, R. Wolford, Department of Hydrology and Water Resources, University of Arizona, Tucson, AZ)
Whole-watershed hydrochemical modeling using point descriptions of snowmelt chemistry, along with distributed estimates of snowmelt volume, is being pursued for the Emerald Lake and other alpine watersheds in the western US. A detailed, multi-year data set was developed for the Emerald Lake watershed, which lies at an elevation of 2800 m in California's Sierra Nevada, under the sponsorship of the California Air Resources Board (CARB). Field studies of snow accumulation and chemistry are continuing at seven sites in the Sierra Nevada, under the direction of J. Melack of UCSB and K. Tonnessen of CARB. For the most part, chemical hydrographs peak during the rising limb of the meltwater hydrograph, which shows the importance of understanding snowpack processes early in the ablation season.

Point models of snowmelt chemistry

(R. Bales, University of Arizona, Tucson, AZ, R. Sommerfeld, US Forest Service, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, CO, R. David, US Army Cold Regions Research and Engineering Laboratory, Hanover, NH, and M. Williams, University of California, Santa Barbarba, CA)
Ongoing laboratory studies at the Sierra Nevada Aquatic Research Laboratory, which is operated by the University of California, Santa Barbara, field studies at the US Forest Service's Glacier Lakes Experimental Ecosystem Study site, and field studies at Mammoth Mountain, California, are aimed towards developing point estimates of ion concentrations in meltwater for use in the distributed watershed models. Cold-room studies with ionic tracers show that 70–80% of the snowpack's solute load is removed with the first 20% of the meltwater. Field studies show similar behavior, and illustrate that the ionic pulse at a point is of very short duration, a few days. At the watershed scale, mixing of meltwater from different subcatchments that melt at different times dilutes the magnitude of the pulse observed in surface waters.

Gaseous uptake on ice surfaces

(M. Conklin, R. Bales, M. Valdez, and G. Dawson, University of Arizona, Tucson, AZ, and R. Sommerfeld, US Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO)
We have looked at the uptake of SO_2 and NO_x by snow and ice and the presence of trace species such as H_2O_2 in snowpacks. Experimental studies and mathematical modeling of SO_2 deposition show that snow acts as a perfect, though diffuse, sink for reactive gases. Liquid-water content, temperature and oxidant concentration are important determinants of SO_2 uptake. It was also observed that SO_2 uptake onto growing ice surfaces at −15°C was in amounts equivalent to Henry's law equilibrium between the gas phase and deposited H_2O.

Monitoring of snowpack chemistry

(Richard Sommerfeld, Robert Musselman, and John Reuss, Rocky Mountain Forest and Range Experiment Station, U.S. Forest Service, Fort Collins, CO, A. Mosier, Agricultural Research Service, Fort Collins, CO, and R. Bales, University of Arizona, Tucson, AZ)
A long-term snow monitoring program was initiated in 1990 at the US Forest Service's Glacier Lakes Experimental Ecosystem Study (GLEES). Eight snow pits are sampled monthly for chemistry, density, structure, and snow-grain type. Analyses are performed according to US Environmental Protection Agency (EPA) protocols for the following: pH, alkalinity, NO_3^-, SO_4^{2-}, PO_4^{3-}, NH_4^+, Ca^{2+}, Mg^{2+}, Na^+, K^+, Al^{3+}, SiO_2, organic and inorganic carbon. Data will be archived in computer readable form and regular reports will be available. Preliminary data confirm the presence of elevated carbon-dioxide gas concentrations in the snowpack at the GLEES site at the critical time of snow-melt initiation. A research program to quantify the effects and to determine the sources of carbon dioxide has been initiated. These studies will include quantifying the biological component of the snowpack.

Snow fencing to increase streamflow

(D.L. Sturges, Rocky Mountain Forest and Range Experiment Station, Laramie, WY)
A snow fence 800 m long and 3.8 m tall was installed on a 307 ha watershed to deposit drifting snow. The study is located in south-central Wyoming on sagebrush rangeland and treatment effects will be evaluated within a paired-watershed study framework. The effects of the fence on total annual streamflow and sediment transport are the principal factors, being studies about treatment effects on snow accumulation, runoff duration and groundwater regime. Economic information about the cost of producing water with snow fences will also be evaluated in the study.

Snow and ice radiation measurements

(L. Radke and R. Ferek, University of Washington,

Seattle, WA, and M. King, NASA)
Using the University of Washington's Cloud and Aerosol Research Group's Convair C-131 research aricraft, a number of investigations over the early summertime north polar ice and oceans were recently completed. Flying from Barrow, Alaska, optical, cloud physics, chemistry, and air pollution data were collected over the Beaufort and Chukchi Seas between 10 and 24 June 1990. Of particular interest is data obtained from a multispectral (visible to near IR) radiometer — over ice, snow, broken ice and ocean under various conditions of cloud cover. Measurements were also obtained of dimethyl sulfide (DMS) as areas of open water increased. Preliminary analysis of this data supports a link between DMS emissions and the formation of nucleation-mode atmospheric aerosols. Arctic haze (anthropogenic pollution) was encountered on about 30% of the flights.

ALPINE GLACIERS

Eliot Glacier, Mount Hood, Oregon

(S. Lundstrom, INSTAAR and Department of Geological Sciences, University of Colorado, Boulder, CO)
Eliot Glacier, located on a large volcano in the northern Oregon Cascade Range, has a moderately debris-covered ablation area. From 1987–90, data has been collected on the surface-velocity field, supraglacial debris characteristics and relation to mass balance, glacier geometry through photogrammetry, proglacial streamflow and suspended-sediment flux, and geologic record of this glacial system. Analysis of these data is directed toward the response of a debris-covered glacier to climate change and to a sediment budget and implied short-term glacial erosion rates.

Subglacial drainage over a till bed

(J.S. Walder, US Geological Survey/CVO, Vancouver, WA, and A.C. Fowler, Oxford University, Oxford, England)
For a glacier or ice sheet resting on porous, permeable sediment, Darcian flow cannot accommodate all melt-water drainage; therefore, some sort of channelized flow must exist at the glacier bed. Applying results of analysis of closure of a channel cut into till (compare Fowler and Walder, *Ice*, 93, p.11), and taking careful account of the mechanics of sediment "flushing", we have defined two possible regimes of channelized flows: one essentially with Röthlisberger channels, the other with "canals" incised into the till with a nearly flat ice roof. A canal system should be distributed over the bed, rather than forming an arborescent network (as do Röthlisberger channels), and will be associated with water pressure near the ice overburden pressure. Such distributed "canal" drainage is likely beneath ice sheets or ice streams, whereas Röthlisberger-channel drainage is expected beneath most mountain glaciers. We are still investigating issures of stability of the two types of drainage network.

Hydrological measurements on glaciers in the Alaska Range

(R. Benedict and C. Raymond, Geophysics, University of Washington, Seattle, WA)
Observations of stage, suspended sediment, and ionic impurities have been carried out for several years on Fels, Black Rapids, and West Fork Glaciers of the Alaska Range. The work is cooperative with the University of Alaska and US Army Cold Regions Research and Engineering Laboratory (Fairbanks). During the last field season, measurements were continued on the Black Rapids and the West Fork Glaciers. The West Fork Glacier is of special interest because of the recent surge in 1987 and 1988. At the termination of this surge in early summer 1988, large amounts of water and sediment were discharged. Analysis of the suspended-sediment particle sizes showed a co-evolution of the particle-size distribution and total suspended-sediment concentration during the last part of the surge and subsequent return to quiescence. Additional particle distributions are being measured to document more fully the relation of the particle-size distribution to variations in the ice dynamics, stream discharge, and sediment load.

Using glacial ice cores from Wyoming as long-term records of atmospheric-deposition quality and climate change

(D.L. Naftz, K.A. Miller, and R.B. See, US Geological Survey, Cheyenne, WY)
During 1988 through 1990, the US Geological Survey has studied selected glaciers within the Wind River Range of Wyoming. The overall objective of this study is to use variations in concentrations of chemical and isotopic constituents from glacial ice to reconstruct long-term records of the chemical quality of atmospheric deposition and to extend long-term climatic and annual discharge records.

In 1988, ice samples were collected from a trench in Knife Point Glacier. Ice stratigraphy exposed on the trench face was used to identify eight annual ice layers corresponding to years 1980–87. Preliminary identification of a Mount St. Helens ash horizon at 2.2 m below the glacier surface was used as a stratigraphic time line to date ice layers.

Chemical results from Knife Point Glacier indicated statistically significant (0.01 confidence level) positive correlation of dissolved-chloride layers to annual-weighted, dissolved-chloride and dissolved-sulfate concentrations measured in wet deposition at the National Atmospheric Deposition Program (NADP) site near Pinedale, Wyoming, from 1982–87 (0.98 for chloride and 0.95 for sulfate).

During June and July 1989, continuous ice cores were obtained from Gannett Glacier at three sites to depths of 14 m below the glacier surface. Geochemical and stratigraphic time lines in the Gannet Glacier ice cores have not been established; however, general trends in the data are observed on a qualitative scale. The cyclical nature of the O^{18}/O^{16} isotope ratios observed in the ice core indicates that ice cores from the Wind River Range glaciers also may be useful for paleoclimate reconstruction. Additional information on the age ranges of the ice cores and postdepositional changes in ice chemistry is needed to verify these speculations.

Although access is difficult, 1990 research efforts were focused on upper Fremont Glacier. On-site activities on Upper Fremont Glacier during the spring and summer of 1990 are summarized as follows:

- Detailed monitoring of the 1989–90 snowpack to evaluate changes in chemical and physical properties during the spring and summer months.
- Radio-echo sounding of the glacier to determine ice

thickness, bedrock topography, and potential deep drilling sites.
- Installation of stakes in the glacier to determine ice velocities.
- Temperature measurements at 10 mm depths to document the mean annual ice temperature.
- Installation of an automatic meteorological station on the glacier to record site-specific temperature, wind direction and speed, relative humidity, and incoming solar radiation.

Glacier hydrology of South Cascade Glacier

(A.G. Fountain, US Geological Survey, Denver, CO)
A combined set of measurements, including streamflow, tracers injections, and water levels in boreholes drilled to the bed, were taken in 1987. To date, the streamflow and tracer measurements have been examined. Three different basins on the glacier drain water to the three glacial streams, and two of the basins and associated streams drain 99% of the water. The streamflow measurements, including discharge and solute load, indicate that the two main basins have different subglacial hydraulics.

One basin has a distributed flow system, characterized by variations in solute load in phase with stream discharge, and the other is channelized and characterized by little variation in load. These results are corroborated by tracer injections. Multiple trace peaks are detected from tracer injections in the distributed flow system, whereas a single peak results from injections in the channelized system. The channelized system is arborescent. Analysis of the tracer dispersion indicates that the distributed flow system consists of either a linked cavity system or a braided stream-like network. The channelized flow system appears to be very sinuous with water depths on the order of 0.1 m and widths on the order of 10 m. The routing of water from the englacial passages significantly affects the tracer traveltime and must be considered when tracers injections are examined.

Glacier variations

(R. Krimmel, Ice and Climate Project, US Geological Survey, Tacoma, WA)
South Cascade Glacier: The 1990 mass balance of South Cascade Glacier was measured with four stakes, a spring snow density measurement, spring snow depth probes, and summer and fall ablation measurements. Winter index station balance was 3.2 m, slightly greater than the previous 10-year average, and net balance was 0.1 m, also above the 10-year average. Basin water discharge, air temperature, and wind were measured continuously.

Columbia Glacier: The retreat of Columbia Glacier was monitored by means of occasional vertical photography. By late summer 1990, the glacier had receded to a length of 61.3 km. Annual recession was about 1.0 km, and recession since 1982 has been 5.0 km. Ice speed near the terminus was 10–15 m per day. An iceberg with a mass of about 5 million metric tons was observed inside the moraine shoal on 25 August 1990. The level of ice-dammed Terentiev Lake dropped to about 20 m, the lowest level yet observed, in the fall of 1989. The following spring and summer the lake was refilling.

Hubbard Glacier: Hubbard Glacier was monitored by means of vertical aerial photography, time-lapse photography, velocity measurements, and tide measurements in anticipation of another closure of Russell Fiord. The zone of potential closure remained 200–500 m wide through 1989 and the fall of 1990.

Glacier air photography: Large format vertical and oblique photographs were obtained in August and September of 1990 of numerous glaciers in western North America. Coverage included glaciers on mounts Hood, Adams, St. Helens, and Rainier, in the Olympics, North Cascades, and southern British Columbia, southeast Alaska, and the Gulf Coast of Alaska through the Kenai Peninsula. The indexed collection is available in Tacoma, WA, at the USGS.

Mechanical and hydrological basis for the rapid motion of Columbia Glacier; a large tidewater glacier in Alaska

(Division of Geological and Planetary Sciences, Caltech, Pasadena)
The physical controls responsible for the large observed flow rates, of order 4–10 m per day operate near or at the base of the ice mass. To obtain direct evidence for them, five boreholes were drilled to the bottom of the ice. A further objective of our work was to shed more light on the current controversy between "hard bed" and "soft bed" advocates in theories of fast glacier flow.

The basal water pressure showed a distinct increase at times of large water input by rainstorms or by strong, warm winds. Basal conditions and materials were observed by penetrometers, by till sampling, and by the bending of the drill stem. At a drill site, 13 km from the calving terminus, where ice thickness is 975 m, the ice is underlain by a layer of about 1 m of penetrable rock debris. At the lower site, 6 km from the terminus, the bed is hard, as found in two boreholes, 527 m deep, where the penetrometer passed through less than 0.1 m debris before hitting hard rock.

The rapid motion and the fluctuations of motion measured at the surface of the glacier (M. Meier and others) are due to rapid basal sliding, which is enabled by the high basal water pressure.
(Participants: M. Blume, M. Fahnestock, K. Echelmeyer, H. Engelhardt, N. Humphrey, B. Kamb, M. Sumkes. NSF grant DPP 86-19352.)

Changes in glaciers and glacier runoff, Wind River Range, Wyoming

(R.A. Marston, Department of Geography, L.O. Pochop and G.L. Kerr, Department of Agricultural Engineering, University of Wyoming, Laramie, WY)
Calculations were made of the ice lost from Dinwoody Glacier in the Wind River Range of Wyoming using parallax measurements on matching aerial photograph stereopairs of 1958 and 1983. Measurements also were made of the ice remaining in Dinwoody Glacier using a portable radio echo-sounder. These point measurements were used to construct isopach maps of lost ice thickness and remaining ice thickness in the glacier. Planimetric measurements from these maps led to calculations of lost and remaining ice volumes which then were converted to water-equivalent values. The water equivalent remaining in Dinwoody Glacier in 1989 was approximately equal to that lost between 1958 and 1983. By an area-weighted extrapolation, the water equivalent lost from all Wind River glaciers in this 25-year period was estimated to have been 34% of the runoff from a 900 km^2 area centered on the Wind River Range, by comparison with a map

published by Schuetz and others (1985). The unusual spatial pattern of downwasting may be explained by long-wave enhancement from the terrain surrounding upper elevation cirques, although this hypothesis requires further study. At this rate of retreat and downwasting, Dinwoody Glacier would disappear in approximately three decades, with significant adverse impacts on late summer and early fall water supplies for downstream irrigators and instream flow needs.

SEA ICE

Remote sensing

(W.J. Campbell, E.G. Josberger, Ice and Climate Project, US Geological Survey, Tacoma, WA)

The Ice and Climate Project (ICP) is continuing its analysis of the decadal satellite passive microwave data sets of sea-ice conditions in both the Arctic and the Antarctic oceans. This cooperative program with NASA Goddard Space Flight Center has shown, once the annual cycle is removed, a small decrease in sea-ice coverage over the past decade. As part of the European Research Satellite 1 (ERS-1) sea-ice validation program, ICP co-directed the aircraft SAR observations of the sea ice in SIZEX 1989 along with the concurrent ship based in situ snow and sea-ice observations. These on-going programs will carry out additional field programs after the launch of ERS-1.

Albedo of East Antarctic sea ice

(R. Brandt and S. Warren, Atmospheric Sciences, University of Washington, Seattle, WA)

R. Brandt and S. Warren were guests of the Australian Antarctic Division (I. Allison) for a ship cruise through the East Antarctic sea-ice zone, October–December 1988. Spectral and total albedos were measured for different types of sea ice. Their fractional coverage (in the region of the ship) was also recorded hourly so that area-average albedos could be estimated.

Active/passive microwave remote sensing of polar ice

(M.R. Drinkwater, F.D. Carsey, J.P. Crawford, and B. Holt, NASA/Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA)

Synthetic aperture radar and passive microwave radiometer data are being combined to develop techniques for calculating geophysical properties of sea and glacier ice using future spaceborne microwave remote sensing systems such as those on board ERS-1, Radarsat, J-ERS-1, and EOS. Accurate coregistration of airborne data sets collected by airborne active and passive instruments over the Bering, Chukchi, and Beaufort Seas is enabling the development of multisensor algorithms for the extraction of information relating to the geophysical properties of the sea ice and its accompanying snowcover.

Arctic Ocean ice–climate interactions

(R.G. Barry, A.S. McLaren, and R.C. Schnell (CIRES/University of Colorado, Boulder, CO)

Under a 5-year Office of Naval Research Program, CIRES in collaboration with Dartmouth College are studying ice–atmosphere interactions in the Arctic. Research at CIRES is concerned with (1) the mechanisms of changes in sea-ice extent, concentration and thickness using remote sensing, buoy and sonar data; (2) the space time characteristics of snow-cover melt, lead occurrence, and ice-thickness distributions; and (3) Arctic atmospheric circulation, synoptic activity, cloud regimes and vertical atmospheric structure and their interactions with ice/ocean surfaces. Highlights of this work include identification of a recurring late summer reversal of ice drift in the Canada Basin, related to persistent cyclonic weather systems; a tendency in late summer for reduced ice concentrations (70–80% concentration) in the southern Canada Basin near 150°–160° W due to ice divergence; and the existence of plumes of ice crystal condensate emanating from major leads in winter that can penetrate up to 4 km into the troposphere. Annual reports and a publication list are available.

DMSP/OLS satellite data and Navy/NOAA Joint Ice Center data for snow-cover and sea-ice research

(G. Scharfen (NSIDC/CIRES/University of Colorado, Boulder, CO)

Defense Meteorological Satellite Program/Operational Linescan System (DMSP/OLS) visible-band and thermal infrared-band film images from the US Air Force are archived at NSIDC, providing 2.7 km resolution global area coverage and 0.6 km resolution local area coverage on a daily basis since 1973. Digital data from the DMSP/OLS will be archived beginning mid-1991. The Navy/NOAA Joint Ice Center routinely gathers polar data streams (NOAA/AVHRR satellite data, NMC model outputs and meteorological field data) for operational forecasting of sea ice conditions. These data and the analysis products from JIC's Digital Ice Forecasting and Analysis System (DIFAS) will be archived at NSIDC beginning late-1991. Digital data from both systems will be available to the research community in several formats at the cost of reproduction. Research underway using these data (in conjunction with other investigators at CIRES) includes: production of a 10 year data base of Arctic Basin surface reflectivity related to summer snow melt (spatial and temporal progression of snow melt atop sea ice, sea-ice extent and related albedo), analysis and assessment of sea-ice fluctuations (extent and concentration) in relation to atmosphere–ocean processes (using the integrated polar ocean–ice–atmosphere data set provided by the JIC DIFAS).

(NSIDC = National Snow and Ice Data Center)

(CIRES = Cooperative Institute for Research in Environmental Sciences)

Retrieval of ice-surface temperature, OLR, and cloud cover from thermal sensors

(J. Key and M. Haefliger, CIRES/University of Colorado, Boulder, CO)

Methods of retrieving ice surface temperature (IST) and outgoing longwave radiation (OLR) from narrow-band thermal sensors are being investigated. Radiative transfer modeling with a new set of Arctic radiosonde data are used to simulate the advanced very high resolution radiometer (AVHRR) thermal bands, and empirical relationships between radiances measured in these channels and IST or OLR are developed. As expected, atmospheric attenuation from the water vapor column is small. As in lower latitude studies, the complicating factor is cloud contamination. The problem is even more complex in the polar regions, where clouds can be warmer than the surface and can also be more reflective. For this reason cloud detection algorithms are being investigated, and it appears that a multispectral, multisensor approach will be needed to retrieve cloud-top height, optical thickness, and cloud fraction. Data sets consisting of AVHRR, TOVS (Tiros Operational Vertical Sounder), and passive microwave data are now being assembled.

Remote sensing of leads with reference to relationships of scale

(J. Key, J. Maslanik, and A.S. McLaren, CIRES/ University of Colorado, Boulder, CO)
Our ability to retrieve statistics of sea-ice leads (e.g. width, orientation, spacing) from satellite data is being examined. Sensor responses are simulated with a radiative transfer model under a variety of atmospheric, surface, and viewing geometry conditions. This approach aids in the determination of what the satellite is actually measuring. The way in which lead statistics change with the satellite field-of-view is an important issue if comparisons between high-, medium-, and low-resolution sensors are to be of any value. Our approach to this problem uses multisensor data sets as well as methods for successively degrading high resolution data. Lead width distributions sampled along a transect and the "true" width distribution are being related in a probabilistic sense.

Variablility in the low-level Arctic temperature inversion

(M.C. Serreze, J.D. Kahl, Russel C. Schnell, CIRES/ University of Colorado, Boulder, CO)
An Arctic temperature-sounding data base, consisting of all available historical Arctic rawinsonde data above 60° N, is being compiled to examine long-term variability and possible trends in Arctic temperatures at the surface and aloft. Current research is focusing on spatial and temporal variability in the low-level Arctic temperature inversion. Recent results for the Eurasian Arctic will be combined with data for Alaska, Canada, and from drifting ice-island stations. Synoptic-scale controls on variability of the inversion layer are also being addressed.

Sensitivity studies of turbulent fluxes in the ice pack

(J. Maslanik, A. Schweiger, J. Key, M. Haefliger, K. Steffen, CIRES/University of Colorado, Boulder, CO)
Design and application of remote-sensing methods to large-scale surface energy budget calculations require an understanding of the sensitivity of flux estimates to uncertainties in measurements of surface conditions. A radiative transfer model, a zero-dimensional ice-growth model, and equations for bulk transfer coefficients adjusted for fetch and stability are being used to calculate the change in turbulent fluxes due to variations in ice thickness, ice-surface temperature, snow cover, lead width, and atmospheric conditions. These sensitivities will be combined with the expected errors in remotely sensed observations to estimate the effectiveness of remote-sensing methods for measuring some of the variables that contribute to the surface energy budget.

Assimilation of observations and two-dimensional ice models

(J. Maslanik, M. Serreze, M. Cavanaugh, CIRES/ University of Colorado, Boulder, CO)
Satellite-derived surface reflectances and ice concentrations are being combined with a two-dimensional dynamic–thermodynamic ice model to study how surface parameterizations compare to remotely sensed surface conditions, and to investigate the effect on modeled ice growth and transport of including the satellite-derived surface conditions directly in the ice model.

Re-analysis of meteorological fields, ice motion, and ice concentration for the Arctic

(M. Serreze, J. Maslanik, J. Key, CIRES/University of Colorado, Boulder, CO)
Gridded meteorological data from NMC and the Arctic Drifting Buoy Program and ice concentration and ice type estimated using passive microwave data are being processed to generate basic statistics for a time series of surface pressures, internal buoy temperatures, geostrophic winds, and ice conditions for regions in the Arctic. Dominant patterns within these fields as well as relationships between the different variables will be defined using discriminant and principal components analyses. Our initial focus is on possible linkages between atmospheric forcing fields, changes in ice concentration, and variations in ice export into the North Atlantic through the Transpolar Drift Stream.

Artificial intelligence applications for sea-ice processes

J. Maslanik and J. Key, CIRES/University of Colorado, Boulder, CO)
The rule-based system methodology has been applied to the analysis of Landsat imagery for the retrieval of sea-ice lead statistics, primarily widths, orientations, and densities. Rule-based systems are also being examined for their application to the retrieval of sea-ice concentration from passive microwave and ancillary data. Neural networks were used to classify polar clouds and surfaces in AVHRR imagery, but were less successful in describing cloud morphologies. We have also developed a neural network to detect melt effects and the "false" multiyear ice signature in a passive microwave time series. Currently, a neural network is being developed that takes as input passive microwave data and a simple sea-ice model, and estimates concentrations of first-, second-, and multi-year ice.

Sea-ice thickness and roughness

(R.H. Bourke and R.G. Paquette, Naval Post Graduate School, Monterey, CA)
We have been working on sea-ice thickness and roughness distributions for the Arctic Ocean based on submarine upward-looking sonar data. We are also working on deriving a data base of these parameters for use in under-ice acoustic transmission predictions, especially near the sea-ice margins.

The Beaufort Sea mesoscale circulation study

(K. Aagaard and C. Pease, PMEL/NOAA, Seattle, WA)
The Outer Continental Shelf Beaufort Sea study was completed, with the following principal conclusions:

(1) Below the upper 40–50 m, the major circulation

feature of the outer shelf and slope is the Beaufort Undercurrent, a strong flow which in the mean is directed eastward, but which is subject to frequent reversals toward the west. These reversals are normally accompanied by upwelling over the outer shelf. The undercurrent is likely part of a basin-scale circulation within the Arctic Ocean.

(2) While the influence of the wind on the subsurface flow in the southern Beaufort Sea is statistically significant, it is generally of secondary importance and accounts for less than 25% of the flow variance below 60 m. Therefore, below the mixed layer the circulation on the relatively narrow Beaufort shelf is primarily forced by the ocean rather than local winds.

(3) There are large changes in wind variance with season, with the largest variance occurring in late summer/early autumn and again in January because blocking ridges in the North Pacific shift the storm track westward over the west coast of Alaska and across the North Slope.

(4) Despite the seasonally varying wind field and the large seasonal differences in the upper-ocean temperature and salinity fields, there is no evidence for a seasonal variability in the subsurface circulation. This situation contrasts with that in Bering Strait, and probably also in much of the Chukchi Sea, where a seasonal wind-driven cycle in the transport is readily apparent.

(5) During 1986–87, the Beaufort Undercurrent appears to have been anomalously deep by 30–40 m. The consequences of such anomalies for the upper-ocean velocity structure and transport are probably significant.

(6) Both 1986 and 1987 were warmer than normal, with less coastal ice in the summer and autumn and more storms passing along the west coast of Alaska and across the North Slope. These climatological near-minimum ice years were followed in 1988 by the heaviest summer ice along the Chukchi coast since 1975.

(7) The atmospheric sea-level pressure field was well represented by the FNOC surface analysis if the 12 h lag of the FNOC pressures is taken into account. However, the FNOC surface air temperature field shows a systematic over-prediction during winter and spring of 10–20°C, leading to an annual over-prediction of air temperature by 3–13°C.

The Freeze experiment

(C. Pease, PMEL/NOAA, Seattle, WA)

The FREEZE experiment, begun in 1987, continued the study of fine- and mesoscale processes related to ice formation over the western Arctic Shelves. A combination of current meter and pressure-gauge moorings were used to estimate dynamical effects, drifting ice buoys to trace ice motion and ice edge advance, and CTD surveys to map heat and salt budgets prior to and during initial fall freezeup.

Investigations in the Greenland Sea

(K. Aagaard, PMEL/NOAA, Seattle, WA)

Convection and water mass transformation in the Greenland Sea, which is being studied under the International Greenland Sea Project (IGSP), is of major consequence to the ventilation of the deep ocean. During FY 89, PMEL was involved in five of the IGSP cruises and an instrument deployment to monitor the Denmark Strait overflow. The work employs long-term moored instrument arrays and seasonally repeated hydrographic censuses of very high accuracy. Preliminary examination of the hydrographic data suggests that during 1988–89 the upper 2 km of the ocean were successfully ventilated following several years of little, if any, deep convection. Two new instrumented arrays were deployed in 1989 to monitor the southwestern part of the Greenland Sea, where recirculation from the East Greenland Current may provide fresh water to the convective gyre. The gyre appears to be rather delicately poised with respect to its ability to sustain convection, so that small variations in the fresh water supply can alter or stop the convection.

Sea-ice processes and modeling

(J. Overland and C. Pease, PMEL/NOAA, Seattle, WA)

As a major step in improving forecasts of coastal sea-ice motion around Alaska, the existing one-dimensional coastal sea-ice/barotropic ocean model is being expanded to two dimensions conforming to the topography of the western Arctic Shelves. The new model has nominal 18 km grid spacing, employs the ice-thickness/strength relation developed for the 1-D model, and retains both the barotropic and wind-driven forcing critical to ice motion on these shelves. The effects of different lateral boundary conditions are being examined together with a sensitivity study of the various model parameters. The model is expected to lead to a full forecasting capability for the Navy/NOAA Joint Ice Center in 2–3 years.

Coordinated Eastern Arctic Experiment (CEAREX)

(J. Overland, PMEL/NOAA, Seattle, WA)

The objective of the PMEL CEAREX effort is to collect a comprehensive high Arctic meteorological data set covering fall through spring. The regional pressure gradient was determined from drifting buoys, while radiation, atmospheric soundings, and near-surface wind and temperature profiles were measured from a drifting ship and ice camp. During spring, two flights were made over the ice camp with the NOAA P3 research aircraft, providing detailed observations of the vertical variation of turbulence, wind, and temperature. A regional atmospheric model will be developed capable of improving ice forecasting and climate models by including the low level temperature inversion structure found in the Arctic in winter.

Vessel icing

(J. Overland and C. Pease, PMEL/NOAA, Seattle, WA)

At high latitudes, spray generated by ships in heavy seas can freeze to vessel structures, producing an extreme hazard. The operational NOAA vessel-icing forecasting algorithm was evaluated against advances in understanding the icing process and against recent operational experience. The NOAA algorithm shows excellent results when compared with a new cold-water data set from the Labrador Sea, as well as having provided excellent forecasts to over 140 fishing vessels in Alaskan waters during late January 1989, the worst icing episode of the decade.

Boundary layer interactions forced by Arctic leads: remote sensing studies

(C. Fairall and B. Neff, NOAA/ERL Wave Propagation Laboratory, Boulder, CO)

The Atmospheric Studies group at WPL is developing instrumentation and techniques for a study of the influence of Arctic leads on the polar PBL during the LEADEX experiment planned for 1992. LEADEX is sponsored by the Office of Naval Research with additional participation by NOAA and NASA. Two different sampling strategies are planned for the surface-based meteorological studies for the field phase of the program. First, a suite of surface-based remote sensors (a UHF doppler wind profiler and a doppler sonar) and micrometeorological in situ sensors on a tower will be continuously operating at a semi-permanent ice camp for the duration of the field program (10 March to 30 April 1992). These systems will provide a continuous record of Arctic boundary layer profiles, standard bulk surface meteorological data, and surface energy budget data for the study of the stable PBL, diurnal cycles, and interactions with atmospheric gravity waves. Second, several portable packages of instruments will be deployed around selected Arctic Leads. Each package will include a micrometeorological tower for surface fluxes and a doppler minisonar for turbulence and vertical velocity profiles up to 200 m. A tethersonde will be used to make profiles of temperature, humidity, and winds at various distances downwind of the lead. The sonar and tethersonde data will indicate the infulence and development of the lead plume as a function of distance downwind. This study will be done in cooperation with turbulence closure model and large eddy simulation studies planned at the Naval Oceanic and Atmospheric Research Laboratory (NOARL/West) in Monterey, CA. The basic goals of the study can be stated in the following questions:

(1) Are the present bulk formula for the fluxes from a single lead adequate?

(2) Can the PBL influence fo a single lead be described by a simple 1-dimensional model?

(3) Can the effects of a field of leads on 50 km scales be parameterized?

(4) How do leads affect the radiative balance?

(5) What is the importance of gravity waves in Arctic PBL dynamics?

(6) How do PBL/Lead scales processes couple to the mesoscale?

(7) Is there a "base state" of the stable Arctic PBL in the local absence of leads?

(R.A. Brown and D. Rothrock, PSC/APL, University of Washington, Seattle, WA)
We have been maintaining an active file on methods of calculating momentum, heat and moisture fluxes over pack ice, the MIZ, and polar oceans. We are currently assessing state-of-the-art calculations and data bases for polar flux calculations.

Moored Upward Looking Sonar

(R. Moritz and N. Untersteiner, PSC/APL, University of Washington, Seattle, WA)
Scientists and engineers at the Applied Physics Laboratory have designed, built, tested, and deployed three Upward Looking Sonar (ULS) instruments to monitor the draft distribution of sea ice passing over a stationary mooring for periods of a year or longer. The ULS is designed to provide absolutely calibrated time-series data on the ice cover of the Arctic Ocean, which are needed for process studies, model validation, and climate monitoring. The first two ULS units were deployed in the Chukchi and Greenland Seas and recovered one year later in 1989. Well-calibrated, geophysically useful data were obtained. Studies of the time series, including comparisons with remote sensing and meteorological data, are continuing in parallel with an engineering effort to fine-tune the ULS design.

Microwave Emission/Cold Regions Research and Engineering Laboratory Experiment (CRRELEX)

(T. Grenfell, Atmospheric Sciences, University of Washington, Seattle, WA, and D. Winebrenner, PSC/APL, University of Washington, Seattle, WA)
Microwave signatures in the transition from open water to various new ice forms are being studied in the Arctic Basin, Greenland Sea, and at the Cold Regions Research and Engineering Laboratory (CRREL). The CRRELEX 90 team succeeded in producing frazil ice, observing the effect of snowfall on this ice, and in producing a pancake ice sheet — all for the first time. Observations of microwave signatures of frazil and pancake ice, in conjunction with analysis of data collected in the field, are being used to develop theoretical models of ice scattering and emissivity. The results of this study will be integrated into the efforts of Rothrock and Thomas on Kalman filtering of SSM/I data for assimilation into models of the ice cover.

Sea ice remote sensing using polarimetric SAR

(D. Winebrenner, PSC/APL, University of Washington, Seattle, WA, and L. Tsang, Electrical Engineering, University of Washington, Seattle, WA)
The utility of polarimetric synthetic aperture radar (SAR) data for sea-ice type discrimination is being investigated. Techniques are being developed for the retrieval of geophysically significant properties of sea ice and its snow cover from microwave observations, based on a quantitative understanding of the physics of formation. This work is in collaboration with the Jet Propulsion Laboratory's polarimetric SAR program.

Arctic Buoy Program

(R. Colony, PSC/APL, University of Washington, Seattle, WA)
Since 1979, a network of meteorological data buoys has been maintained in the Arctic as part of the Coordinated Arctic Buoy Program. The buoys, tracked by satellite using Service Argos, provide measurements of sea-ice motion, surface atmospheric pressure, and surface temperature. Data are collected, analyzed, and archived at the Polar Science Center; distribution is through the World Data Center for Glaciology. The scientific objectives of the Arctic Buoy Program are to collect information for climatology (ice motion, surface winds, and temperature); to monitor climate and global change; to support ice–ocean–atmosphere analysis and forecasting; and to support other ongoing research and field programs.

Sea-ice motion

(R. Colony, PSC/APL, University of Washington, Seattle, WA)
This research involves the study of the conditional/spatial statistics of ice motion using a large database of sequential SAR images, sequential AVHRR images, and the trajectories of buoys tracked by satellite using Service Argos. Particle pairs separated by distances of 20–800 km are being analyzed to provide a complete description of some types of ice motion. Application of this research is for studies of ice deformation, combining the large-scale discontinuities in the field of ice motion.

Mean ice motion in the Arctic Basin

(R. Colony, PSC/APL, University of Washington, Seattle, WA)

The mean seasonal fields of sea ice motion are analyzed wholly in terms of the observed motion of individual ice particles. The motion data are derived from the trajectories of beset ships, manned ice stations, and automatic data buoys. About 400 trajectories have been collected in the database. The analysis procedure is based on the theory of statistical interpolation. An optimal estimation, u, of the field of motion is expressed as a linear combination of the observations. The estimate is optimal in the sense of minimizing the departure of u from the true mean fields of ice motion. The procedure also produces an optimal estimate of the spatial gradient of ice motion. Mean seasonal fields of motion, vorticity, divergence, and shear are also analyzed.

Autonomous Conductivity-Temperature Vehicle

(J. Morison, PSC/APL, University of Washington, Seattle, WA)

An Autonomous Conductivity-Temperature Vehicle (ACTV), has been designed and built to record the horizontal variation of ocean temperature and salinity under the pack ice. The vehicle can operate for over an hour at a speed of $2\,m\,s^{-1}$ and depths of up to 250 m. Its Sea-Bird SeaCat sensor package logs data at a rate of 9 Hz with 16-bit resolution. A typical run consists of launch from a fixture suspended 17 m below the ice, a programmed dead-reckoning run pattern, a homing run with shutdown near a homing beacon, and recovery by divers. The ACTV was used successfully in the Coordinated Eastern Arctic Experiment north of Fram Strait in spring 1989. Work is continuing to increase reliability, to accommodate new instrumentation, including a three-axis rate gyro package, and to improve recovery techniques. Further tests and experiments to study the convection pattern around leads are planned for the Leads Accelerated Research Initiative in 1991.

Arctic Oceanographic Buoy Program

(J. Morison, PSC/APL, University of Washington, Seattle, WA)

Since 1981, PSC has been involved in developing and deploying drifting SALARGOS bouys. The buoys, with chains of temperature and conductivity sensors, have been collecting and transmitting ocean temperature and salinity data. PSC is now building the next generation of polar ocean profiler (CTD) buoys. The scientific objectives of the Arctic Oceanographic Buoy Program are to collect information on the basic hydrography of the Arctic Ocean (upper ocean temperature and salinity) and the surface climatology (ice motion, atmospheric pressure and temperature). These data are used for ice–ocean–atmosphere analysis forecasting, to support other ongoing research and field programs, and to monitor climate and global change.

Arctic mixed-layer dynamics

(J. Morison (PSC/APL, University of Washington, Seattle, WA)

The objective of this work is to further our understanding of the dynamic and thermodynamic processes causing changes in the velocity and density structure of the upper Arctic Ocean. Data obtained from the ONR-sponsored Arctic Internal Wave Experiment (AIWEX) have been analyzed and a model of air–sea-ice interaction in the Marginal Ice Zone has been completed. In 1989, two major projects involving new instrument systems, a yoyo CTD and the Autonomous Conductivity Temperature Vehicle (ACTV), were successfully carried out during CEAREX, the Coordinated Eastern Arctic Research Experiment.

An integrated system for measuring and modeling ice–ocean–atmosphere heat flux in a winter lead

(M. Steele, PSC/APL, University of Washington, Seattle, WA)

One objective of this project is to introduce a measure of floe geometry into numerical models of sea ice. The breakup of the summertime ice pack affects the average melt rate over a given region, but this is quite crudely parameterized in most large-scale models. Various schemes are under consideration which will include a measure of average floe diameter (or the distribution thereof) and its evolution in time. The other major objective is to quantify the amount of heat that escapes from a newly-formed winter lead during ice growth. Several "freeze-in buoys" are under construction for deployment in a lead, where they will obtain high-resolution thermal data within the resulting ice cover. From this we can estimate the heat flux as well as the ice thickness.

SAR and microwave remote sensing of sea ice

(D. Rothrock and D. Thomas, PSC/APL, University of Washington, Seattle, WA)

The goal of this research is to apply satellite data to the geophysical description and understanding of the polar ice cover and oceans. Synthetic aperture radar imagery, passive microwave, vertical sounder, and thermal infrared satellite data, and drifting buoy data are being used to estimate the ice mass balance and ocean surface fluxes. Progress has been made in analyzing a series of SAR images of the same ice throughout the life of Seasat, evaluating the performance of tracking algorithms in relation to environmental conditions, calculating the sensitivity of surface fluxes to lead and wind parameters, comparing in situ and satellite observations of Antarctic ice concentration, and estimating ice drift in peripheral Arctic seas from meteorological data for use in a Kalman filter analysis of the SMMR passive microwave satellite record.

Arctic ice balance

(D. Rothrock, PSC/APL, University of Washington, Seattle, WA)

One 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. Satellite Scanning Multichannel Microwave Radiometer (SMMR) data are being integrated with Arctic Buoy Program (ABP) data for the purpose of quantifying the sea ice mass budget. We have shown how passive microwave data can be combined with a simple sea ice model, using a Kalman filter, to give improved estimates of ice concentration and the area of multiyear ice, and to provide estimates of the strengths of the controlling processes.

Polar exchange at the sea surface (POLES)

(D. Rothrock, R. Brown, S. Martin, M. Steele, and D. Winebrenner, PSC/APL, University of Washington, Seattle, WA)

As part of NASA's multidisciplinary Earth Observing System (EOS) program, the surface exchange in high-latitude oceans is being investigated. The work emphasizes applying satellite and other data to the estimation of surface fluxes over polar seas, and providing these fluxes as an archiveable data set. Project objectives are to (1) develop a surface flux model for ice-covered and ice-free oceans (which assimilates satellite and ground-based observations, and which incorporates an atmospheric planetary boundary-layer model, a sea-ice model, and an upper ocean model); (2) provide a long-term data set of polar surface exchange of momentum, heat, salt, moisture, and radiation; of biomass and primary production; of the structure of the atmospheric planetary boundary layer and upper ocean; and of sea-ice properties; (3) study the dynamics of the upper ocean and ice cover, which contribute to the formation of the intermediate and deep water masses of the World Ocean; (4) determine the processes controlling sea-ice mass and momentum balance, and extent; and (5) observe and quantify the biomass and primary productivity of the polar seas and their relation to sea-ice and oceanic conditions.

Remote sensing of lead systems and lead fluxes

(D. Rothrock, PSC/APL, University of Washington, Seattle, WA)

The objective of the leads study is to lay fundamental groundwork for quantifying useful geometric statistics of lead systems and for observing these statistics from satellites, to observe the regional and temporal variability of lead statistics, and to investigate the utility of thermal and synthetic aperture radar data in the estimation of lead properties and surface fluxes.

MISCELLANEOUS

Interaction of hot eruptive products with snow and ice

(J.S. Walder and C.L. Driedger, CVO, US Geological Survey, Vancouver, WA)

Significant hazards are associated with floods and debris flows triggered by eruptions of snow- and ice-clad volcanoes, such as Redoubt Volcano in Alaska, active during 1989–90. Motivated by field observations by ourselves and others, we are investigating by theory and experiment fundamental physics of such interactions, including (1) heat transfer between hot eruptive products and snow/ice; (2) mechanical mixing of hot and cold phases; and (3) implications for sedimentologic interpretation of deposits.

Outburst floods and debris flows at Mt Rainier National Park

(J.S. Walder and C.L. Driedger, CVO, US Geological Survey, Vancouver, WA)

Since autumn of 1986, more than ten moderately large debris flows have moved along Tahoma Creek, which drains South Tahoma Glacier on the southwest flank of Mt Ranier in Washington state, USA. Debris flows during hot, dry spells in summer apparently are triggered by glacier outburst floods, whereas debris flows during periods of heavy rain in autumn may be related to the glacier. The source area for rock debris in these flows is an proglacial area that was covered by ice during the 1960s and 1970s, but is now completely detached from the glacier, although an ice 'core' remains. This source area has been incised as much as 30 m locally; debris has been transported as much as 5 km downstream. This deeply incised area, with its steep slopes at least partially ice-cemented, is likely to remain unstable and contribute to debris flows for some years to come. Concomitant damage to roads and facilities in the national park has caused serious concern amongst park managers.

The physics of water ice in the Martian environment

(D.M. Anderson, Texas A&M University, College Station, TX)

Sufficient evidence has been obtained from experiments with terrestrial analogues of the Martian Regolith and from the results of the Viking Orbiters and Landers to allow reliable predictions and conclusions to be drawn from the known thermodynamic phase diagram for water. The range of atmospheric water contents on Mars is generally known, as are atmospheric temperatures and pressures. Water ice has been detected at the surface of the Martian polar regions. Water is known to be present in the Regolith in at least two of its most common forms, water vapor and ice. In addition, there is evidence of water in the form of crystalline hydrates and as adsorbed phases on the surfaces of mineral matter present. Several types of subsurface ice are possible on Mars inasmuch as the crystal structure of terrestrial subsurface ice is known to be variable. Most subsurface ice is hexagonal, Ice-1; clathrate structures are known, however. Because of the very much lower temperatures, cubic ice is a possibility on Mars.

Water-ice phase composition data have been obtained for a large number of terrestrial mineral mixtures that are known to be possible Martian analogues. Data have been obtained from a number that have high concentrations of naturally occurring soluble salts. Experiments performed on these material under controlled conditions corresponding to those characteristic of the Martian environment conform in every way to the thermodynamic equilibria described by the water-ice phase diagram when the possible presence of solutes and interaction with mineral matter through adsorbed phases is taken into consideration.

In terrestrial permafrost, ice contents are only a fraction of the total water present. A significant portion of this water exists in an unfrozen state, distributed throughout the internal pore space and over interfacial areas. The proportion of the ice to unfrozen water varies in a characteristic manner as temperatures, solute concentrations, and pressures vary. These basic relationships are well established for terrestrial conditions and must be expected to prevail in the Martian environment as well. The strength and deformation characteristics of terrestrial permafrost are known to be directly related to the unfrozen water-ice contents, and this must also be the case on Mars. Hydrological properties and electrical properties are similarly dependent on these thermodynamic relationships.

Because the Martian Regolith is much colder than terrestrial permafrost, the amounts of unfrozen water present must be generally lower, although the effect of lower temperatures probably is significantly offset by the probability of significantly higher salinities in the Martian Regolith. Terrestrial permafrost deforms readily under stress in the terrestrial environment. Martian permafrost is also expected to deform when stress is applied, but because of the very much lower prevailing temperatures and the greater thickness of Martian permafrost, the surface of Mars is undoubtedly very stable, at least over short time periods. It is possible that in earlier times, Mars was a warmer planet with considerably higher concentrations of water vapor in its atmosphere. Under such conditions the presence of ice fields and glaciation characteristic of terrestrial Alpine regions might have been possible.

Interfacial water in hydrated smectite systems subjected to freeze–thaw temperature cycles

(D.M. Anderson, Texas A&M University, College Station, TX)

The phenomenology of hydrated smectite systems has been investigated extensively over a period of many decades. The complex physical and chemical behavior of these systems results primarily from the nature and property of the interfaces present. Among them are the following types: ice-ice (grain boundary); ice-water-air (capillary); silicate-water-silicate (primarily interlamellar; and silicate-water-ice-air (extralamellar). The latter is of particular interest in interpreting the behavior of hydrated smectite systems subjected to temperature cycles through the normal freezing point of water (0°C).

Experimental evidence now in hand is sufficient to establish that an interfacial phase with liquid-like properties, the thickness of which changes with temperature, separates both the silicate-ice and the ice-air phases. Smectite clays attract water very strongly and, because of their expanding lattices, this group of minerals is capable of absorbing very large quantities of water. Consequently, the silicate-water interfaces predominate at temperatures above 0°C, whereas the silicate-water-ice interfaces predominate at temperatures below freezing, although some gaseous interfaces may be present.

Well established thermodynamic relationships govern the relative amounts of unfrozen, interfacial water and ice present at sub-zero temperatures for a given material. With variables such as pressure, electrolyte contents, and other solute contents, etc., held constant, the quantities of interfacial water present in these frozen systems may be expressed as a function of temperature by the "water-ice phase composition curve". It can be determined by any of a variety of methods, including dilatometry, calorimetry, X-ray diffraction, heat capacity measurements, nuclear magnetic resonance spectra, differential thermal analysis, water vapor adsorption isotherms, tensiometric and pressure membrane apparatus measurements, and, finally, freezing point depression curves. These methods are described briefly, and the interpretation and use of the water-ice phase diagram for hydrated smectite systems is explained and illustrated.

Detailed studies made by differential scanning calorimetry of several hydrated smectites have revealed complexities in the unfrozen interfacial water layer as its thickness decreases with decreasing temperature and more and more interfacial water is added to enlarging ice crystals. At −35°C to −50°C, exotherms associated with complex phases appear. When these materials are warmed, other anomalies are observed. In the case of smectites containing electrolytes, the melting endotherms observed by differential scanning calorimetry persist to temperatures significantly above the normal melting point of ice, suggesting that chemical interactions during freezing and subsequent deep cooling may produce hydrated ionic or molecular complexes that are stable up to a few degrees above 273°K (0°C) and that these complexes decompose endothermically as the temperature continues to rise. This work is continuing.

Coordinated Eastern Arctic Experiment (CEAREX) data management

(C.S. Hanson, NSIDC/CIRES, University of Colorado, Boulder, CO)

Under contract to the Office of Naval Research, NSIDC is preparing a CD-ROM containing data from the CEAREX field experiments. This is planned to be the first in a series of CD-ROM's presenting Eastern Arctic data, and will contain hydrography, bathymetry, bio-optics, meteorology, ice stress and deformation, samples of ambient noise, and several other small data sets.

CEAREX field experiments were carried out between August 1988 and May 1989, to examine the structure and function of the meso- to small-scale processes in the exchange of momentum, heat, and biomass between the Arctic Ocean and the Nordic Seas. Ice process studies included intrafloe stress and deformation, floe failure, and algal habitat. The experiment included two camps located on drifting ice floes and was supported by three ships, with remote sensing and support flights using helicopter and fixed-wing aircraft. CEAREX data management at NSIDC is initially a two-year project, with production of one CD-ROM scheduled during each year. Distribution of the first disc to the CEAREX investigators is planned for early April 1991. General distribution will begin in June 1991, pending review of the disc by ONR and the data contributors. (November 1990.)

Snow and ice data management

(R.G. Barry, National Snow and Ice Data/World Data Center-A for Glaciology, CIRES, University of Colorado, Boulder, CO)

The Data Center continues to expand its role as a national and international focal point for snow and ice data. The CITATION Data Base containing over 27 000 bibliographic entries is now available through the National Information Services Corporation on a CD-ROM "Arctic and Antarctic Regions." The World Data Center also published *Glaciological Data Report* 23 ("Ice Core Update, 1980–89; Permafrost Data Workshop"). New data holdings include updates to records of Arctic and Antarctic sea-ice concentration, MIZEX/CEAREX data, and gridded passive microwave data from SMMR and SSM/I.

Green icebergs

(I. Allison and V. Morgan, Australian Antarctic Division, and R. Brandt and S. Warren, University of Washington, Seattle, WA)

A green iceberg was sampled near Mawson Station (East Antarctica), and its spectral reflectance was measured. The reason for the green color is being investigated. The oxygen isotope analysis indicated that the ice was formed by freezing of seawater, probably to the bottom of an iceshelf.

Optical constants of CO_2 ice

(G. Hansen, University of Washington, Seattle, WA; Geophysics, working at Jet Propulsion Laboratory, Pasadena, CA)

G. Hansen has succeeded in growing large clear crystals (several centimeters thick) of CO_2 ice, for use in measuring the spectral absorption coefficient at wavelengths where the absorption is weak. These measurements are needed for remote sensing of the polar caps of Mars, and for understanding their energy budget.

Under-ice chemistry of Stella and Teresa Lakes, Great Basin National Park, Nevada, during winter 1989

(R.C. Metcalf, G.D. Merritt, and M.A. Stapanian, Lockheed Engineering and Sciences Company, Las Vegas, NV)

Great Basin National Park is one of the newest national parks in the United States (est. in 1987). As part of an interagency agreement between the US Environmental Protection Agency and the National Park Service, the water chemistry of Stella (3165 m elev.) and Teresa (3128 m) Lakes was sampled in air temperatures to –30°C, under 0.28–0.64 m of ice during February and March, 1989. Lake ions were concentrated as a result of ice formation by about a factor of 5 to 8 times compared to summer values, as indicated by chloride and in situ conductivity measurements. Dissolved organic carbon measured 6.6 to 8.1 mg dm^{-3}, and dissolved oxygen was undersaturated (5.6 mg/dm^{-3}) for the temperature (0.2°C) and elevation. Additional work examining the relationship between sub-ice winter fish kills at Johnson Lake (3280 m), the available nutrients for fish, climatic stresses, and possible pollution from an old mine is currently under consideration.

Difficulties in inferring past atmospheric chemistry from snow-pit and ice-core samples

(R.C. Metcalf and D.V. Peck, Lockheed Engineering & Sciences Company, Las Vegas, NV)

Examination of the small-scale (6–64 m^2) spatial variability of pH measurements within individual stratigraphic layers deposited by single storms at Mt Evans, Colorado, Duck Creek, Utah, and Chomolungma (Mt Everest), Tibet (data courtesy of J.I. Drever), showed that the natural pH variation within horizons may be a sufficient source of "noise" to effectively "mask" any inferred temporal pH variations (variations with depth). We have developed procedures to minimize the effects of spatial variability while interpreting ice cores by solving the equation for the minimum number of samples needed to achieve the required precision (usually the long-term analytical method precision) about the mean chemical variable measured for a given layer. Using such procedures, only a handful of modern studies are adequately sampled (usually greater than 12 samples per layer in our preliminary work), most notably the careful CO_2 studies of Neftel and others at Berne. Without adequately accounting for spatial variability, deductions concerning temporal changes in precipitation chemistry are suspect.

Climate modelling

(T.S. Ledley, Dept. of Space Physics, Rice University, Houston, TX)

Recent work has been to understand the role of the polar regions in shaping global climate on a wide range of time scales by examining the possible mechanisms of climate change. The polar regions of the Earth can have a large impact on global climate despite the fact that they occupy a small percentage of its total area. The main feature of the polar regions that make them different from others is the presence of snow and ice. The impact of snow and sea ice on the climate of the polar regions and globally has been examined with an isolated sea-ice model, and with a coupled energy-balance climate–thermodynamic sea-ice model. These modeling studies showed the large extent to which snow and sea ice affect the energy exchange between the atmosphere and ocean, and how the change in that interaction affects climate.

This work has led to current research on the shorter time scales, which involves (1) examining the effects of man induced changes in the system, such as the increase in atmospheric trace gases, on climate through their impact on snow and sea-ice thickness and concentration, and identifying the mechanisms that produce those effects; (2) examining the impact of the inclusion of particulate matter, such as soil particles from contact with land areas, ash deposited from volcanic eruptions, and deposition of man-made pollutant, in snow and ice on the climate; (3) examining the role of the hydrologic cycle in shaping climate; and (4) studying the mechanisms of interannual variability of climate. On the longer time scales she is working on a study of the role that snow and sea ice play in producing the large scale glacial/interglacial cycles recorded in the geologic record through their impact on the hydrologic cycle. Future plans include incorporating a dynamic ice-sheet model into the coupled system in order to study the interactions between the different components of the climate system, and identifying the different mechanisms that produce the large scale variations in ice sheets.

Remote sensing of atmospheric ice

(K.B. Katsaros and G.W. Petty, Dept. of Atmospheric Sciences, University of Washington, Seattle, WA)

In 1987, the United States launched the first Special Sensor Microwave Imager (SSM/I) on the F-8 satellite as part of the Defense Meteorological Satellite Program (DMSP). Among the SSM/I algorithms which have been developed for observing atmospheric water in its various forms is a general technique for detecting and mapping, at 15 km resolution, high concentrations of large ($>100\ \mu m$) atmospheric ice particles. The specific algorithm we use is a minor modification (Petty and Katsarso, 1990) of one originally proposed by Spencer and others (1989). These are based on the ability of large ice particles within clouds to dramatically depress thermal 85 GHz (3.5 mm) radiances via the mechanism of volume scattering.

One important objective of our research has been to help document the relationship between the presence of large ice particles aloft, as inferred from the SSM/I 85 GHz data, and the intensity and character of precipitation processes within storms. The technique also responds to surface volume scatterers (principally snow cover), but we have not made a detailed study of its interpretation in such cases.

GLACIAL GEOLOGY

The Antarctic ice sheet and sea level changes

(J.T. Hollin, INSTAAR, University of Colorado, Boulder, CO)

Hollin and Hearty (*Quaternary Research*, 1990) present further evidence for a sea-level jump of more than 14 m at the end of isotope stage 5e; such a jump is the distinctive requirement of Wilson's Antarctic ice-surge theory of ice ages. The pollen evidence that the highest sea level occurred at the end of the interglacial implies that the high Barbados III terrace, with its U-series coral dates of 125 ka BP, was built in stage 5d not 5e. This fits the evidence from Devils Hole that 5e began well before 135 kaBP, too soon for Milankovitch's orbital theory of ice ages. A difficulty with the above glaciological theory: although the Antarctic ice sheet represents at least 60 m of sea level, it is divided into distinct drainage basins, and it is hard to imagine a quarter of the ice sliding into the sea at once. Work continues on the sea-level evidence.

Energy and mass-balance modelling of the Late Pleistocene Middle Boulder Creek Glacier, Colorado Front Range

(E. Leonard, Colorado College, Colorado Springs, CO, and W. McCoy, University of Massachusetts, Boston, MA)

We are applying an energy and mass-balance model to the reconstructed late Pleistocene Middle Boulder Glacier in an attempt to model the combinations of climatic conditions (temperature depression, precipitation, cloudiness, windiness, seasonality of precipitation, etc.) which would have allowed the glacier to have sustained itself in mass-balance equilibrium at its Late Pleistocene maximum extent.

Rock glacier Kinematics, Ten Mile Range, Colorado

(E. Leonard, Colorado College, Colorado Springs, CO)

This is an ongoing project, now in its fifth year, involving ongoing monitoring of the Spruce Creek Rock Glacier, near Breckenridge. We have established a strain net on the rock glacier involving three transverse lines surveyed across the rock glacier from bedrock to bedrock and twelve strain diamonds on the rock glacier surface. In addition to standard determination of velocity variations we hope to be able to identify characterize strain conditions (extending vs compressing flow) and determine principal strain rates and orientations at different points on the rock glacier and to relate these to surface characteristics of the glacier (transverse and longitudinal furrows, etc.)

Glacier reconstruction

(D. Murray and W.W. Locke, Montana State University, Bozeman, MT)

We investigated the inverse solution of glacier morphology, as preserved by moraines and trimlines, for climate, in the form of annual mass flux. The method hinges on a reasonable assumption of basal slip. Error analysis suggests an uncertainty of about 20% in estimation of mass flux. In southwest Montana (and adjacent Idaho), the reconstructions are consistent with a peak-glacial climate 20–50% drier than present.

Ice cap reconstruction

W.W. Locke, Montana State University, Bozeman, MT)

We are modeling the extent of the ice cap which drained the northern Rocky Mountains of Montana (south of Glacier National Park). In addition, investigation into post-glacial deformation in the Yellowstone (Wyoming) caldera, appears to contain a glacio-isostatic component as well as information on Holocene (Hypsithermal) climate in the Yellowstone Lake basin.

A Pliocene–Pleistocene record of events in Fairbanks area, Alaska

(T.L. Pewe, Arizona State University, Tempe, AZ, and J.A. Westgate and S. Preece, University of Toronto, Scarborough Campus, Scarborough, Canada)

A detailed geologic record from late Pliocene time is well-preserved in the non-glacial sediments of the Fairbanks area in central Alaska. Perennially frozen gravel, loess, and retransported loess with several interbedded tephra layers, preserve a rich floral and faunal history and record climatic changes in a periglacial environment only tens of km from the glaciated Alaska Range. The long-studied loess succession is perhaps one of the oldest and thickest in North America. With geochemical and petrographic identification and isothermal plateau (ITP) fission-track dating of tephra, and paleomagnetic study of loess, the record has become greatly refined and ages reinterpreted.

The oldest unconsolidated deposit is the Cripple Gravel, a reworked solifluction deposit produced in a periglacial climate which is Pliocene in age. The Fox Gravel, accumulated during a later rigorous periglacial climate, contains large bones of mammoth and *Bison priscus* and underlies Pliocene–early Pleistocene loess. The Dawson Cut forest bed represents a Pliocene–early Pleistocene interglacial interval when a taiga forest was present.

The next younger formation is the massive Gold Hill Loess, as much as 57 m thick. The base is about 3 Ma by paleomagnetic dating, and the PA tephra, 15 m above the base, is 1.9 Ma by ITP fission-track dating.

After deposition of most or all of the Gold Hill Loess, there was a major interval of erosion and thawing of permafrost during a climate warmer than now, as indicated by ice wedge casts and a forest bed 1 m thick, containing rooted stumps and prostrate spruce and birch logs (radiocarbon age > 57 ka). The forest bed formed during the latter part of the last interglacial as demonstrated by the presence of Old Crow tephra (140 ka) directly under the forest bed.

Overlying the Eva Formation is the Goldstream Formation; a widespread deposit of perennially frozen, poorly bedded, organic-rich, gray to black retransported loess 10–35 m thick. Numerous radiocarbon ages confirm a Wisconsin age for the formation.

Unconformably overlying the Goldstream Formation are Holocene loess (on hillslopes) and perennially frozen retransported loess in valley bottoms. Both units have basal radiocarbon ages of about 10 ka.

Submitted by Andrew Fountain

ANNUAL GENERAL MEETING 1991

MINUTES OF THE ANNUAL GENERAL MEETING OF THE INTERNATIONAL GLACIOLOGICAL SOCIETY

25 August 1991 in Lanzhou, China

The President, Dr G. K. C. Clarke, was in the Chair. 20 members from 11 countries were present.

1. The Minutes of the 1990 Annual General Meeting, published in *ICE* 95, p. 10–11, were approved and signed by the President.

2. The President gave his report for 1990–91:

It is a great pleasure to present this report at the Symposium on Mountain Glaciology Relating to Human Activities, the Society's first symposium to be held in China. This is an historic moment that celebrates both the international character of the Society and the international stature of our host organization, the Lanzhou Institute of Glaciology and Geocryology. I shall begin this report with very good news: Hans Röthlisberger has been selected as the next recipient of a Seligman Crystal in recognition of his fundamental and lasting contributions to glacial hydrology. It will be my pleasure to present this award to him in May 1992 in Boulder, Colorado.

IGS membership remains at approximately 855 with library subscriptions totalling approximately 558.

It has been a challenging and sometimes frustrating year for those involved in preparing the *Journal of Glaciology*. We have reorganized the editorial structure of the *Journal* and are working hard to improve the appearance of the final result. Douglas MacAyeal is now installed as Chief Editor and he has responsibility for assigning submitted manuscripts to the appropriate Scientific Editor, for seeing that the review process is speedy and fair, and for final acceptance or rejection of manuscripts.The new system appears to be working well. Efforts to upgrade the appearance of the *Journal*, especially to improve the presentation of mathematics, havc caused unforeseeable delays in meeting our publication schedule. Only one issue, No. 125, has been completed and at this moment it is being mailed to the membership by Lochemdruk, our printer in The Netherlands. Special circumstances account for the delay. In order to use new desktop publishing software, the Society was compelled to replace much of the computing hardware at IGS Headquarters. This transition required our office staff to become familiar with new equipment and a new computer operating system. Despite promises to the contrary, the 3B2 desktop publishing software provided by Advent did not live up to expectations and, in fact, was incapable of setting complex mathematics, although its handling of non-mathematical manuscripts is splendid. As a stop-gap measure we are using a version of TeX to prepare all mathematical manuscripts and rely on 3B2 for setting the non-mathematical ones. Advent has taken our advice, and is preparing a new user-friendly version of 3B2 that will employ TeX for its handling of the mathematical expressions; they will seek our opinion at each stage of development. By 1992 we should be able to set everything in 3B2 and to import authors' TeX disks directly on to our equipment.

Adjustment, simultaneously, to two new desktop publishing software systems placed a great strain on our staff and added to the delay in publishing No. 125. Now that the changeover is accomplished we expect to complete Nos 126 and 127 in rapid succession so that, by December 1991, our printing schedule will be on target. There is a backlog of manuscripts that could be cleared by printing one or more extra-long issues of the *Journal*. The planned publication date for Vol. 15 of the *Annals*, the Proceedings of the Symposium on Ice–Ocean Dynamics and Mechanics, has not been affected by the foregoing difficulties.

Although the process of upgrading the Society's publishing capability has been more challenging than anticipated, the results leave IGS in a strengthened position. Future issues of the *Journal* and *Annals* will look impressive and we shall be able to turn attention to other publishing projects that will diversify the published offerings of the Society. Among these are a translation, in cooperation with CRREL, of Aleksandr P. Makshtas' book *The heat budget of Arctic ice in the winter*, a reprinting of E. R. LaChappelle's classic *Field guide to snow crystals*, a new edition of the SPRI *Illustrated glossary of snow and ice* and the launching of a new publication series *Glaciology Sourcebooks*. It is our long-term hope to broaden the Society's financial base by increasing the range and distribution of IGS publications.

At present the Society maintains the Secretary General's office at the Scott Polar Research Institute and leases a satellite office, a short distance from SPRI, that houses the IGS office staff. The satellite office has become the focus of repeated burglary attempts. The owner of the satellite office shares our concern for security and has offered IGS alternative space at comparable cost. The new space offers greater security, an improved working environment and preserves proximity to SPRI. The changeover is planned for December 1991.

Looking ahead, the Society will be organizing a busy schedule of symposia: in Boulder, U.S.A., from 17–22 May 1992, the Symposium on Remote Sensing of Snow and Ice; in Nagaoka, Japan, from 14–18 September 1992, the Symposium on Snow and Snow-Related Problems; in Rovaniemi, Finland, from 18–23 April 1993, the Symposium on Applied Ice and Snow Research.

In closing I would like on behalf of the Society and myself to thank our Secretary General, Hilda Richardson, the IGS office staff – Pat Lander, Beverley Baker, Sally Stonehouse, Linda Gorman, and David Rootes – the IGS 1991 House Editors, Ray Adie and Evelyn Dowdeswell, our Scientific Editors and Referees, our Treasurer, John Heap, and all those who have aided the Society by serving on Council, Committees and in less conspicuous ways.

3. The Treasurer, Dr J. A. Heap, submitted a report with the audited accounts for 1990. He regretted he was unable

to be present at the meeting. The President highlighted some items and suggested that questions about details on the accounts be addressed to the Secretary General after the meeting.

In his report, the Treasurer drew attention to the fact that expenditure in 1990 had remained the same as in 1989, despite inflation, showing that HQ office retained tight control of purchases and salaries. On the income side of the accounts, yearly fluctuations in two items over which we had no control — page charge support for papers in the *Journal* and foreign exchange fluctuations — had reduced income despite increases in income from dues, sales, and bank interest. The result was a deficit of £3,877. This is within the expected fluctuations of surpluses and deficits over a 10-year period.

D. Trabant proposed and S. Hastenrath seconded that the audited accounts for 1990 should be adopted. This was agreed unanimously.

4. Election of auditors for the 1991 accounts. R. Hooke proposed and A. Ohmura seconded that Messrs Peters, Elworthy and Moore of Cambridge be elected auditors for the 1991 accounts. This was carried unanimously.

5. Election to the Council 1991–94. After circulation to all members of the Society of the Council's suggested list of nominees, no further nominations were received, and the following people were therefore elected unanimously.

Vice President:	G. Wakahama
Elective Members:	J. Jania
	S. J. Jones
	D. R. MacAyeal
	N. Reeh

6. Motion to adjourn was proposed by R. Hooke, seconded by D. Collins and agreed unanimously.

. . . .

After the conclusion of the formal business of the meeting, an informal discussion took place. Suggestions included possible entry of telephone, fax and e-mail numbers in future editions of the address list, and inclusion of given names, rather than initials, on name tags at IGS symposia.

The opening ceremony was well arranged by Shi Yafeng, Honorary Director of the Lanzhou Institute of Glaciology and Geocryology

Shi Yafeng	Sec. General IGS (H. Richardson)	Sun Honglie Vice-President Chinese Academy of Sciences	President IGS (G.K.C. Clarke)	Vice-President IGS (B. Wold)	Xie Zichu Director LIGG

Shi Yafeng shares a happy moment with Sun Honglie

The Secretary General congratulates Mrs Zhang Shunying on her success with the local arrangements

SYMPOSIUM ON MOUNTAIN GLACIOLOGY RELATING TO HUMAN ACTIVITIES, 1991

POST-SYMPOSIUM TOUR TO TIBET

Report by Julie Cruikshank

Following the International Glaciological Society Symposium held in Lanzhou, China (26–30 August 1991), the Lanzhou Institute of Glaciology and Geocryology (Academia Sinica) organized a field trip through southern Tibet. Arrangements for the excursion were made by Xie Zichu, Director of the Institute, who was unfortunately prevented from accompanying the tour at the last moment, and by his assistant Liu Shiyin who guided us with humour and patience from Lanzhou as far as the Tibet/Nepal border.

Fifteen conference participants travelled from Lanzhou by overnight train to Chengdu; by plane from Chengdu to Lhasa, the capital of Tibet; by road for almost 1000 km in four 4-wheel drive vehicles to Everest basecamp and ultimately to the Nepal border; and finally by a series of buses to Kathmandu, Nepal.

Even though we all experienced roughly the same events, an adventure of this magnitude means that each of us returns with sets of stories and impressions which undoubtedly vary wildly, particularly after two months of processing. At the invitation of Hilda Richardson, I am providing my own truncated synopsis of an experience far richer than I can summarize in a few words.

We each approached the field trip with enthusiasm but also with some reservations — my own concerned discomfort about travelling to Tibet with Chinese guides at a time when Tibetan resistance to Chinese occupation had recently met brutal suppression in 1989. We were grateful to our Chinese hosts who had been most gracious in welcoming us as visitors to their country, yet uneasy about the starkness of the political situation in Tibet. At the same time, most of us come from countries with imperfect human rights records at home or abroad, so we are not always able to claim a moral high-ground. That uneasiness never really left, but I especially appreciated the sensitivity of our guide, Liu Shiyin, who quietly deferred to Tibetan guides, busying himself with logistics and allowing Tibetans to offer us their own introduction to their country. Those of us who came to the trip with experience of travel in non-western countries were somewhat startled by adherence to printed schedules — there were few of the deviations, delays, alterations and surcharges more commonly experienced during travel in countries where language and customs of the hosts differ from those of the travellers.

Leaving Lanzhou by train on 31 August, in the relative comfort of 'soft sleeper', we began our 26-hour overnight trip south from the dry, almost arid, terraced loess of central China through a series of broad valleys and mountains. When we woke up the next morning, we had entered a monsoon climatic zone where rice paddies, prosperous-looking villages, oleander hedges and banana trees outside our windows replaced the dryness of Lanzhou where we had spent the previous week on the edge of the Gobi Desert.

Chengdu, capital of Sichuan province, provided additional contrasts. Lanzhou has the appearance of an enormous village — with less sense of a city centre than of autonomous hamlets strung for miles like beads along the Yellow River, one of China's major arteries. It comes as a surprise to learn that 2 million people live in Lanzhou. Compared to Lanzhou, Chengdu is recognizably a metropolis, sometimes referred to locally as the 'Paris of the East'. Leaving the train we joined thousands of other passengers thronging from the train, many of whom crowded around to stare politely. Near our hotel, we visited extensive open-air markets where varieties of edible animal and vegetable products are sold next to trays of sophisticated transistor parts — a kind of high tech Radio Shack interspersed with the most exotic ingredients of Sichuan cuisine.

On an outing from Chengdu, we followed six-lane highways which serve more specialized functions than those in the west: the two outer lanes are reserved for processing rice which is spread out to dry, sometimes on huge unfurled mats and other times directly on the road. The middle lanes are reserved for bicycles, some modified with two large rear wheels supporting a platform piled high with food, produce or other moveable goods. Buses command the central lanes and assert their authority by travelling at high speed, honking continuously.

Chengdu is the only city in China with regular air service to Lhasa. Two planes leave daily at 7 a.m., requiring a 4 a.m. rising and a dark, early morning bus trip to the airport some distance from Chengdu. The hour-and-a-half flight crosses spectacular ranges of snow-covered mountains, illuminated by sunrise, and lands on a broad plateau at Gongkar Airport, 110 km from Lhasa. As we leave the plane, any reveries about standing 'on the roof of the world' are cut short as we are chased from the runway to make way for the second daily plane arriving only minutes behind our own. We are 3600 m higher than Chengdu and watch for tangible affects of altitude which become clear as soon as we carry our bags from the airport to our waiting bus.

Again, we have entered a different climatic zone, this time alpine tundra hills with broad alluvial fans. A bus transports us along the banks of the Brahmaputra River until the road crosses that river to follow the Kyichu River to Lhasa. Periodic debris flows submerge the road and our guide, Dawa Sogi, explains that these have been caused by recent heavy rainfalls brought by the monsoon. Two hours later we see our first glimpse of the Potala, its white walls reflecting in the distance, and then Lhasa comes into view.

Although Lhasa is one of the lowest places in Tibet, it is 4000 m above sea level. After settling into the Ximalaya hotel — a small and comfortable hotel accommodating mostly trekkers — we head off independently to explore the city. And while symptoms vary considerably, most of us experience some mild altitude effects, usually headaches, during the three days we remain in Lhasa to acclimatize. This period also provides our only opportunity in Tibet to have any extended contact with local people other than our guides and to gather impressions about contemporary Tibetan culture and the present situation of Tibetans.

The images of Lhasa which remain weeks and months after the trip cluster in two competing and contradictory directions, one, the overwhelming sense of an occupied city; the other, impressions of a determined Tibetan resistance. Lhasa is a Chinese fortress with pockets of Tibetan culture: more than 70% of the population is now Chinese. A military presence dominates the city, functional tin-roofed buildings displacing Tibetan architecture; trucks of the People's Liberation Army driving through town at high speed; noisy military exercises carried on as soldiers march chanting through the streets early each morning while the city is still in darkness; armed soldiers guarding military installations and swaggering in the courtyards of the Potala; official signs everywhere exhorting the citizens to celebrate '40 years of peaceful liberation of Tibet, 1951–1991'.

On the other hand, a quiet but firm Tibetan passive resistence permeates the Barkor, the old city of Lhasa which remains the religious and mercantile focus of the city, where Tibetan customs are now apparently allowed to continue, at least for the time being. 'Barkor' means 'Intermediate Circuit', referring to the walking circuit around the Jokhang cathedral, dominating the old city. The Jokhang, established in the 7th century by King Songsten Gampo, is the most sacred temple in Tibet and every Tibetan hopes to visit it at least once in his or her lifetime. Each day we were in Lhasa, pilgrims came by the hundred, prostrating themselves repeatedly before entering the monastery, polishing the stones with their bodies like thousands before them, then weaving past the massive rotating prayer wheels and through the cathedral in long lines, bringing offerings of candles and yak butter as though the army were invisible. Our Tibetan guide led us through the Jokhang, explaining the meaning of each of the chapels; at the base of a statue in one chapel one member of our group noticed a small sign bearing the inscription 'Free Tibet 1991'. Monks, many of them fluent in English, sometimes stopped us to enquire where we came from and where we would travel in Tibet. Others intoned chants while still others stopped to explain how the debating process worked.

Despite '40 years of peaceful liberation' many of the pilgrims we saw are under 40 years of age and have never experienced a free Tibet, yet persist in honouring traditions they have learned from parents and grandparents. When the pilgrims were attacked in the Barkor in 1989, the Jokhang monastery was occupied by the military who used it as a barracks, removing the gold and the Buddhas and exporting them for sale. Today, there is evidence of restoration work being done throughout the Jokhang, possibly because it is the temple most frequently seen by western visitors. But after we left the cathedral, we learned that some young Tibetans demonstrating briefly with 'Free Tibet' flags had been arrested in the plaza while we were inside. Amnesty International provides chilling reports on the state of human rights in Tibet. Yet some Tibetans reported that the military ultimately fear the Tibetans because they refuse to admit defeat.

Our days in Lhasa were full, with visits to the Potala, to the Norbulingka (the summer palace built for the Fourteenth Dalai Lama in 1951), to the Sera Monastery where debating still occurs and where youngsters are once again being sent for training as monks. The Potala palace, perched high above the city, remains the dominant feature of Lhasa. First built 1300 years ago of rock and wood with no mortar, the present buildings were completed during the 17th century. Once home to hundreds of monks, we are told that there are now 40 monks and 20 soldiers living there. During the Cultural Revolution, when so many of the Tibetan monasteries were destroyed, Chou En Lai personally forbade the destruction of the Potala, and so many hundreds of sacred objects and Buddhas were brought here, and remain here for safe keeping.

The sounds of Lhasa are memorable. During the day workers chant in unison as they hammer, repairing the roofs of the Potala; children chant as they play; monks chant in the Barkor and in the monasteries. Our nights are also filled with unfamiliar sounds. Dogs (there are hundreds of dogs in Lhasa) howl in unison during the night, thought they rest peacefully sleeping on the warm steps of the Barkor during the day. Cocks begin to crow before first light as the dogs drift off to sleep. The inevitable military chants begin just before first light of day. And at dawn, official news programs are beamed throughout the city on loudspeakers. All of China's Autonomous Regions are on Beijing time, so as we move west sunrise occurs later and later; in Lhasa the sky begins to lighten about 9 a.m.

On Friday 6 September, we climb into four jeeps and join the early morning traffic leaving Lhasa — yaks, sheep, army vehicles, bicycles and the ubiquitous motorized three-wheel vehicles (which appear to combine concepts from both tractor and tricycle). The navigational strategy for motorized vehicles seems to involve sounding one's horn loudly and then moving decisively, thereby driving others off the road. There is a divided highway, but in treacherous winding hillside areas where authorities are serious about discouraging passing, they provide additional encouragement for single-lane travel by placing large boulders strategically on the centre line.

Following the approved 'visitors' route' south and west, we begin the first of many climbs rising from valley bottom, this time along the Brahmaputra River, through a series of switchbacks to Yumco Lake, a sacred lake now being turned into a questionable power project. A community on the edge of Yumco Lake has a familiar schizophrenic look — half the traditional whitewashed clay and sod-block housing on terraced agricultural fields, half tin-roofed concrete Chinese army barracks. Further along, we pass between Qiangyong Glacier, on our left, and then the Karela Glacier, on our right at the highest pass we cross that day (5042 m). We are told that the Karela Glacier, source of the Nianchu River, is the largest of the 54 glaciers in this region. We are all thrilled to be on these high passes, yet it seems that however high we stop we are always greeted by children and sheep running *downhill* from even higher slopes to inspect us. In the distance, we can often hear herders singing, voices ricocheting from hill to hill.

Our drivers are extremely well trained and negotiate, with care and attention, stretches of road we would consider impassible. They tell us that the road is in unusually bad condition this year because of a heavy July and August monsoon. A number of bridges have washed out and there is considerable evidence of flooding and landslides. Camps of road builders doing repairs are posted regularly along the route.

We reach our destination of Shigatse, 354 km west of Lhasa, at sundown about 9.30 p.m. and are informed that our baggage will arrive separately 'sometime during the night' on a truck which has taken a different route from us. After a quick meal, some of us begin a brief walk through the town, but at 10.30 the street lights are extinguished, discouraging further exploration. Shigatse, located at the junction of the Brahmaputra and Nyang Chu Rivers, is the second largest town in Tibet and has long been a commercial and political centre of Tsang Province. The massive castles which dominated town have been replaced by Chinese functional buildings. Since the time of the Fifth Dalai Lama, Shigatse has been the seat of the Panchen Lama; unfortunately we did not have time to visit his monastery, Tashilhunpo, though we stopped briefly to see it on our way out of town the next morning.

As we drive westward,we learn more about the Chinese strategy for tourism. It is necessary to drive long distances each day because accommodation for a group as large as ours is available only in specific locations. The magnificence of the landscape contrasts sharply with the scale of the hotel. Our next stop at New Tingri is in a hotel built specifically to accommodate foreign visitors. Certain appliances have been installed to accommodate westerners — bathtubs and flush toilets, for example. But because they are decorative rather than functional, they are inclined to disappoint. They also seem to have a short life history; the two-year old hotel at Tingri offers a striking facade, a lobby and dining room with 25 ft ceilings have the casual appearance of a grand Soviet ballroom, yet electrical wiring dangles unprotected from the walls, tiles have fallen from walls, carpets are tattered and stained, sheets are not changed between guests and plumbing is non-functional.

Leaving Tingri, we are delayed at a provincial checkpoint by Chinese military because a Tibetan doctor accompanying us does not have the appropriate exit papers. A successful crossing involves one of our drivers transporting the Commanding Officer, several of his assistants, and the doctor to the next town to accomplish the paperwork. It is clear that this is a unique travel opportunity for the soldiers, posted as they are at what must be one of the world's most isolated check points with no access to transportation.

Climbing from Tingri to Jiula Pass (5200 m) we once again see switchbacks snaking up the side of mountains and begin our slow ascent toward Mount Everest (Qomolangma), passing the comunity of Pazhuo and finally arriving at Rongbuk late in the afternoon. Once the site of a major monastery, Rongbuk was destroyed during the Cultural Revolution; during the last five years it has undergone some restoration, again possibly because of its visibility to foreigners who visit Everest. Fifteen monks and nuns live here now, and after we pitch our eight two-person tents and watch our guides and drivers efficiently raise the kitchen tent in a few minutes, we are visited by one young monk who lifts the flap of our individual tent politely but unexpectedly, asking whether we might have batteries to spare. We cobble together four 'A cells' and he heads back to the monastery, possibly to resurrect a transistor radio? Almost immediately our attention shifts to a herd of 15 yaks walking slowly through our camp, bells ringing, herders singing a song we heard earlier in the distance when we stopped on the mountain passes. The yaks are laden with gear belonging to a group of climbers who are leaving from Everest.

We spend two nights camped at Rongbuk and during our full day there drive the remaining few miles to Everest basecamp and spend the day climbing on Rongbuk Glacier. For many members of our group, this is the highlight of the trip, something they have dreamed about since childhood. We are extraordinarily fortunate with weather: Mount Everest, or Qomolangma, is in view much of the day. Some of us position ourselves in the centre of a Rongbuk Glacier at a high vista where we can observe her: 'Qomolangma' we learn, means 'mother goddess' and indeed she sits there, a massive presence looking down at the world below her. At the end of the day the weather begins to change, and we are glad to return to camp for warm dinner, tea and coffee. Snow begins to fall during the evening and when we waken the next morning our tents and campsite are covered in fresh snow.

We are not long alone at Rongbuk. A party of genial Russian scientists is camped next to us. They are doing a broad-based survey of geological, faunal and floral characteristics of Rongbuk Glacier and are extremely hospitable, inviting us all into their kitchen for 'Russian breakfast' on our last morning. At Everest basecamp we also meet two Canadian climbing parties, impressively outfitted for climbing with complex telecommunications — including a FAX machine — in case of injury. Even so, we return with letters to deliver to Canada via more conventional delivery systems.

As we descend the mountain to join the main road and return to Tingri, we are aware that we reached Everest at a particularly fortunate moment, between the summer monsoon and the winter winds and snows. Roads slither down the sides of hills in weather like this and again it is difficult to believe that roads can sustain so much damage and still be driveable. Our drivers are cautious and we feel utterly safe in their hands. They watch the roads — and us — with detached amusement, hunkered down at their cigarette breaks smoking and comparing notes about road conditions. Each driver has his own favourite tape recording along, and in our vehicle we are treated to background music by North American pop-star Madonna singing her less-than-melodic song, 'Like a Virgin', on an endless audio loop. Periodically, our drivers take 'short-cuts', leaving the road entirely to drive downhill, across-country, eliminating a loop or two of a switch-back turn.

Ditches have evidently been dug to deter this kind of activity, but with little success. The only problem this poses is our occasional separation from other vehicles and the need for lengthy pauses while we reassemble our caravan before heading off downhill again.

After a return night to our New Tingri hotel, we continue, stopping at Old Tingri where we are befriended by precocious children in search of ball-point pens. We begin our last slow ascent to the Nyenye Xiogla Pass which rises to 5200 m and provides a stunning view of the Himalayas, brilliant white on all sides. From these high, arid, vast passes, we begin our final descent. Within a few hours of driving, we are surrounded by Nepal gorges. Cascading waterfalls originate high in the mountains and gain volume and momentum as they accumulate more water. Our switchback route brings us down and down, passing a single cascade a dozen times or more; on one occasion the road passes directly under a waterfall and each vehicle pauses for a vigorous and thorough carwash. We speculate about the impact of this procedure on our bags, travelling separately in an open-backed vehicle.

Several of our members have altimeters, so we are able to observe a 3000 m drop during the relatively short distance from Nyenge Xiongla Pass to Zhamus where we spend the night. The main street of this town spirals down the side of the mountain against which the whole town appears to rest precariously. The view from our Zhamus hotel room is spectacular. We are in a deep valley trough with jungle surrounding us on all sides for 360 degrees — above, below, and as far as one can see in either direction.

The power goes off sometime in the early morning, so we awake to pitch dark at 9 a.m. at this, the westerly extension of Chinese Imperial Time. Since we are about to cross the border to Nepal there are obligatory trips to be made to a bank. A walk to the bank constitutes a stiff mountain climb up city streets, and when we reach our destination, we learn that orders have come from Beijing which alter banking hours, so there will be a delay.

Exit passage through Chinese customs is effortless and we bid farewell to Liu Shiyin and to Dawa Dogi who have been such extraordinarily good hosts during our tour. Because they must return to Lhasa, they arrange for our transfer to a Nepalese guide, Boj Kumar. At this point, we pile into the back of an army vehicle with our bags and stand crowded into relatively restricted vehicle space. Suddenly, we are off: no seatbelt nonsense here. Our new driver, less cautious than his Tibetan counterparts, clearly derives pleasure from careening down switchbacks at high speed, inches from thousand-metre drop-offs, accelerating whenever near children, animals or houses, horn blowing.

The contrasts in a few hours between Tibet and Nepal are stunning: on the north, Tibet, stark and spare and open with its windswept plains of alpine tundra; on the south side Nepal with its cavernous canyons, steamy hot jungles, and furious economic transactions.

We see first-hand evidence of the devastation caused by landslides. Two major slides have blocked the road (one for several years now) and we must cross each, both 30–40 min walks, and employ porters to assist with baggage. Accustomed, by now, to an orderly socialist approach to travel, we are thrown headlong into the free market economy as 50–100 packers shout competing offers to us for carriage fees. We emerge from these transactions and our first slide-crossing shaken but intact. Another half-hour bus ride, this time between slides, reminds us that the bus we now occupy is unlikely to have been serviced since the slides blocked its exit in both directions some five years ago. At the second slide, we negotiate a block fee for service: all the bags to be carried and one payment to our guide who will in turn pay the packers. One optimistic note here is that our new guide seems clearly to be working for the Nepalese porters and not for us; there is a sense that this apsect of tourism may work more effectively for the Nepalese than it does for the Tibetans. A further 40 min walk over the slide brings us to a third bus which will transport us to Kathmandu.

Our drive to Kathmandu takes four hours, but provides a textbook view of Nepal: village life, political campaigns, vegetation, irrigation systems and Himalayan erosion are all spread out before us. We stop for lunch at a fine restaurant hotel with a view of the Himalayas and a delicious Indian menu, marred only by unexpected altercations concerning quadrupling prices as we exit. By now it is becoming clear that these transactions are more troubling to us than to our Nepalese hosts, and arrangements are made amicably. We arrive in Kathmandu after dark, with a sense of entering a major city — an impression complicated only by cattle beasts negotiating the evening traffic on the major thoroughfares along with buses, taxis and pedestrians.

From here, our paths diverge as we explore the city for two days and make our separate ways home, some staying on for treks in Nepal and others returning via Hong Kong, Europe, North America or to carry on fieldwork in Asia.

We all bring our own interpretive framework to trips like this, based on experiences we have had travelling elsewhere and impressions we have gained while we are here. Being able to share those impressions with 14 other people inevitably complicates our sense of what we each experience individually. I would guess that each of us found travelling in Tibet very different from previous travels, and that given the intensity of being there it is difficult to realize how soon it feels utterly distant. We cannot return from a trip like this and hope to follow events in Tibet knowledgeably in the press, because Tibet does not officially exist. On 9 October, less than a month after our visit, the Dalai Lama announced his intention to return to Tibet — his first visit since 1959 — on a fact-finding mission as soon as he can obtain permission from the Chinese government. Most Tibetans may never have an opportunity to learn anything about the world outside their border. But they do know that their country was once very different from the way it is now. And many of them retain a conviction that they will some day be able to chart a future very different from the past on terms more their own than is possible in 1991.

BRANCH NEWS

WESTERN ALPINE BRANCH

The 1991 meeting was held in the Oisans area 5–8 September. Thirty-five participants took part in the tour.

On 5 September, the group climbed in a heavy storm to the Refuge de la Lavey, where an excellent lunch was served. Representatives of the Ecrins National Park gave a presentation of their activities and of the scientific work completed since the creation of the National Park.

On 6 September, an early start was made for the Vallon de la Lavey, to visit the glacier de la Lavey. Some participants climbed as far as the Col de la Lavey and a few courageous people then returned to Oisans via the Chardon and Bérarde glaciers. In the evening, participants were driven to the Col d'Ornon, where a warm welcome was given at Schuss.

On 7 September, the group went from d'Ornon to the Taillefer plateau to study the lakes and remnants of a forest that once occupied the area. Evidence of post-Würm chronology was seen. In the evening, the annual banquet was held.

On 8 September, the annual meeting of the branch was held, followed by four talks. The meeting finished with a visit to the very interesting local mineral museum.

(François Valla, translated and summarized by Hilda Richardson)

JOURNAL OF GLACIOLOGY

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

A OHMURA, P KASSER AND M FUNK
Climate at the equilibrium line of glaciers.

T HUGHES
On the pulling power of ice streams.

S HASTENRATH
Ice-flow and mass changes of Lewis Glacier, Mount Kenya, East Africa, 1986–90: observations and modeling.

W GREUELL
Hintereisferner, Austria: mass balance reconstruction and numerical modelling of the historical lenth variations.

R S W VAN DE WAL, J OERLEMANS AND J C VAN DER HAGE
A study of ablation variations on the tongue of Hineteisferner, Austrian Alps.

C C SMART
Temperature compensation of electrical conductivity in glacial meltwaters.

Z XIA AND M-K WOO
Theoretical analysis of snow-dam decay.

I G ENTING
Statistics of firn closure: a simulation study.

K ECHELMEYER, W D HARRISON, T S CLARKE AND C BENSON
Surficial glaciology of Jakobshavns Isbræ, West Greenland: Part II. Ablation, accumulation and temperature.

E BRUN, P DAVID, M SUDUL AND G BRUNOT
A numerical model to simulate snow-cover stratigraphy for operational avalanche forecasting.

P G KNIGHT
Ice deformation very close to the ice-sheet margin in West Greenland.

R J BRAITHWAITE, O B OLESEN AND H H THOMSEN
Calculated variations of annual ice ablation at the margin of the Greenland ice sheet, West Greenland, 1961–90.

M R ALBERT AND W R McGILVRAY
Thermal effects due to air flow and vapor transport in dry snow.

T HUGHES
Theoretical calving rates from glaciers along ice walls grounded in water of variable depths.

K TAYLOR, R ALLEY, J FIACCO, P GROOTES, G LAMOREY, P MAYEWSKI AND M J SPENCER
Ice-core dating and chemistry by direct-current electrical conductivity.

R LeB HOOKE, V A POHJOLA, P JANSSON AND J KOHLER
Intraseasonal changes in deformation profiles revealed by borehole studies, Storglaciären, Sweden.

A FUCHS, J SCHWANDER AND B STAUFFER
A new ice mill allows precise concentration-determination of methane and most probably also other trace gases in the bubble-air of very small ice samples.

H M MADER
Observations of the water-vein system in polycrystalline ice.

H M MADER
The thermal behaviour of the water-vein system in polycrystalline ice.

W AMBACH
Effects of climatic perturbations on the equilibrium-line altitude, West Greenland.

K HUTTER
Thermo-mechanically coupled ice sheet response. Cold, polythermal, temperate.

J F NYE
A topological approach to the strain-rate pattern of ice sheets.

W T PFEFFER
Stress-induced foliation in the terminus of Variegated Glacier, Alaska, U.S.A., formed during the 1982–83 surge.

E W BLAKE AND G K C CLARKE
Interpretation of borehole-inclinometer data: a general theory applied to a new instrument.

J M HARBOR
Application of a general sliding law to simulating flow of a glacier cross-section.

E ISAKSSON
The western Barents Sea and the Svalbard archipelago 18 000 years ago — a finite-difference computer model reconstruction.

W D HARRISON, K A ECHELMEYER, D M COSGROVE AND C F RAYMOND
The determination of glacier speed by time-lapse photography under favorable conditions.

M PELFINI AND C SMIRAGLIA
Recent fluctuations of glaciers in Valtellina (Italian Alps) and climatic variations.

V BARCILON AND D R MacAYEAL
Steady flow of a viscous ice stream across a no-slip/free slip transition at the bed.

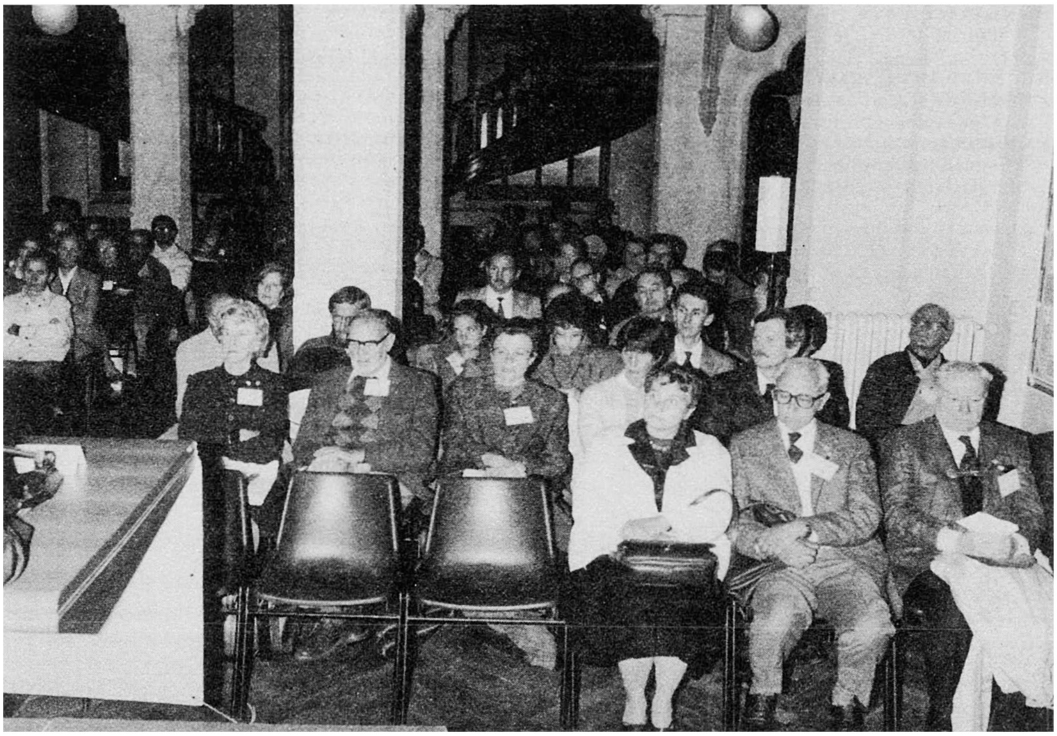
H EICKEN
Automated image analysis of ice thin sections — instrumentation, methods and extraction of stereological and textural parameters.

D R MacAYEAL
A tutorial on the use of control methods in ice sheet modelling.
B HUBBARD AND M SHARP
Weertman regelation, multiple refreezing events and the isotopic evolution of the basal ice layer.
V A POHJOLA
TV-video observations of bed and basal sliding on Storglaciären, Sweden.
A FOUNTAIN
Geometry and flow conditions of subglacial water at South Cascade Glacier, Washington State, U.S.A.: an analysis of tracer injections.
J OERLEMANS
Climate sensitivity of glaciers in southern Norway: application of an energy-balance model to Nigardsbreen, Hellstugnbreen and Alfotbreen.
K C JEZEK, M R DRINKWATER, J P CRAWFORD, R BINDSCHADLER AND R KWOK
Analysis of sythentic aperture radar data collected over the southwestern Greenland ice sheet.
W G REES AND R E DONOVAN
Refraction correction for radio echo-sounding of large ice masses.
A IKEN, K ECHELMEYER, W HARRISON AND M FUNK
Mechanisms of fast flow in Jakobshavns Isbræ, Greenland: Part I. Measurements of temperature and water level in deep boreholes.
E REIMNITZ, P W BARNES AND W S WEBER
Particulate matter in pack ice of the Beaufort Gyre.
S S JACOBS, H H HELLMER, C S M DOAKE, A JENKINS AND R M FROLICH
Melting of ice shelves and the mass balance of Antarctica.

Recent meetings (of other organizations)

COMITATO GLACIOLOGICO ITALIANO

The VIth meeting of the Committee was held in Gressoney, Aosta Valley, Italy 26–28 September 1991, and was co-sponsored by the International Glaciological Society, Club Alpino Italiano, Regione Peimonte, and Walser Alpengemeinschaft Lys Hochtal. Financial support was given by the Regione Autonoma Valle d'Aosta, Commission of the European Communities and Ente Nazionale Energia Elettrica (ENEL). The organization was excellent, and everyone enjoyed the accommodation, food and wine. 150 participants from 7 countries attended the meeting in the beautiful upper part of the Lys valley. The opening ceremonies were held in the Castello Savoia in the village of Gressoney-St. Jean. The other sessions were held in the Hotel Monboso, in Gressoney La Trinité. On the final day there was a tour to the Lys Glacier.



Opening session:
Prof. A. Biancotti, President, Comitato Glaciologico Italiano; Avv. G. Bondaz, President, Regione Autonoma Valle d'Aosta; On. F.M. Pandolfi, Vice-President, Commission of European Communities; Prof. L. Filippa, Mayor of Gressoney-St. Jean

Richardson, H. (Secretary General IGS) The work of the International Glaciological Society (invited paper)
Cerutti, A.V. (CGI – Regione Autonoma Valle d'Aosta) Presentazione della raccolta di scritti di Umberto Monterin
Grassi, U. (Club Alpino Italiano) Profili di uomini nei riverberi dei ghiacciai.
Visit to the exhibition La Montagna di Ghiaccio, storia dei ghiacciai italiani del Monte Rosa, organized by Comitato Glaciologico Italiano with the collaboration of Walser Kulturzentrum.

Papers were also presented in the following sessions:
Session I: Present and future perspectives in glaciological research.
Session II: Glaciers and climatic change.
Session III: Glaciers, water resources and hydroelectric power.
Session IV: Glaciers, pollution and hazards.
Session V: Glaciers and tourism.
Session VI. Glacial morphology.
Poster session.

Photo. by Luca Mercalle

On Saturday, 28 September, participants took the chairlift to Sitten and then walked to the Lys Glacier, 2350 m, one of the outlet glaciers of the Monte Rosa group

Glaciological Diary

** IGS Symposia
* Co-sponsored by IGS

1992

4-6 May
Second Circumpolar Symposium on Remote Sensing of Arctic Environments, Tromsø, Norway (The Roald Amundsen Centre for Arctic Research, University of Tromsø, N-9000 Tromsø, Norway)

12-15 May
1992 Joint Spring Meeting of the American Geophysical Union, Canadian Geophysical Union and Mineralogical Society of America, Montreal, Canada (AGU Meetings, 2000 Florida Avenue, N.W., Washington, DC 20009, U.S.A.)

17-22 May
** Symposium on Remote Sensing of Snow and Ice, Boulder, CO, U.S.A. (Secretary General, IGS, Lensfield Road, Cambridge CB2 1ER, U.K.)

20-21 May
Discussion meeting: Antarctica and Environmental Change, London, England. (The Executive Secretary, The Royal Society, 6 Carlton House Terrace, London SW1Y 5AG, U.K.)

7-11 June
OMAE 1992. 11th International Conference on Offshore Mechanics and Arctic Engineering, Calgary, Canada. (N.K. Sinha, Institute for Mechanical Engineering, National Research Council of Canada, Ottawa, Ontario, Canada K1A0R6)

14-19 June
ISOPE-92, Second Annual International Offshore and Polar Engineering Conference, San Francisco, U.S.A. (Jin S. Chung, ISOPE, P.O. Box 1107, Golden, CO 80402-1107, U.S.A.)

15-19 June
IAHR 11th International Ice Symposium, Banff, Alberta, Canada (Conference Secretariate, IAHR Ice Symposium, c/o Mrs Yolande Matsusaki, Manager Conference Centre, 4 Lister Hall, University of Alberta, Edmonton, ALTA, Canada T6G 2H6)

29 June-3 July
Interpraevent 1992: Protection of Habitat against Floods, Debris Flows and Avalanches, Berne, Switzerland (Interpraevent 1992, c/o Bundesamt für Wasserwirtschaft, Postfach, CH-3001 Berne, Switzerland)

1 July-24 August
National Science Foundation Summer Program: Research experiences for undergraduates in Geo-Sciences in the Juneau Icefield, Alaska and the Atlin, B.C.-Yukon area (Dr Maynard M. Miller, Director, Glaciological and Arctic Sciences Institute, University of Idaho, Moscow, ID 83843, U.S.A.)

2-14 August
XVII Congress, International Society for Photogrammetry and Remote Sensing, Washington, DC, U.S.A. (Lawrence W. Fritz, ISPRS Congress Director, GE Aerospace, P.O. Box 8048-10A26, Philadelphia, PA 19101, U.S.A.)

14-18 September
** Symposium on Snow and Snow-related Problems (as part of an International Forum on Snow Areas), Nagaoka, Japan. Co-sponsored by the Japanese Society of Snow and Ice and the City of Nagaoka (Secretary General, IGS, Lensfield Road, Cambridge CB2 1ER, U.K.)

4-8 October
International Snow Science Workshop, Breckenridge, CO, U.S.A. (ISSW'92, P.O. Box 733, Fort Collins, CO80522, U.S.A.)

30 November-3 December
Circumpolar Universities Cooperation Conference, Rovaniemi, Finland (Outi Snellman, International Relations, University of Lapland, P.O. Box 122, SF-96101 Rovaniemi, Finland)

1993

18-23 April
** Symposium on Applied Ice and Snow Research, Rovaniemi, Finland. Co-sponsored by Ministry of Education, Finland, Arctic Centre, University of Lapland, City of Rovaniemi (Secretary General, IGS, Lensfield Road, Cambridge CB2 1ER, U.K.)

6-11 June
ISOPE-93, Third International Offshore and Polar Engineering Conference, Singapore (ISOPE-93, P.O. Box 1107, Golden, CO 80402-1107, U.S.A.)

26 June-1 July
4th Canadian Marine Geotechnical Conference, St John's, Newfoundland, Canada (C-CORE, Memorial University of Newfoundland, St John's, NF, Canada A1B 3X5)

5-9 July
6th International Conference on Permafrost, Beijing, China (Cheng Guodong, Lanzhou Institute of Glaciology and Geocryology, Academia Sinica, Lanzhou 730000, China)

5-11 September
* Fifth International Symposium on Antarctic Glaciology, Cambridge, U.K. (E.M. Morris, Head, Ice and Climate Division, British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET, U.K.)

20-26 September
International Symposium on Seasonal and Long-term Fluctuations of Nival and Glacial Processes in Mountains at Different Scales of Analysis, Tashkent, Uzbekistan (Dr V.G. Konovalov, Central Asian Regional Research Hydrometeorological Institute, 72, Observatorskaya str., Tashkent, Uzbekistan 700052)

News

AWARDS AND APPOINTMENTS

Vladimir M. Kotlyakov has been elected an Academician of the Academy of Sciences of Russia, and **Igor Zotikov** has been elected a Corresponding Member of the Academy.

Andrei F. Glazovskiy has been appointed Vice-Minister of Geology and Defence of the Environment, in the Russian government. He retains his links with the Institute of Geography in the Academy of Sciences of Russia, and with Moscow State University.

Professor **M. Kuhn** (Austria) is Secretary General of the International Association of Meteorology and Physics of the Atmosphere.

Professor **Keiji Higuchi** (Japan) is Vice-President of the International Association of Hydrological Sciences.

Dr. **Robin D. Muench** (USA) is President of the International Association of the Physics Sciences of the Ocean.

Professor **Geoffrey Stewart Boulton** (UK) has been elected a Fellow of the Royal Society in recognition of his observational, experimental and theoretical studies of glacial erosion and sedimentation.

ANTARCTIC PENINSULA FJORD STUDIES

Since 1987 Hamilton College has been conducting research related to sedimentation patterns as they reflect local and regional glacial/climatic variation along the western side of the Antarctic Peninsula. So far we have documented fluctuating conditions of productivity and ice shelf positions in several fjords. Work is continuing through the 1992–93 season with sediment traps and very high resolution seismic stratigraphy. Periodic reports are available from E. Domack upon request.

Cenozoic glaciation: the marine record established by ocean drilling. A supplement to undergraduate curricula. Eugene Domack and Cynthia Domack, Hamilton College. The booklet, sponsored by JOI/USSAC, covers the results of five ODP high-latitude legs: two in the northern hemisphere (Legs 104 and 105) and three in the southern hemisphere (Legs 113, 119 and 120). *Cenozoic glaciation* is intended for use as a supplement to regular class materials in courses such as oceanography, glacial geology, marine geology, and sedimentology, and is designed specifically for undergraduates. A coordinated color poster illustrating the core intervals described in the text is included. Contact May Reagan, Joint Oceanographic Institutions, Inc., 1755 Massachusetts Ave., NW, Suite 800, Washington, DC 20036-2102, U.S.A.

New members

Simon P. M. Brown, 10 Elizabeth Crescent, East Grinstead, West Sussex, RH19 3JA, U.K.
Gareth Davies, 12 Minley Grove, Fleet, Hampshire, GU13 8RJ, U.K.
Alan Dennis, Box 2426, Revelstoke, British Columbia, V0E 2S0, Canada.
Seymour W. C. Laxon, Mullard Space Science Laboratory, University of London, Hombury St Mary, Dorking, Surrey, RH5 6NT, U.K.
Tad Pfeffer, INSTAAR, University of Colorado, Campus Box 450, Boulder, CO 80309-0450, U.S.A.
Katsumoto Seko, Water Research Institute, Nagoya University, Chikusa-ku, Nagoya 464, Japan.
Brian S. Waddington, Dept. of Geophysics & Astronomy, University of British Columbia, Vancouver, British Columbia, V6T 1Z4, Canada.

The heat budget of Arctic ice in the winter

Aleksandr P. Makshtas

Arctic and Antarctic Research Institute
Leningrad
U.S.S.R

Russian version edited by
Yu. V. Nikolayev
Arctic and Antarctic Research Institute

Published by
Gidrometeoizdat, Leningrad, 1984

English translation edited by
Edgar L Andreas
U.S. Army Cold Regions Research and Engineering Laboratory
Hanover, New Hampshire 03755
U.S.A.

August 1988

Published by
International Glaciological Society
Cambridge CB2 1ER
U.K.

August 1991

ISBN = 0 946417 12 1

The United States Office of Naval Research provided funding for the publication of this monograph

INTERNATIONAL GLACIOLOGICAL SOCIETY

The heat budget of Arctic ice in winter

This recently published English translation of a Russian work on Arctic ice may be purchased from the Society. The book is 80 pages long, in a 165mm wide x 235 mm long format; the cover is glossy and shaded in green.

There are 2 ways to order: one is direct from the IGS office in Cambridge, U.K., for all members except those in U.S.A; the other is from Hanover, N.H. for all members resident in U.S.A.

The prices are as follows:

(a) Members in all countries except U.S.A. - from the I.G.S. office: £15 including packing and postage by surface mail; or: £17.50 for airmail to destinations outside Europe, excluding U.S.A. - see section (b).

Payments in currencies other than £ sterling should be calculated at the exchange rate in force at the time of payment. Then add sufficient money to cover the bank charges (currently £9). The Society needs the full payment, so that the extra £9 to cover bank charges should be paid by you. Thank you.
We do not accept payment by credit card.

(b) Members in the U.S.A. only - from S.C. Colbeck, CRREL: $25 including packing and postage.
Payments should be made by US $ check. No credit cards.

If you wish to purchase a copy of the book, please complete the attached order form and mail to the address indicated.

8 April 1992

Hilda Richardson
Secretary General

INTERNATIONAL GLACIOLOGICAL SOCIETY

Arctic ice book

I wish to order ...... copy/copies of the book, as follows:

(a) By cheque/bank transfer to International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, U.K. (bank account no. 54770084, National Westminster Bank plc, 56 St. Andrew's Street, Cambridge CB2 3DA, U.K.):

£15 surface mail

or £17.50 airmail

(b) By US $ check to S.C. Colbeck, CRREL, 72 Lyme Road, Hanover, NH 03755-1290, U.S.A: $25

Name .... Date ....

Address ....

....

INTERNATIONAL GLACIOLOGICAL SOCIETY

Lensfield Road, Cambridge CB2 1ER, England

SECRETARY GENERAL H. Richardson

COUNCIL MEMBERS

			Date first elected to the Council (in present term of office)
PRESIDENT	G.K.C. Clarke	1990-93	1987
VICE-PRESIDENTS	D.J. Drewry	1990-93	1989
	G. Wakahama	1991-94	1988
	B. Wold	1990-93	1990
IMMEDIATE PAST PRESIDENT	S.C. Colbeck	1990-93	1984
TREASURER	J.A. Heap	1989-92	1980
ELECTIVE MEMBERS	*P. Duval	1989-92	1989
	*F. Nishio	1989-92	1989
	*G. Weller	1989-92	1989
	*N. Young	1989-92	1989
	H. Björnsson	1990-93	1990
	*K.C. Jezek	1990-93	1990
	M.A. Lange	1990-93	1989
	*A. Ohmura	1990-93	1990
	J. Jania	1991-94	1991
	S.J. Jones	1991-94	1991
	D.R. MacAyeal	1991-94	1991
	N. Reeh	1991-94	1991

*first term of service on the Council

CORRESPONDENTS

AUSTRALIA	T.H. Jacka	JAPAN	R. Naruse
AUSTRIA	B. Lackinger	NEW ZEALAND	T. Chinn
BELGIUM	R.A. Souchez	NORWAY	H. Norem
CANADA	C.S.L. Ommanney	POLAND	S. Kozarski
CHINA	Zhang Xiansong	SWEDEN	S. Jonsson
DENMARK	H. Thomsen	SWITZERLAND	W. Haeberli
FINLAND	M. Seppälä	USSR	A. Glazovskiy
FRANCE	L. Reynaud	UK	J.A. Dowdeswell
GERMANY	H. Oerter	USA (Eastern)	W.B. Tucker
ICELAND	H. Björnsson	USA (Western)	A. Fountain
ITALY	G. Zanon	USA (Alaska)	L. Mayo

SELIGMAN CRYSTAL AWARD RECIPIENTS

1963	G. Seligman	1983	W.O. Field
1967	H. Bader	1983	J. Weertman
1969	J.F. Nye	1985	M.F. Meier
1972	J.W. Glen	1986	G. de Q. Robin
1972	B.L. Hansen	1989	H. Oeschger
1974	S. Evans	1989	W.F. Weeks
1976	W. Dansgaard	1990	C.R. Bentley
1977	W.B. Kamb	1990	A. Higashi
1982	M. de Quervain		

HONORARY MEMBERS

W.O. Field	M. de Quervain
R.P. Goldthwait	U. Radok
P. Kasser	H. Richardson
R.F. Legget	R.P. Sharp
L. Lliboutry	A.L. Washburn
M.F. Meier	Z. Yosida

The Society is registered as a charity in the United Kingdom with the Charity Commissioners – number 231043

INTERNATIONAL GLACIOLOGICAL SOCIETY

Lensfield Road, Cambridge CB2 1ER, England

DETAILS OF MEMBERSHIP

Membership is open to all individuals who have scientific, practical or general interest in any aspect of snow and ice study. Payment covers purchase of the *Journal of Glaciology* and *Ice*. Forms for enrolment can be obtained from the Secretary General. No proposer or seconder is required.

ANNUAL PAYMENTS 1992

Private members	Sterling	£36.00	
Supporting members	Sterling	£136.00	
Contributing members	Sterling	£56.00	
Junior members (under 25)	Sterling	£18.00	
Institutions, libraries	Sterling	£110.00	for Volume 38 (Nos. 128, 129, 130)

Annals of Glaciology – prices vary according to size of volume. For further information, apply to the Secretary General.

Note: Payments in currencies other than £ sterling should be calculated at the exchange rate in force at the time of payment. Then add sufficient money to cover the bank charges (currently £9). The Society needs the full payment, so that the extra £9 to cover bank charges should be paid by you. Thank you.
We do not accept payment by credit card.

ICE

Editor: H. Richardson (Secretary General)
Assisted by D.M. Rootes and S. Stonehouse

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 £16.50

All enquiries about the International Glaciological Society should be addressed to the Secretary General of the International Glaciological Society, Lensfield Road, Cambridge CB2 1ER, England.