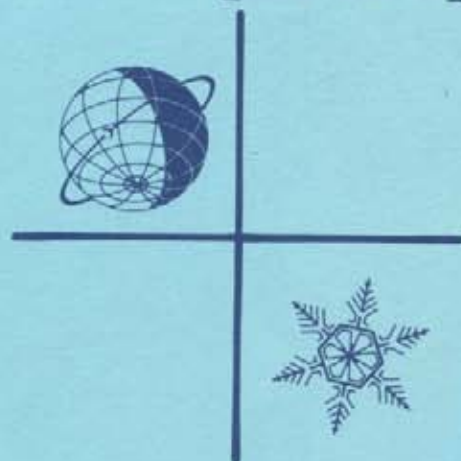


GLACIOLOGICAL
DATA

TENTH ANNIVERSARY SEMINAR
PASSIVE MICROWAVE USERS WORKSHOP
MICROWAVE RADIOMETRY BIBLIOGRAPHY

World Data Center A
for
Glaciology
[Snow and Ice]



October 1987

WORLD DATA CENTER A
National Academy of Sciences
2101 Constitution Avenue, NW
Washington, D.C. 20418 USA

World Data Center A consists of the Coordination Office
and the following eight Subcenters:

COORDINATION OFFICE

World Data Center A
National Academy of Sciences
2101 Constitution Avenue, NW
Washington, D.C. 20418 USA
[Telephone: (202) 334-3359]

GLACIOLOGY (Snow and Ice)

World Data Center A: Glaciology
(Snow and Ice)
Cooperative Inst. for Research in
Environmental Sciences
University of Colorado
Boulder, Colorado 80309 USA
Telephone: (303) 492-5171

MARINE GEOLOGY AND GEOPHYSICS

(Gravity, Magnetism, Bathymetry,
Seismic Profiles, Marine Sediment,
and Rock Analyses):

World Data Center A for Marine
Geology and Geophysics
NOAA E/GC3
325 Broadway
Boulder, Colorado 80303 USA
Telephone: (303) 497-6487

METEOROLOGY (and Nuclear Radiation)

World Data Center A: Meteorology
National Climatic Data Center
NOAA, E/CC
Federal Building
Asheville, North Carolina 28801 USA
Telephone: (704) 259-0882

OCEANOGRAPHY

World Data Center A: Oceanography
National Oceanographic Data Center
NOAA, E/OJ
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Washington, D.C. 20235 USA
Telephone: (202) 634-7510

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Geomagnetic Variations, Aurora,
Cosmic Rays, Airglow):**

World Data Center A
for Solar-Terrestrial Physics
NOAA, E/GC2
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Telephone: (303) 497-6323

**SOLID-EARTH GEOPHYSICS (Seismology,
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World Data Center A
for Solid-Earth Geophysics
NOAA, E/GC1
325 Broadway
Boulder, Colorado 80303 USA
Telephone: (303) 497-6521

World Data Centers conduct international exchange of geophysical observations in accordance with the principles set forth by the International Council of Scientific Unions. WDC-A is established in the United States under the auspices of the National Academy of Sciences. Communications regarding data interchange matters in general and World Data Center A as a whole should be addressed to World Data Center A, Coordination Office (see address above). Inquiries and communications concerning data in specific disciplines should be addressed to the appropriate subcenter listed above.

GLACIOLOGICAL DATA

REPORT GD-19

TENTH ANNIVERSARY SEMINAR PASSIVE MICROWAVE USERS WORKSHOP MICROWAVE RADIOMETRY BIBLIOGRAPHY

Published by:

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[SNOW AND ICE]

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Boulder, Colorado 80303 U.S.A.

October 1987

DESCRIPTION OF WORLD DATA CENTERS¹

WDC-A: Glaciology (Snow and Ice) is one of three International data centers serving the field of glaciology under the guidance of the International Council of Scientific Unions Panel of World Data Centers. It is part of the World Data Center System created by the scientific community in order to promote worldwide exchange and dissemination of geophysical information and data. WDC-A endeavors to be promptly responsive to inquiries from the scientific community, and to provide data and bibliographic services in exchange for copies of publications or data by the participating scientists.

1. The addresses of the three WDCs for Glaciology and of a related Permanent Service are:

World Data Center A
University of Colorado
Campus Box 449
Boulder, Colorado, 80309 U.S.A.

World Data Center B
Molodezhnaya 3
Moscow 117 296, USSR

World Data Centre C
Scott Polar Research Institute
Lensfield Road
Cambridge, CB2 1ER, England

Permanent Service on the Fluctuations
of Glaciers
Swiss Federal Institute of Technology
CH-8092 Zurich, Switzerland

2. Subject Matter

WDCs will collect, store, and disseminate information and data on Glaciology as follows:

Studies of snow and ice, including seasonal snow, glaciers, sea, river, or lake ice, seasonal or perennial ice in the ground, extraterrestrial ice and frost.

Material dealing with the occurrence, properties, processes, and effects of snow and ice, and techniques of observing and analyzing these occurrences, processes, properties, and effects, and ice physics.

Material concerning the effects of present day and snow and ice should be limited to those in which the information on ice itself, or the effect of snow and ice on the physical environment, make up an appreciable portion of the material.

Treatment of snow and ice masses of the historic or geologic past, or paleoclimatic chronologies will be limited to those containing data or techniques which are applicable to existing snow and ice.

¹International Council of Scientific Unions. Panel on World Data Centers. (1979) Guide to International Data Exchange Through the World Data Centres. 4th ed. Washington, D.C. 113p.

*The lowest level of data useful to other prospective users.

This guide for Glaciology was prepared by the International Commission on Snow and Ice (ICSI) and was approved by the International Association of Hydrological Sciences (IAHS) in 1978.

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This guide for Glaciology was prepared by the International Commission on Snow and Ice (ICSI) and was approved by the International Association of Hydrological Sciences (IAHS) in 1978.

3. Description and Form of Data Presentation

- 3.1 General. WDCs collect, store and are prepared to disseminate raw, analyzed, and published data, including photographs. WDCs can advise researchers and institutions on preferred formats for such data submissions. Data dealing with any subject matter listed in (2) above will be accepted. Researchers should be aware that the WDCs are prepared to organize and store data which may be too detailed or bulky for inclusion in published works. It is understood that such data which are submitted to the WDCs will be made available according to guidelines set down by the ICSU Panel on WDCs in this Guide to International Data Exchange. Such material will be available to researchers as copies from the WDC at cost, or if it is not practicable to copy the material, it can be consulted at the WDC. In all cases the person receiving the data will be expected to respect the usual rights, including acknowledgement, of the original investigator.
- 3.2 Fluctuations of Glaciers. The Permanent Service is responsible for receiving data on the fluctuations of glaciers. The types of data which should be sent to the Permanent Service are detailed in UNESCO/IASH (1969)*. These data should be sent through National Correspondents in time to be included in the regular reports of the Permanent Service every four years (1964-68, 1968-72, etc.). Publications of the Permanent Service are also available through the WDCs.
- 3.3 Inventory of Perennial Snow and Ice Masses. A Temporary Technical Secretariat (TTS) was recently established for the completion of this IHD project at the SWISS Federal Institute of Technology in Zurich. Relevant data, preferable in the desired format**, can be sent directly to the TTS or to the World Data Centers for forwarding to the TTS.
- 3.4 Other International Programs. The World Data Centers are equipped to expedite the exchange of data for ongoing projects such as those of the International Hydrological Project (especially the studies of combined heat, ice and water balances at selected glacier basins***), the International Antarctic Glaciological Project (IAGP), and Greenland Ice Sheet Project (GISP), etc., and for other developing projects in the field of snow and ice.

4. Transmission of Data to the Centers

In order that the WDCs may serve as data and information centers, researchers and institutions are encouraged:

- 4.1 To send WDCs raw or analyzed data in the form of tables, computer tapes, photographs, etc., and reprints of all published papers and public reports which contain glaciological data or data analysis as described under heading (2); one copy should be sent to each WDC or, alternatively, three copies to one WDC for distribution to the other WDCs.
- 4.2 To notify WDCs of changes in operations involving international glaciological projects, including termination of previously existing stations or major experiments, commencement of new experiments, and important changes in mode of operation.

*UNESCO/IASH (1969) Variations of Existing Glaciers. A Guide to International Practices for their Measurement.

**UNESCO/IASH (1970a) Perennial Ice and Snow Masses. A Guide for Compilation and Assemblage of Data for a World Inventory; and

***UNESCO/IASH (1970b) Combined Heat, Ice and Water Balances at Selected Glacier Basins. A Guide for Compilation and Assemblage of Data for Glacier Mass Balance Measurements; and

UNESCO/IASH (1973) Combined Heat, Ice and Water Balances at Selected Glacier Basins. Part II, Specifications, Standards and Data Exchange.

FOREWORD

This issue contains material from a seminar held in Boulder in November, 1986, to commemorate the tenth anniversary of the transfer of WDC-A for Glaciology from the U.S. Geological Survey to the University of Colorado. On that occasion, Margaret E. Courain, former Deputy Assistant Administrator for Information Services, NESDIS, presented the Center with a 'birthday weather map' for 14 October 1976, the formal date of the Center's transfer to Boulder. Talks were given on various aspects of WDC-A for Glaciology by its three directors, Dr. W.O. Field (1957-1971), Dr. M.F. Meier (1971-76), and myself, and also by Alan H. Shapley, Secretary of the International Council of Scientific Unions, Panel on World Data Centres.

We are also publishing the results of a Passive Microwave Users Workshop, held in Boulder in October, 1986, to discuss the status of, and plans for data products to be derived from the Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave Imager. The satellite carrying that sensor was successfully launched on 19 June 1987. The specific scheduled activities of the National Snow and Ice Data Center (co-located with WDC-A for Glaciology) in producing and archiving passive microwave data sets for snow and ice parameters through the Cryospheric Data Management System (CDMS) are described in a separate section. In addition, this issue includes a bibliography of research on microwave radiometry.

We thank Carol Pedigo and Margaret Strauch for their patient word processing support during preparation of this issue.

The staff of WDC-A for Glaciology at the University of Colorado looks forward to serving the glaciological community for snow and ice information and data products through a second decade of operations in Boulder. Interest in questions of global environmental change and their societal implications are now receiving unprecedented international attention and we expect many new challenges and opportunities to arise in the area of data management as efforts are made to address these issues through satellite remote sensing and other *in situ* measurement programs.

Roger G. Barry
Director, WDC-A for Glaciology

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**TENTH ANNIVERSARY SEMINAR
14 NOVEMBER 1986**

A Legacy of the IGY - The World Data Centers

Alan H. Shapley
Director, National Geophysical Data Center, 1971-1981

To many or most of the audience, the International Geophysical Year (IGY) is a matter of history; to some it is almost ancient history. Imagine a time without electronic computers, without instrumental earth satellites, without organized government dominance of science. Imagine a time with very spotty international coordination mechanisms, a time when an international commission of scientists, broadly expert in geophysics, spoke about what needed doing in science, and scientists, universities, academics, and governments listened. That was the time of the IGY.

Its genesis is quite well known. Lloyd Berkner, an American entrepreneur in the good sense, was thinking about post World War II science. He recognized the huge wartime strides in instrumentation, in logistics capabilities, even in some basic science of the Earth's physical environment. He saw the relative weakness of the scientific establishment in many of the war-torn countries. He also recalled the history of cooperation in several areas of geophysics, including the "Polar Years" programs at 50-year intervals. He thought why not shorten the spacing, and have a third "Polar Year" after only 25 years and put to good work all the newly available tools and capabilities. The concept fell on receptive ears, domestically and internationally, and was soon made global into the International Geophysical Year - 1957-1958. Its official, actual, and effective sponsor was a Special Committee of the International Council of Scientific Unions (ICSU) and the research was accomplished by the non-governmental academics of some 66 countries and many thousand individual scientists and groups. I was privileged to be on the ICSU international IGY Committee and the National Academy's IGY Committee which organized, raised and, in effect, disbursed the needed extra funds for the U.S. effort.

The main IGY objectives were to provide baseline data sets in all areas of geophysics. For more or less rapidly varying phenomena, there would be concentrated observations, worldwide if appropriate, over an 18-month period, 18 months so that the seasons would be well covered in both hemispheres. There are examples in meteorology, geomagnetic activity, and cosmic rays variations. For more slowly changing aspects of geophysics, there would be a new and coordinated baseline epoch of data, again on a global basis. Characteristics of the rotation of the earth, gravity, and mean sea temperatures are examples. A natural topic in this area was a 1957-58 "snapshot" of the extent of mountain glaciers for comparison with invaluable 19th century photographs and the still-to-come 21st century data.

The U.S. IGY Committee took the lead in pressing for orderly preservation of all this epochal data from the IGY. We had in mind the bad example of the unorganized heaps of data from the Second Polar Year (1932-33), then still scattered in the attics of the Carnegie Institution of

Washington, its so-called Department of Terrestrial Magnetism, of which Lloyd Berkner and indeed your speaker were alumni. Its then Director, Merle Tuve, one of the premier geophysicists of the day, forcefully lectured us at the U.S. National Committee in 1953 that he would have no part with the IGY unless there were provisions for coping with the problem of the preservation and, most importantly, the convenient and active use of the huge volume of resulting data. He had no more room in his attics. I may note that Tuve did indeed play an active and crucial role in the U.S. program for the IGY.

The international community did indeed get together on this problem under our leadership at various IGY regional and plenary meetings. Ad hoc working groups hammered out recommendations on how data should be recorded, what should be exchanged, and eventually, how this should be accomplished. There was some mistrust of data centralization in one big country or another, on a scientist sending away data copies before they had used it for prestigious or even possibly prize-winning studies. Why wasn't the "old boys club" of data exchange good enough? Sir Edward Appleton and some distinguished Englishmen and Frenchmen and others said: "We don't need any organization for that. If I need some data, I can simply write a letter and the data comes." But the community of geophysics was growing rapidly and becoming more and more interdisciplinary. It was awfully difficult to join "the club," especially for younger scientists.

In time, the differences in points of view were finally compromised at a snowy meeting in Brussels in the Spring of 1957, only about three months before the IGY was to begin. One major compromise was a hedge on the working of the exchange system. Almost all key data would be published in the *IGY Annals*; indeed more than 30 of the some 45 volumes published were data volumes. Because of the success of the data exchange system, the *IGY Annals* are hardly ever read or referenced. Another compromise was to provide for duplicate centers, A, B, and C, in different parts of the world, for the convenience of both the providers and users of data, and as insurance in case data disappeared from one by fire or for other reasons. At the meeting we identified the duplicate A, B, and C centers of the World Data Center for the IGY, based on the offers of several countries, and at their expense. The IGY Guide for data exchange was mimeographed and mailed. A new position of IGY Coordinator was established in Brussels to oversee the exchange.

The data flow started very slowly. The A, B, and C centers sent monthly reports to the Coordinator which were promptly published and circulated. This helped shame the slow-pokes or at least get them to apologize. For example, there was only one mail a year from remote observing stations in Siberia or Antarctica. By the end of the IGY, 1958, and its one-year extension 1959, the data collections were growing in all the IGY disciplines. More importantly, scientists were finding they could get data copies from the centers, whether blueprint copies, thermofax, photographs, or transcriptions; and catalogs were appearing. This was happening at the center in Moscow, the dozen discipline centers in the United States, centers in England, Japan, Australia, and so on. The voluntary exchange of geophysical data through the WDCs was beginning to be seen as a valuable asset to the world community of geophysics. Thus in 1960 the ICSU committee charged with completing the IGY project recommended that appropriate post-IGY observations also be sent to the WDCs, if the WDCs were willing to play this continuing role; most of them did agree.

This is some of the historical perspective on what we now see here. The activity which was started to cope with the epochal data for 1957-58-59 has been coping with new data ever since. The WDCs are almost 30 years old. This lively and up-to-date center servicing Glaciology has had ten years of important service in Boulder, following the equally important beginnings of Bill Field at the American Geographical Society in New York and Mark Meier at the U.S. Geological

Survey at Tacoma. It is not exactly what Sir James Wordie, the international "Rapporteur" for Glaciology for the IGY nor even his then young assistant, Gordon Robin, had in mind, nor perhaps the U.S. leader in Glaciology, Bill Field, or the Executive of the US-IGY program, the late Hugh Odishaw, but it is clear that it has been serving the contemporary user community needs very well.

I mentioned that there were times of mistrust and other problems in the planning stages of IGY data exchange, and many compromises were made. I recall another such problem, almost ten years ago. People like me thought the term "Glaciology" was synonymous with the scientific study of glaciers, mountain glaciers. I was gradually taught by Larry Gould, Bert Crary, Willie Weeks, and of course, Roger Barry, that the needed work covered all manifestations of snow and ice. But the name was misleading to workers in related geophysical disciplines and to government bureaucrats, as well as most of the general public. I recall discussing this with Roger and the visiting Dr. Kotliakov of the USSR and others. Most or all of the cold, "cryo...", words had been preempted for other uses. But the simple words "snow and ice" were still available and appropriately descriptive of the data activity. Before taking action on changing the name of the data center, Roger wrote for the opinion of his counterpart, WDC-C Glaciology at the Scott Polar Research Institute in Cambridge, England. The response, as I understand it, was that back in the 1920s the "Royal something Society" had formally decreed that the word Glaciology included all aspects of snow and ice. Thus "Glaciology" was the one and only correct word. They would not look kindly on the change. After that I suggested the square-bracket solution which WDC-A still uses. I wonder how many more generations will have to elapse before we can modify the decree by the "Royal something Society"?

Warm congratulations on the tenth anniversary of Boulder's highly respected World Data Center A for Glaciology [Snow and Ice].

World Data Center A for Glaciology at The American Geographical Society

William O. Field
Director, WDC-A for Glaciology, 1957-1970

Introduction

The record of the first 13 years of the operation of World Data Center A for Glaciology is now almost ancient history. The records that still exist and that can be located, plus such personal memories as can be resurrected, are sufficient only to present part of the picture. The following account must be considered as largely subjective.

The idea, which developed into the International Geophysical Year (IGY) was first proposed in 1950 by Lloyd V. Berkner. He suggested that a third Polar Year Programme should be undertaken in 1957-58 as a suitable activity to celebrate the 25th Anniversary of the Second International Polar Year (*Annals*, I, 1959, p. 383). The following year the World Meteorological Organization (WMO) proposed that the program of observations should be expanded to cover the whole surface of the earth and might be called an International Geophysical Year. (*Annals*, I, 1959, p.384.) Eventually the program was organized under the International Council of Scientific Unions (ICSU) which set up a special committee known as the the Comité Spécial pour l'Année Géophysique Internationale (CSAGI) to undertake the central planning of the program.

The Beginning of a Glaciological Program

During the First and Second International Polar Years (1882-83 and 1931-32) there had been no specific glaciology programs. At the meeting of the International Union of Geodesy and Geophysics (IUGG) in Rome in September 1954, glaciology was added to the IGY program. "The study of the extent, character and behaviour of glaciers and snow cover, from observations in many parts of the world, forms another section of the IGY programme. This simultaneous survey will be far more geographically comprehensive than any made hitherto, and will be of great importance to meteorology and climatology. It was considered desirable that terrestrial phenomena with very slow variations should be observed during the IGY, so as to provide basic data with which similar data, collected later, can be compared.

The evolution of glaciers provides a clue to climatic changes and it is, therefore, planned . . . to determine the extent of glaciers, of snow cover over the continents, and of ice pack over the oceans. [For] certain glaciers selected in advance, observations will be made of mass changes, movement, height and ice accumulation, the effect of radiation on the ice, and of melted water; weather observations will be made simultaneously to determine the relationships between the evolution of glaciers and of climate. The extent, thickness, and duration of snow cover will be under constant observation" (*Annals*, I, 1959, p. 399).

Although glacier ice had been thought of primarily in the early stages, the new planning included floating ice on oceans, lakes, and rivers, permafrost, as well as ice in the atmosphere. The concept of glaciology was rather narrow at the beginning of the IGY, but has expanded gradually . . . to include all studies of natural or artificial ice and snow.

Planning the World Data Centers

It was foreseen that unlike the two earlier International Polar Years, the IGY program would result in a far larger mass of data. Accordingly, at the third meeting of CSAGI in Brussels, Belgium, in September 1955, a Committee on Availability of IGY Data was appointed.

"This committee recommended that centres should be set up in different countries as repositories for the collection of the IGY data to be exchanged between the nations participating in the IGY" (*Annals*, I, 1959, p. 405). This was the first Commitment to the concept of world data centers.

As Sidney Chapman, CSAGI Bureau President, Chair, Committee on Availability of IGY Data reported: ". . . it is an essential principle that the far greater mass of data to be obtained by the many co-operating Participating Committees shall form a common fund of knowledge open to all. The arrangements for the fulfillment of this principle have been a major concern of CSAGI. Some of the IGY data will be published by individual national institutions or by international unions or associations. But there will remain a vast amount of unpublished data. This will be collected in IGY World Data Centres (WDCs). These will be repositories of material contributed by the many IGY nations. There the material will be stored and catalogued, and made available at minimum cost to research workers everywhere." (*Annals*, VII, p. 145.) CSAGI encouraged offers "from IGY Participating Committees willing to set up and maintain such repositories in their own countries and at their own expense, as an international service conforming to rules laid down internationally." (*Annals* VII, p. 146.)

The Establishment of World Data Centers

At the fourth meeting of CSAGI in Barcelona in September 1956, "CSAGI authorized the establishment of at least three IGY World Data Centres, each of which . . . would be at the service of all countries and scientific bodies. . . . The offers from the National Committees of the U.S. and the USSR to establish and manage a World Data Centre were accepted. It was decided that the IGY World Data Centre A would be in the U.S.A.; the IGY World Data Centre B would be in the USSR . . ." (*Annals*, I, 1959, p.410-411). Later World Data Centre C was established at the Scott Polar Research Institute in Cambridge, England, to be operated by the British Glaciological Society.

Detailed recommendations regarding the operation of these Data Centers were evolved at a meeting at Uccle, Belgium, in April 1957. Additional recommendations were made at the Fifth CSAGI Assembly in Moscow in August 1958. These recommendations resulted in the "CSAGI Guide to IGY World Data Centers" which appeared in *Annals of the IGY*, vol. VII, Part II, 1959.

It was suggested that the American Geographical Society (AGS) would apply to operate the World Data Center A for Glaciology, since its Department of Exploration and Field Research had been collecting and maintaining glaciological data since 1940. In addition to its own collection of photographs of glaciers, the AGS, by the mid-1940s, had already acquired responsibility for the preservation and development of the collection of photographs, maps, and other data which had been established by the Research Committee on Glaciers of the American Geophysical Union (AGU) under the chairmanship of Dr. Francois E. Matthes, research geologist in the U.S. Geological Survey (USGS). Prior to this time, the collection had been kept in the office of Dr. Lawrence Martin, Chief of the Division of Maps at the Library of Congress. The AGS program of glaciological research included field work concerned with the fluctuation of a number of glaciers in southern Alaska and the Canadian Rocky Mountains. By the middle 1950's, the AGS collection was substantial.

Eventually the U.S. National Committee for the IGY (USNC-IGY) awarded the operation of WDC-A for Glaciology to the AGS. This was the only one of the 11 data sub-centers in the United States established at a small, independent, private organization. The other 10 were to be administered by either government or quasi-government organizations, or well-established universities.

World Data Center A for Glaciology began operations on 1 July 1957 under the author's direction. An advisory group of scientists representing various aspects of glaciology and related disciplines was appointed. This group consisted of Henri Bader, Chief Scientist, U.S. Army Snow Ice and Permafrost Research Establishment (SIPRE), later the Cold Regions Research and Engineering Laboratory (CRREL); Phil E. Church, Executive Officer, Department of Meteorology and Climatology, University of Washington; A.P. Crary, geophysicist, of the U.S. Antarctic Program; Louis de Goes, National Academy of Sciences (NAS); Richard Foster Flint, Professor of Geology, Yale University; Richard P. Goldthwait, Professor of Geology, The Ohio State University; Donald B. Lawrence, Professor of Botany and Ecology, University of Minnesota; Mark F. Meier, Project Hydrologist, Water Resources Division, General Hydrology Branch, U.S. Geological Survey (USGS); Louis O. Quam, Head, Geography Branch, Office of Naval Research, (ONR), John C. Reed, geologist, U.S. Geological Survey; George P. Rigsby and Robert P. Sharp, Geological Sciences, California Institute of Technology; Paul Siple, Office of the Chief of Research and Development, Army Research Office; and A. Lincoln Washburn, Polar Regions Geomorphology, Dartmouth College.

In planning the WDC-A for Glaciology program, consideration was given to the differences in the development of operation of glaciological programs in the United States and in the other nations involved in the IGY. In most of the European nations and the USSR there were organizations which kept track of activities and, to some extent, coordinated individual, academic, and public research projects. In the United States, however, there had been a minimum of coordination on a national or regional level; the few active glaciologists had been operating largely on an individual basis, performing their observations and research activities where they sensed a need and where funds were obtainable. Efforts had been made from time to time to publish summaries of data on glacier fluctuations, such as H.F. Reid's series on the Variations of Glaciers from 1896 to 1916, published in the *Journal of Geology*, and the reports by F.E. Matthes for the Research Committee on Glaciers of the AGU which appeared in its *Transactions* from 1931 to 1945, but over the years there was relatively little coordinated activity.

Beginning in July 1957, pertinent data and information on glaciological subjects received at the AGS Department of Exploration and Field Research were handled as part of the IGY Data Center operation. Initially, two members of the Department were assigned to the Data Center on a part-time basis.

After WDC-A for Glaciology began operations, the lists of data received were sent to the World Data Center Coordination Office at the IGY Secretariat in Washington, DC. A series called "Catalogue of Data in World Data Center A" was then issued for various disciplines represented in the IGY.

In keeping with the efforts of IGY World Data Center A for Glaciology to act as an information center for individuals and organizations, a decision was made in the fall of 1959 to establish a new publication concerned with the study of ice and snow, which was to be issued at quarterly intervals during the next year. The bulletin was to act as a source of information about current activities, studies, and publications in the field of glaciology, and to describe the operations on the Data Center. In the first issue of *Glaciological Notes* (1960), its purposes were described as including the following: (a) listing acquisitions of the Data Center Library; (b) news of current glaciological research activities, field work, publications in preparation, future plans, and any other notes which might be of interest; (c) schedules of future meetings and reports on meetings recently held; (d) positions available in glaciology and related fields, and notes on sources of support for research projects; (e) newly available translations of foreign publications of glaciological interest; and (f) occasional special reports of such topics as new equipment, techniques, and logistics.

The first issue appeared in January 1960. The schedule of four issues per year was maintained in its original form until the summer of 1963. In the combined issues numbered 15 and 16, dated July-October 1963, it was announced that ". . .with regret . . . due to budgetary limitations, this Data Center finds it necessary to curtail the coverage of this and future issues of *Glaciological Notes*. Until further notice, therefore, it will be possible to publish only the list of library acquisitions, including photographs and maps, received by the Data Center each quarter. News of meetings, research, and field projects which were formerly included in *Glaciological Notes*, will be sent for publication in *Ice*, which is issued by The Glaciological Society." (*Glaciological Notes*, no. 15-16, p.1)

Other publications issued by the Data Center included seven separate reports of the IGY Glaciological Report Series. These were designed to make field data available as soon as possible after the completion of the field work without waiting for final publication. In no way was it to supercede such final publication.

The Post IGY Period

Some of those who were active in the glaciological activities of the IGY in 1957 and 1958 feared that after the tremendous effort and infusion of enthusiasm, cooperation, and funding of that period, there could be a relapse into the pre-IGY condition of more or less *laissez-faire* operation, lacking in central planning, and a gradual disappearance of much vital financial support. However, at the Fifth General Assembly of CSAGI in Moscow in July-August 1959, it was proposed to extend the IGY program for a one-year period to be called International Geophysical Cooperation 1959 (IGC-59). It specifically recommended a continuation of data exchange among the three IGY World Data Centers.

At the end of the IGY in 1958, ICSU established the Committee on International Geophysics (CIG) to succeed CSAGI which was scheduled to be terminated on 30 June 1959. CIG was to terminate the work of the IGY and IGC-59 programs and assume responsibility for continued international and interdisciplinary scientific cooperation in the fields of geophysics and related sciences. At the first meeting of CIG at The Hague in November 1959, it was resolved that the IGY World Data Centers should continue as permanent world data centers, acting as depositories for IGY/IGC data and new data. This was confirmed by the Geophysics Research Board Panel on International Exchange of Geophysical Data: "In view of the recommendations by various international and domestic scientific councils that these data centers should continue their activities on a permanent basis . . . the GRB Panel recommends that World Data Center A continue to exchange data internationally on a permanent basis in accordance with international recommendations developed through CIG and the assorted committees of ICSU." (Hart, p. 8)

The CIG objectives were: "First, to ensure the fullest possible exploitation of the IGY and IGC-59 data, including: maintaining the efficient functioning of the WDC's, encouraging the discussion and utilization of IGY and IGC-59 results, and publishing the IGY and IGC-59 results and bibliographies. . . ." "The uninterrupted operation of the World Data Centers, however, was deemed necessary, in part because they afford a natural and existing medium of data collection and in part because they already represent an invaluable depository for the research worker. Many decades will pass before the riches of these reservoirs shall have been exhausted, providing as they do a unique opportunity to correlate data in many fields. Special note was taken of U.S. and USSR intentions to continue their centers. . . ." (Odishaw, 1960).

A reply from the AGS to Odishaw, dated 4 March 1960, states: "In glaciology, there is a need for a central organization embracing the functions of an archive and information center. The present WDC-A for Glaciology attempts to do this. There is a further need of a coordinating center in glaciology [which would help the] orderly developing in this country of a well-balanced, modest glaciology program" (Field, 1960)

The AGS managed to operate World Data Center A for Glaciology during the 1960's because it was an organization with special research and library projects which provided required staff, especially persons who could work for the Data Center on a part-time basis. By juggling personnel schedules, it was possible to maintain the Data Center staff at an equivalent of about two persons full time and from two to five on a part-time basis.

Those who served in full-time capacities as either editor or librarian and who therefore, over the years, bore the basic responsibility for the operation were: Marie (Hatcher) Morrison; Camilla (McCarthy) McCauley; Charlotte Fahn; Martha (Buchwalter) Utley, Eva Horvath and Georgia Bergness. Others, such as the secretaries, researchers on other projects, including the author, who was Director of the Data Center throughout the period, worked for the Data Center on a part-time basis.

Budgetary Problems

The USNC-IGY allotted about \$30,000 per year for the two and a half year period of the IGY and ICG-59. This launched the Data Center. In the next two calendar years, 1960 and 1961, the average annual grant from the National Science Foundation (NSF) was close to \$27,000. The grant covering a period of one year beginning 15 August 1962 totaled \$25,000.

Having been encouraged by a memorandum from the World Data Center Coordinating Office, stating that the subject of data exchange had been reviewed by a variety of international scientific bodies, all of whom recommended maintaining the World Data Centers, the AGS submitted a proposal to NSF in May 1963 for continued funding of the Center at the same level as in the previous year. However, in late July 1963, when the Data Center was already well into its new fiscal year and commitments had already been made for the next few months, NSF advised that the budget submitted in May would have to be reduced by about one-half.

In a letter of 4 October 1963 to the World Data Center Coordination Office at NAS, the author wrote that the funds on which the Data Center had been operating would run out in November and that since 1 July the Data Center was now using funds originally set aside for publication of the remaining scheduled issues of the IGY Glaciological Report Series. The letter confirmed that the Center was now on the reduced budget which had been put into effect in accordance with the revised figure submitted on 25 July. The staff had been reduced to one full-time librarian, with three other part-time staff, and this reduction in staff during the summer had interfered with the Center's ability to fulfill its obligations. It was further implied that IGY Glaciological Report Series, No. 8, would now have to be canceled (Field, 1963). In early December 1964, a further note of uncertainty was added when the AGS was informed that there was considerable feeling at NSF that support for the Data Center would be phased out during 1965.

A reduced budget as requested by NSF was submitted in December 1964 which totaled slightly more than \$15,000. After that, NSF found it possible to provide \$20,000 for each of the next two years. Then a letter in December 1968 stated: "I am writing to let you know that it is no longer possible for NSF to provide continuing support for the World Data Center A for Glaciology. This decision reflects current restrictive budgets together with heavy demands for support of specific research projects. . . . To assist in closing out that part of the Center's operation previously funded by NSF, we are willing to consider one additional year of support in the amount of \$20,000 (Ray, 1968)." This made it possible to carry the Data Center through 1969.

In retrospect it was apparent that the financial support of the Data Center had to come from funds primarily intended by NSF for basic research, and that the Data Center could not fully qualify for this, as it was concerned almost entirely with gathering and distributing information, rather than with basic research.

The matter was discussed at a number of the annual meetings of the Glaciology Panel of the Committee on Polar Research. It seemed clear, since NSF could not provide long-term support, that it would be preferable for the Data Center to be operated by another organization, not dependent on year-to-year funding. Meanwhile, several other institutions had become interested and had requested they could be considered in any transfer of the Data Center. However, at the same time it was pointed out that in most cases these institutions were also dependent on the same source for funding as the AGS had been.

Move from AGS to USGS Tacoma

A Committee on Polar Research memorandum of 19 March 1969, to A.L. Washburn, Chairman of the Committee on Polar Research Glaciology Panel, and Richard P. Goldthwait, Chairman on Glaciological Data, stated that "The American Geographical Society's . . . contribution to the Center has successfully established its value to the international scientific community and the desirability of perpetuating the center (Hart, 1969)." The Committee on Data Interchange and Data Centers had also pointed out what was becoming apparent to all concerned that the WDC-A for Glaciology was " . . . in jeopardy for financial reasons . . ." (Hart, 1969). A memorandum in September from Washburn to the Glaciology Panel stated " . . . it now seems quite clear that the effort cannot continue to be financially supported by the American Geographical Society and that probably the best way to assure maximum use and continuity of the center would be to have it attached to a civilian government agency that is active in research and in a position to fund the center as a line item. Most of the other World Data Centers are now operated in this manner and the pattern is well established." (Washburn, 1969a). AGS agreed that the Center "should be housed and administered where year-to-year funding can be assured." (Lakovitch, 1969). It was also suggested by Washburn that the Data Center work should be expanded " . . . to serve as a communication and coordination device to bring together work in snow hydrology, frozen ground, sea ice, snow avalanches, etc. (Washburn, 1969a)."

A letter of 30 October 1969 from Washburn to Laurence M. Gould, Chairman, NAS Committee on Polar Research, noted that he had now heard from nearly all members of the Glaciology Panel, and that the vote was overwhelmingly in favor of seeking the transfer of the Data Center to the USGS if appropriate arrangements could be made. He added that "It was clear that the Panel regards the continuation of the center as an urgent and high priority matter (Washburn, 1969b)." On April 15, 1970, William A. Radlinski, Acting Director of the USGS agreed with Thomas Malone, Chairman, Geophysics Research Board, NAS-NRC, to assume responsibility for the WDC-A for Glaciology. It was housed at the USGS Project Office Glaciology in Tacoma, Washington, under the direction of Dr. Mark Meier. In a previous letter recommending the move to the Director of the Survey, Malone states "There is widespread interest in Glaciological research on the west coast and it is felt that the relocation of the WDC-A for Glaciology as an activity such as the USGS office in Tacoma, which is involved in glaciological research, would admirably serve the interests of the glaciology community in this country and best meet our international obligations in this field." (Malone, 1970)

The official transfer was set for October 1, 1970, but the Survey was to assist the AGS in the publication and distribution of the July and October issues of *Glaciological Notes*. The October issue was no.44 in the series.

Conclusion

This report would be incomplete without mention of the strong support at the beginning of the Data Center operation by the U.S. National Committee for the IGY through its Chairman Joseph Kaplan, and the Executive Director, the late Hugh Odishaw; members of the NAS-NRC IGY Secretariat: Pembroke J. Hart and the late John Hanessian; and after the IGY by Laurence

M. Gould, Chairman of the Committee on Polar Research and A. Lincoln Washburn, and the various members of the original Glaciology Panel of the IGY which later continued under the Committee on Polar Research. In compiling this report the author wishes to acknowledge with thanks the help of Marie T. Morrison and Charlotte Fahn, each of whom served in turn as editors and coordinators in the early years of the Data Center; and to C. Suzanne Brown of Project Office Glaciology, U.S. Geological Survey, Tacoma.

Over the thirteen years that the Data Center was at the AGS, many people gave their time and energy to the Data Center. Records show that no less than 25 different individuals worked for the Center at different times. However, less than half ever work full time, while the others had multiple assignments extending over several other separate projects. It was a difficult time, with fiscal uncertainty, and varying annual budgets, at times the operations were reduced to the barest essentials. But as the AGS involvement ended and the transfer to the USGS became a reality, those who had been responsible for its first years could look back with some satisfaction at their achievement.

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Where Do We Go From Here? Glaciology: 1987 and Beyond

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I will first try to put your mind at ease: I will not use acronyms, but most especially I will not use the word "cryosphere".

The assigned title for my talk suggests that I am supposed to talk about the Tacoma years of the Data Center, 1971-1976. I really don't have much to say about those years. I think our principal accomplishments were modest. We did take Bill Field's *Glaciological Notes* and expand it to a larger magazine with pretty pictures on the cover. These publications were essentially nothing more than Accession Lists as Bill's (W.O. Field) *Glaciological Notes* were, but we did add items, such as a listing of aerial photography, so it was not just a compilation of bibliographic references.

One of the things I tried to do was to incorporate non-glacial glaciology, but at that time the scientific community was heavily involved with glaciers and not so involved with snow cover and sea ice and matters like that. That was the time of the International Hydrological Decade which followed the IGY and it was a period of great stimulation in glacier glaciology with programs on World Glacier Inventory and the Permanent Service on the Fluctuation of Glaciers. There was also a program on Combined Heat, Ice and Water Balances at Selected Glacier Basins throughout the world; so as these programs indicate, there was a huge surge of glacier glaciology at that time.

One thing we tried to do in Tacoma was to put together a more secure organization of historical glacier photographs including the Austin Post photography which began in the late fifties and continues more or less to this day. This is being continued here in Boulder; the Tacoma office and the WDC have been working very productively on that, but the job is not finished.

Bill Field mentioned that it was supposed that all the problems of funding would be solved by moving the Data Center into a government agency. As you might have suspected it was not quite that simple. We did manage to get the princely sum of up to \$50,000 per year to run the Data Center, but in a government agency you have much less flexibility. I think one of the reasons for the major success that Roger Barry has achieved here in Boulder is the fact that he combines the best of both worlds and has both flexibility and a fairly stable funding base.

In 1976 the Data Center was transferred from the U.S. Geological Survey in Tacoma to Boulder under Roger Barry's direction, and at that time, real life was breathed into it.

Now, I haven't used up much of my allotted time, so perhaps it would be appropriate to talk about where the science of snow and ice or glaciology is heading, or my personal view of which opportunities or thrusts are coming up. Then one can mesh the Data Center's interest with the thrust of the field itself. A few weeks ago John Walsh (U. of Illinois) and I and a few other colleagues were privileged to address the National Science Board on the matter of polar science and so I prepared some viewgraphs showing what I

think are likely to be the major new opportunities in the field of snow and ice science.

After considerable thought and discussion with colleagues, I gathered that there are really about five areas in snow and ice that should be highlighted; these are presented roughly in order of scientific interest and priority. First, and most exciting, are the records of environmental history that come from ice cores and other environmental indicators; second, glacier ice sheet dynamics; third, sea ice; fourth, seasonal snow; and fifth, permafrost. Let us look at some of these.

Ice cores such as the ones obtained in the last three or so years are really exciting. For instance the ice core in Quelccaya, Peru, shows 1500 annual layers displaying the history of El Niño and the seasonal pollen of the Amazon Basin and all kinds of things like that, continuously in time. There is no other record on Earth that really shows this. It is interestingly just upwind from type area of El Niño; this Amazonian precipitation, in other words, is all the way around the world from the El Niño area.

Another very exciting result, obtained with inexpensive shallow ice cores, is the documentation of the rise of a variety of anthropogenic substances, such as methane and chlorofluorocarbons (Figure 1), from preindustrial times through the industrial revolution right up to the present. Now we know what the CO₂ content of the atmosphere was in the year 1700, for instance. With the present concern over the greenhouse effect these data are really significant. Ice cores are the only way we can sample fossil atmospheres.

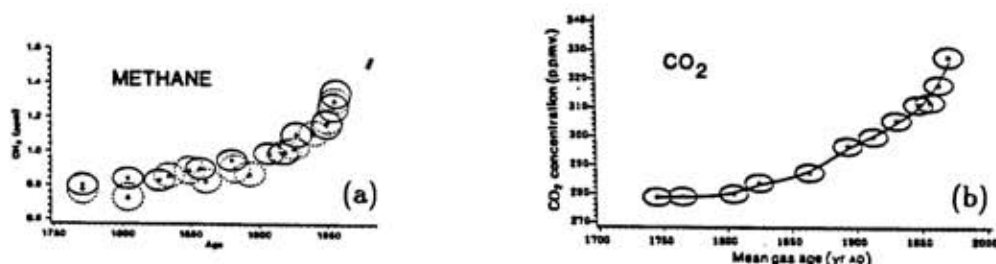


Figure 1. Methane (a) and CO₂ (b) concentrations measured in ice samples from Siple Station in western Antarctica. (After: (a) Stauffer, B., et al., *Science*, 220 (4720), p. 1386; (b) Neftel, A., et al., *Nature* 315 (6014), p. 45).

In Greenland the recent Dye-3 core showed some very exciting things. Dye-3 is a U.S. radar station on the Ice Sheet in south central Greenland. It was a great place to work as far as logistics was concerned. Scientifically it was a terrible place to drill, but the results are still amazingly good. The most interesting result to me was the evidence found for rapid oscillations of climate. For instance, the transition from the last glacial period to the Holocene (or present non-glacial time) shows marked changes in chemical elements, such as chloride, sulphate, and nitrate, and these changes occur in only a few decades. The climate switched abruptly from full glacial conditions to present day conditions! This abrupt switch shows also in the ice core records of air temperature, precipitation, dust, and almost every other variable measured in the cores. These rapid swings are very interesting, and can be seen in the last glacial period also. The climate near the end of the last glacial period abruptly switched toward a non-glacial condition, later it suddenly reverted back to full glacial, and then suddenly again to the non-glacial which continues to the present. These rapid transitions, occurring in just a few decades, completely destroy our prior understanding of how carbon is cycled through the atmosphere and oceans. The conventional wisdom does not permit these fast flip flops. In view of these

evidences for rapid climate switching, we are wondering what is going to happen if man modifies the environment.

Ice cores are exciting, but you cannot understand ice core results without first knowing something about the dynamics of the ice sheets. There is much current interest in glacier dynamics for this and other reasons. The interest is now focusing on the fast sliding of certain kinds of glaciers and ice streams. Ice streams are jets of fast moving ice that remove ice from ice sheets. Recent work by scientists from the University of Wisconsin shows what appears to be a 6 meter thick layer of subglacial debris, probably glacial till, that is pressurized with water under the fast-moving Ice Stream B in Antarctica. Deformation of this debris layer may account for the rapid motion of that ice stream. Another thing we are noticing about ice streams in the Antarctic is that they appear to turn on and turn off. We do not know whether they slide fast and then slide slowly, or whether they pirate each others drainage basins, or just what happens, but it is obvious that this behavior is not a steady-state process. These questions are absolutely critical to any analysis of the future of the West Antarctic Ice Sheet in terms of possible instability due to the greenhouse effect.

Tidewater glaciers are also of considerable interest. The one that I study, Columbia Glacier, is very interesting because it flows very rapidly (15 meters per day) yet is currently disintegrating in a manner suggestive of possible Antarctic ice streams disintegration. The iceberg-calving Jakobshavn Glacier in Greenland is the fastest glacier in the world, flowing continuously at 22 meters per day. There are many questions about it that scientists are addressing. It is a cold ice stream, but melt-water disappears into the glacier from the surface; we do not know where that water is in the glacier and whether it is permitting the glacier to slide rapidly on its bed or not. Both the Columbia and Jakobshavn Glacier studies have a difficulty, the lack of a well-defined terminus condition, which is critical to analysis of the dynamics of the glacier. The terminus boundary condition must include a calving law, the rate of iceberg calving into the sea, and that has not yet been clearly established.

There is a third type of glacier which has long been of great dynamical interest, that is the surging glacier. These are glaciers that periodically flow very fast and then lapse into a longer period of quiescence. By fast, I mean fifty to a hundred or more meters per day. What starts the surge is only partly understood; why some glaciers surge, but not others, is not totally understood. Can there be one time surges? It has been suggested that the West Antarctic Ice Sheet could surge. Uwe Radok and his collaborators have modeled this but we have not observed such a surge, so at the present time it is still a question whether this really happens or not. Much of our current understanding of the dynamics of glacier surges comes from a major study of the Variegated Glacier in Alaska, which surged in 1982-1983.

Every once in a while glacier dynamics hits the national news media, for instance, the recent "surge" of the Hubbard Glacier in Alaska which blocked Russell Fjord. The early news reports and press releases described the "surge" of the Hubbard Glacier, and magazine articles asked: "Why did the Hubbard Glacier get the urge to surge?". Hubbard Glacier is not a surging glacier. It probably never surged and it probably never will. It is, however, a tidewater glacier that ends in the sea by breaking off icebergs, like the Columbia Glacier. The Hubbard has been advancing slowly, moving its submerged terminal moraine forward since before 1895. In a few hundreds or thousands of years, it will get close to Yakutat and then quit moving forward. It is undergoing a slow and steady advance, characteristic of advancing tidewater glaciers. This advance just happened, in 1986, to block a fjord, as was predicted many years ago (Figure 2). A lake formed in the

fjord, broke out in October, 1986, and will undoubtedly reform and break out again. This cycle may go on for some time, but eventually the Hubbard Glacier will have enough ice in that area to permanently close off the fjord. This glacier is controlled by calving glacier dynamics, not surging glacier dynamics.



Figure 2. The Hubbard Glacier, Alaska, in 1982 (above) and after the 1986 advance (below). U.S. Geological Survey photographs.

New thrusts in sea ice are many. Sea ice is critical to the formation of bottom water which affects oceanographic circulation, and sea ice affects heat and mass transfer between atmosphere and ocean at high latitudes; thus sea ice studies are critical to any global studies of what is going to happen in the future.

Remote sensing of sea ice has been with us for a long time. Passive microwave sensing can tell us the ice extent, something about ice concentration, but it cannot tell us if the ice is multi-year ice, except in certain special cases. I think what is really holds promise for the future is synthetic aperture radar working together with passive microwave radar, combined with data from drifting buoys. Finally we will have enough information to really understand the mass balance and dynamics of sea ice. This is, of course, essential because one of the problems with our existing atmospheric circulation models and ocean models is the inability to properly parameterize the sea ice.

Let me move on very quickly. Large-scale study of seasonal snow cover is in part a remote sensing problem. How can we measure the snow mass and how can we measure the wetness (the liquid water content) of the snow? These problems are not solved. We can estimate the areal extent of snow cover using passive microwave sensors if we know that the snow is not patchy, is cold everywhere, and is not covered by vegetation. We can estimate, in some cases, the mass of the snow. We can also tell whether it is wet or not, but quantitatively we do not have enough reliable information for remote sensing to be useful routinely in large scale snow studies or forecasting.

There are a number of exciting things in permafrost science, such as permafrost temperatures, permafrost ecology and so on. Unfortunately I will not have time to discuss these further.

I would like to conclude with some general points. Some of the major thrusts as mentioned above, such as studies of ice cores and remote sensing of sea ice, are large in scale, long in term, and/or are very data intensive; because of this they need data centers. There is a real data management problem that will require a centralization of facilities. On the other hand, some research topics such as the study of surging glaciers and problems like the formation of sun cups in snow packs are topical, short-term studies that are engaged in very intensively for short periods of time, and are peculiar to a certain area. With these there is not data management problem at all, because the data probably reside in one scientist's office and no one else really wants the data unless they want to check it. What this means is that data centers, such as this one, will really be involved in part of the action, the action that requires extensive data management. But the data centers will be challenged because they should also keep up with what is going on in these topical, basic science studies. I leave that as a challenge for the data center system.

Another thing I wanted to mention is the structure of international science as it is evolving now. As you know, one international program is developing that will be even larger in extent than the IGY. This is the International Geosphere-Biosphere Program (IGBP). The U.S. National Committee put together a report (the so-called Academy Red Book) on an International Geosphere Biosphere Program and it describes the catechism as follows, "to describe and understand the interactive physical, chemical and biological processes that regulate the Earth's environment for life, the changes that are occurring in this system, and the manner in which they are influenced by human actions." The international program has now been approved by the International Council on Scientific Unions, and its objective is almost identical with that of the U.S. National Committee's document. In addition the National Science Foundation has established a Global Geosciences Initiative. NASA has put out beautiful publicity material on Earth Systems Science Program, and other agencies are getting on the bandwagon. This new

opportunity is, I think, going to require reorganization of our system of getting science done.

First of all these new programs are blatantly interdisciplinary. Biology and physical science are in the IGBP together. How do you incorporate that in the organization of the National Academy of Sciences? How do you incorporate that in the National Science Foundation structure?

There are, or will be, all sorts of organizations involved in the IGBP. The International Council of Scientific Unions (ICSU) consists first of Unions, such as International Union of Geodesy and Geophysics, as well as scientific committees outside the union structure, like the Scientific Committee on Antarctic Research, and there are other *ad hoc* bodies under ICSU. Involved also are inter-governmental agencies, such as WMO, and non-governmental agencies; it is a real tangle of organizations. This is a real problem. In many respects, our national and international structures are not well suited to broad, global, interdisciplinary science, and it is going to take a lot of initiative to cope with this situation. Even in the last 50 years we have seen some important fields of science fall through the cracks. Which office in the National Science Foundation funds non-polar snow studies for instance, or which government agency? How about the global hydrologic cycle?

We need to develop structures on a national and international basis and in the data management community to cope with these problems.

World Data Center-A for Glaciology: The First Ten Years at the University of Colorado

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The activities of the WDC-A for Glaciology since its transfer to Boulder in 1976 can be put into an historical perspective, a data management perspective, and a research perspective. This overview will try to combine all three aspects.

Historical Perspective on the Data Center's Move to Boulder

I will begin by thanking a number of individuals who over the years have been enormously helpful to me and the staff in expanding the capabilities of the data center. Alan Shapley, formerly Director of the National Geophysical Data Center, initiated the transfer of the WDC-A from the U.S. Geological Survey Glaciology Project Office to NOAA - Environmental Data and Information Service (now the National Environmental Satellite, Data, and Information Service, NESDIS). That came about through his discussions with my colleague Jack Ives, then Director of the Institute of Arctic and Alpine Research, University of Colorado. The proposed move of the Center was discussed by the Polar Research Board, Committee on Glaciology at its annual meeting in 1976. There were a number of institutional contenders for the relocated center including Ohio State University's Institute of Polar Studies. Nevertheless, following the decision to transfer the activity to Boulder, there has been no greater supporter of our work than Colin Bull (former Dean of the College of Mathematics and Physical Sciences, Ohio State University) who served on the first Panel on Glaciological Data. Apart from the University of Colorado's general commitment and institutional support, undoubtedly one of the factors in this decision was the proximity of the National Geophysical Data Center and the mix of university and government agency involvement. A healthy symbiosis has certainly been fostered through the support of Alan Shapley and Jim Lander, and through Mike Chinnery, the current Director of the National Geophysical Data Center.

In the early days, I frequently called Pembroke Hart at the National Academy WDC-A Coordination Office for guidance on how we should approach the other WDCs and advice on data management problems in general. The members of the Panel on Glaciological Data, established by the Committee on Geophysical Data and the Polar Research Board in 1980, initially Colin Bull, Mark Meier, and Paul McClain, have been most supportive. Subsequently, Tony Gow and John Walsh joined and we now have a new member, Will Harrison. In NOAA, our primary funding source, we worked initially with Tommy Austin, Director of EDIS, who was extremely supportive in broadening the scope of activity to include data inventories. He also encouraged the initial planning for a national center, which bore fruit with the designation of a National Snow and Ice Data Center by NOAA in 1982. The expansion of our contacts with other agencies was fostered by his successor Tom Potter and most recently, Marjorie Courain, Deputy Assistant Administrator for Information Services, NESDIS, has continued to maintain our support during a period of severe fiscal constraints.

So there have been an enormous number of players and over this decade the center has grown from a staff size of two to ten. Ann Brennan who was appointed in 1977 to take care of our information center collection and Claire Hanson who joined us later in

1977 are still with us. Without the staff's dedication and the management skills of Ron Weaver, Scientific Manager, we could not have accomplished half of what has been achieved in our diversification since 1980.

The Significance of Snow and Ice

Glaciology is concerned with the study of all forms of snow and ice, not merely glaciers. Scientists in the climate community have begun to refer to global snow and ice cover by the term *cryosphere*. The etymology of this word derives from the Greek "kryos", meaning icy cold or frost; in particular it refers to the freezing of liquids, in words like cryophorus. Cryology has the particular meaning of low temperature science. Nevertheless, in parallel with the biosphere, the lithosphere, the atmosphere, the ionosphere and so on, it seems reasonable to apply the term cryosphere to the domain of snow and ice.

The components of the cryosphere cover a large fraction of the earth's surface. In winter almost a quarter of the Northern Hemisphere is covered by seasonal snow and sea ice. Another key figure is the amount of water locked up in the ice sheets. Global sea level would rise by 70 meters if all of the Antarctic Ice Sheet were removed; 5 meters of that is in the West Antarctic Ice Sheet and there is a further 7 meters in Greenland. The mountain glaciers, although they are a very minor component, have a shorter time scale of variation and glacier recession appears to be an important component of recent sea level change. Overall, the ice sheets appear to be gaining mass at present, whereas the glaciers shrank dramatically through the middle part of the century and undoubtedly were a component in the observed sea level rise of the last hundred years (Polar Research Board, 1985).

Snow and Ice Observations

There is growing recognition of the role of the cryosphere in the climate system. Table 1 summarizes the minimum observation requirements identified by the Committee on Earth Sciences of the Space Science Board (1985). It is important, however, to note that there is little information on any of these variables. In the case of snow cover, only extent is routinely mapped (since 1966); there are few data sets on water equivalent and albedo; grain size is measured infrequently due to the complexity of snow pack structure. Sea ice limits and concentrations are mapped (since 1972/73) but the type of ice, its motion, thickness, lead traction, roughness, and surface temperature are not and such data require new types of sensors of high resolution (European Space Agency, 1985). Similar deficiencies exist for glaciers, ice sheets, and permafrost.

The History of Snow and Ice Observations

Glaciological research began in earnest during the First International Polar Year (IPY) (1882-83) in connection with the establishment of various Arctic geophysical stations. See Table 2 for a "glaciology timeline." The proposal that led to the IPY program began with an Austrian Navy Lieutenant, Karl Weyprecht, although he did not live long enough to see it come to fruition. The International Commission on Glaciers was established in 1894; Arctic sea ice observations from ships began in the 1880s; and shortly thereafter, the Danish Meteorological Institute began to publish Northern Hemisphere ice charts. The earliest charts date from 1877 and they were issued regularly from 1901 (Barry, 1987). The International Ice Patrol, which has responsibility for monitoring icebergs in the northwestern Atlantic, was set up in 1913 after the *Titanic* disaster. About the same time, snow surveys in the western United States became coordinated by the

Table 1. Observational requirements for snow and ice data (after Space Sciences Board, 1985).

Problem	Variable	Observation	Accuracy	Resolution	Time
Snow cover	Extent	Percent of area	10%	50 km	7 days
	Thickness	Area average	10%	50 km	2 weeks
	Density	Area average	10%	50 km	2 weeks
	Water equivalent	Area average	10%	50 km	2 weeks
	Grain size	Area average	10%	50 km	2 weeks
	Albedo	Area average	4%	100 km	2 weeks
Sea and lake ice	Boundaries	Line position	10 km	10 km	30 days
	Concentration	Area average	10%	50 km	30 days
	Ice type	Percent of area	10%	50 km	30 days
	Motion	Point displacement	1 km/d	10 km	7 days
	Thickness	Area distribution	1 m	25 km	30 days
	Leads	Percent of area and orientation	10%	50 km	7 days
	Surface roughness	Area distribution	1 m	20 km	30 days
	Ice surface temperature	Area average	2 K	20 km	7 days
	Snow characteristics	Area average	See Snow cover above		
	Sea surface temperature	Area average	2 K	20 km	7 days
	Wind velocity	Area average	2 m/s	50 km	3 days
	Ice islands	Point location, size	2 km, 100 m	2 km, 100 m	30 days
	Icebergs	Point location, size	2 km, 100 m	2 km, 100 m	30 days
	Ice sheets and shelves	Surface elevation	Profile	2 m	50 km
Elevation change		Change in profile	0.5 m	50 m	10 yr
Boundaries		Line profile	0.5 km	0.5 km	10 yr
Thickness		Line profile	10 m	50 km	10 yr
Accumulation rate		Area average	20 cm/yr	50 km	10 yr
Surface temperature		Area average	2 K	50 km	10 yr
Surface velocity		Point displacement	1 m/yr	n/a	10 yr
Internal properties		Profiles	varies	50 km	50 yr
Condition at ice-rock interface		Profiles	varies	50 km	50 yr
Iceberg discharge		Regional average	10%	n/a	5 yr

Department of Agriculture based on the pioneering work of Phil Church. A second International Polar Year was held in 1932-33. Some of those archives are supposedly in Copenhagen at the Meteorological Institute, but during a visit there in 1983, I found that their whereabouts was apparently unknown.

Sea ice observations were initially made by ships and shore stations. Airborne ice reconnaissance began in the late 1930s in the U.S.S.R. and in the 1950s over the North American Arctic. Subsequently, ice draft has been determined from submarine sonar. The *USS Nautilus* traversed the Arctic under the pack ice in August 1958. These data and those collected by the *USS Queenfish* in 1970, repeating the *Nautilus* track, have recently been analyzed in detail by McLaren (1986).

Glacier observations, which began in Europe and elsewhere in the nineteenth century, were systematically assembled following establishment in 1967 of the Permanent Service for Fluctuations of Glaciers (PSFG) in Zurich, now re-named the World Glacier Monitoring Service. The first weather satellite was launched in the 1960s and shortly thereafter, satellite snow and ice mapping became operational. Indirectly, Table 2 indicates the available record length for the different glaciological variables (see Barry, 1985a; 1987). However, there are more specific concerns as to what is observed and how the observations are made. For example, meteorological stations report daily snow depth, while monthly observations at snow courses provide snowpack water equivalent for

Table 2. A timeline of snow and ice research and data collection.

	- 1880 -		- 1960 -
1882/3	- First International Polar Year. Coordinated observation of the Arctic	1966	- Global snow and ice extent from satellites
	- 1890 -		- First satellite observation of snow and ice extent
1894	- International Commission on Glaciers founded to make regular observations on glaciers	1967	- Permanent Service on Fluctuation of Glaciers (PSFG established - World Glacier inventory initiated by PSFG using computer techniques
	- 1900 -		- 1970 -
1900-1950	- Arctic sea ice observed from ships	1972	- Glacier mass balance measurement techniques standardized
1901	- First Danish Routine observations of Arctic Seas published - <u>State of the Ice in Arctic Seas</u>		- Routine polar sea ice charts produced by Fleet Weather facility
	- 1910 -		- AIDJEX data buoy deployed
1913	- First Annual Report of International Ice Patrol, integrating N. Atlantic iceberg data	1972/3	- Arctic and Antarctic sea ice mapping from satellites
	- 1920 -	1973/4	- All-weather, all-year satellite observations of sea ice
	- 1930 -	1978	- SNOTEL - snow and other hydrometeorological data collection, transmission and processing - data transmitted from 500 remote sites to a central computer
1932/3	- Second International Polar Year. Coordinated observations of the Arctic		- World-wide inventories of snowcover and sea ice published by WDC-A Glaciology
1935	- Responsibility of supervising and coordinating snow surveys in West delegated by Congress to Department of Agriculture	1978/9	- All weather ice extent and multi-year ice fraction from satellite passive microwave imagery
	- Responsibility for integrated snowcover observation in Western U.S. delegated to USDA by Congress	1979	- FGCE buoy program begins
	- 1940 -		- 1980 -
	- 1950 -	1985/86	- Cryospheric Data Management System developed - integrated processing of SSM/I data and military data DMSP, SSM/I, NODS/NSIDC
	- First routine U.S. Aircraft reconnaissance of sea ice in Arctic	1989/90	- N-ROSS, ERS-1, RADARSAT operational radar - sea ice altimeters - ice elevation
1957/8	- I.G.Y. - formation of WDC-A Glaciology		- Improved passive microwave observations of sea ice and snow cover
	- I.G.Y. - major Antarctic Glaciological Research Programs		- First routine radar, high resolution satellite imagery of sea ice
1958	- Nautilus under Arctic pack ice maneuvers with sonar		

hydrological assessments. In the western United States there are SNOTEL (snow telemetry) systems using meteor burst transmission technology, and more recently the National Weather Service has collected airborne gamma radiation data to map snow cover on the Great Plains. Research satellites also provide passive microwave data from which global sea ice extent and concentration and snow cover extent can be mapped.

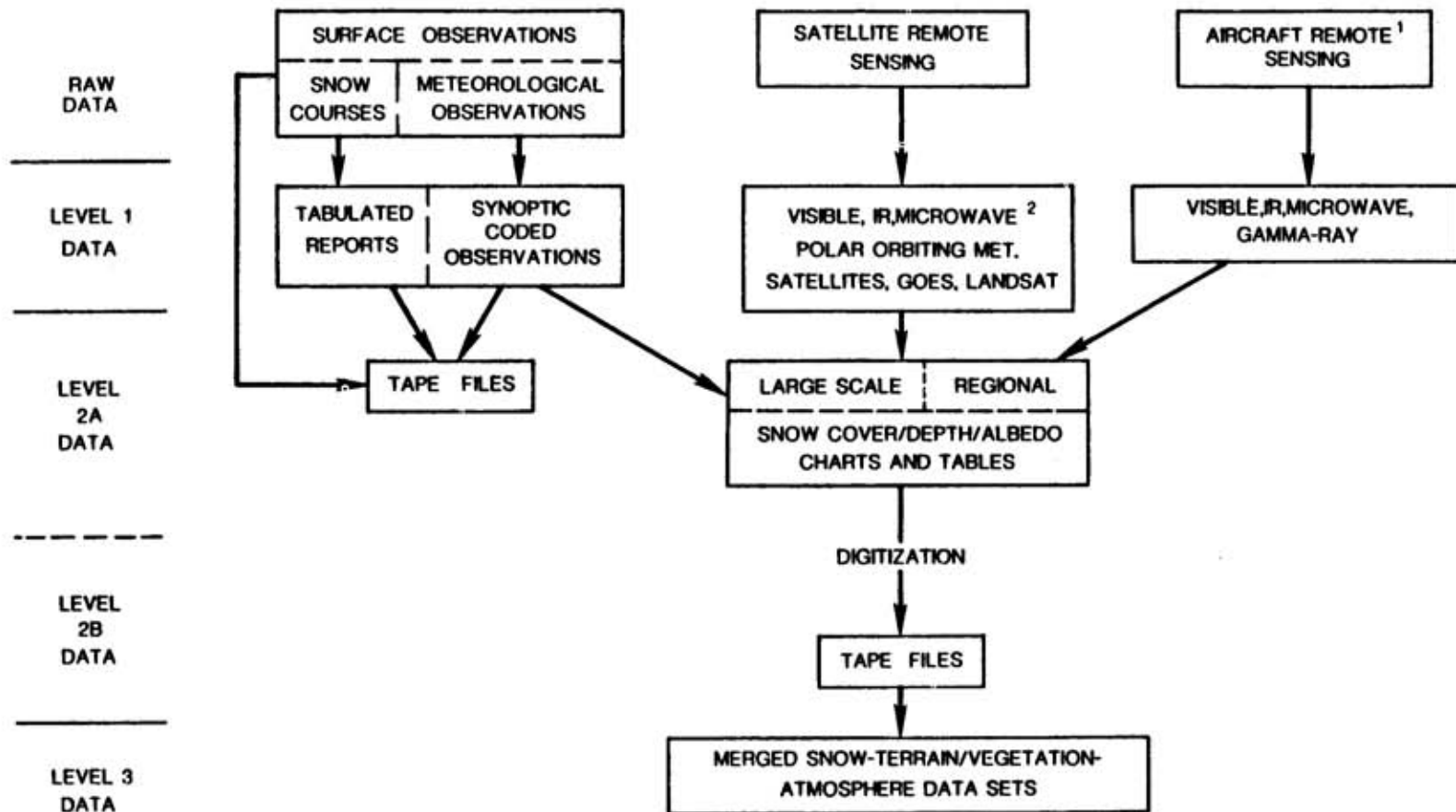
Permafrost measurements are still restricted to drill holes and most of the data are in the private sector.

The agencies involved in data collection differ from country to country. This is one of the factors hindering data set acquisition. Snow data are collected by hydrological and meteorological agencies; sea ice observations are the responsibility of oceanographic and meteorological agencies in different countries. Fresh water ice is the responsibility of hydrological agencies and private sector or state power companies. Information on glaciers and ice sheets is primarily collected by university researchers and also by geological and hydrological agencies, particularly in eastern block countries. Permafrost data are also obtained by private sector and university agencies except in countries like China and the Soviet Union where it is obtained by research institutes of the respective National Academy of Sciences.

The implications of this are that there are a variety of data streams, as illustrated in Figures 1 and 2. The data are often categorized according to a scheme developed by meteorologists: raw data are considered level zero, that might be an ice core sample. In the case of satellite remote sensing, level zero would be the electronic output from which is determined a physical measurement (level one data). In the case of surface observations, these are transmitted as coded reports and subsequently processed into a digital tape file. Satellite data come down digitally, but in many cases the data are interpreted subjectively to prepare operational snow cover and sea ice charts that at some later time are digitized. This is the case for our present digital archives of sea ice and snow cover data. It is hoped that in the near future it will be feasible to short circuit the process and transfer the digital satellite data directly to digital archives. However, for purposes of the International Geosphere Biosphere Program (IGBP), for example, there will also be a need to merge snow cover data with information on terrain variables, land surface type, soil conditions, and vegetation cover. We are nowhere near being able to do this at the present time. For North America there are many agencies and groups involved in snow data collection (Table 3). For the western states, the principal agency is the Soil Conservation Service, but California has its own state system. There are about 500 SNOTEL sites and 1600 of the regular ones. A separate system is provided by the Westwide Network which the Forest Service maintained for avalanche forecasting. The U.S. Department of Agriculture produces a *Weekly Weather and Crop Bulletin*. Until recently, snow depth contours were shown, but since 1984 only values are given. This product began in the 1930s. John Walsh has digitized these weekly maps from 1953 through 1977. On a finer scale, aircraft gamma radiation data provide additional information that can be fed into regional snow cover maps and products. There are currently over 800 flight lines of gamma radiation data that cover much the western U.S. and parts of Canada.

An enormous amount of data exists. Most of them are unfortunately buried in files that are very costly to access in order to provide the information in map or gridded form. Canada has maintained large number of snow courses, many of these are now being eliminated (for cost reasons) and they will be replaced by automatic station measurements (Goodison, 1986). WDC holds only a small fraction of the available data. The monthly snow course data are in tabular form from which only annual extreme values have been extracted and digitized. For Europe, there are many different countries and different

SNOW COVER DATA STREAMS



¹ Primarily in a research mode, or operational at the local/regional scale.

² The microwave is used primarily in a research mode.

Figure 1. Schematic diagram of snow cover data streams . The levels in the left column refer to the GARP categories of data processing.

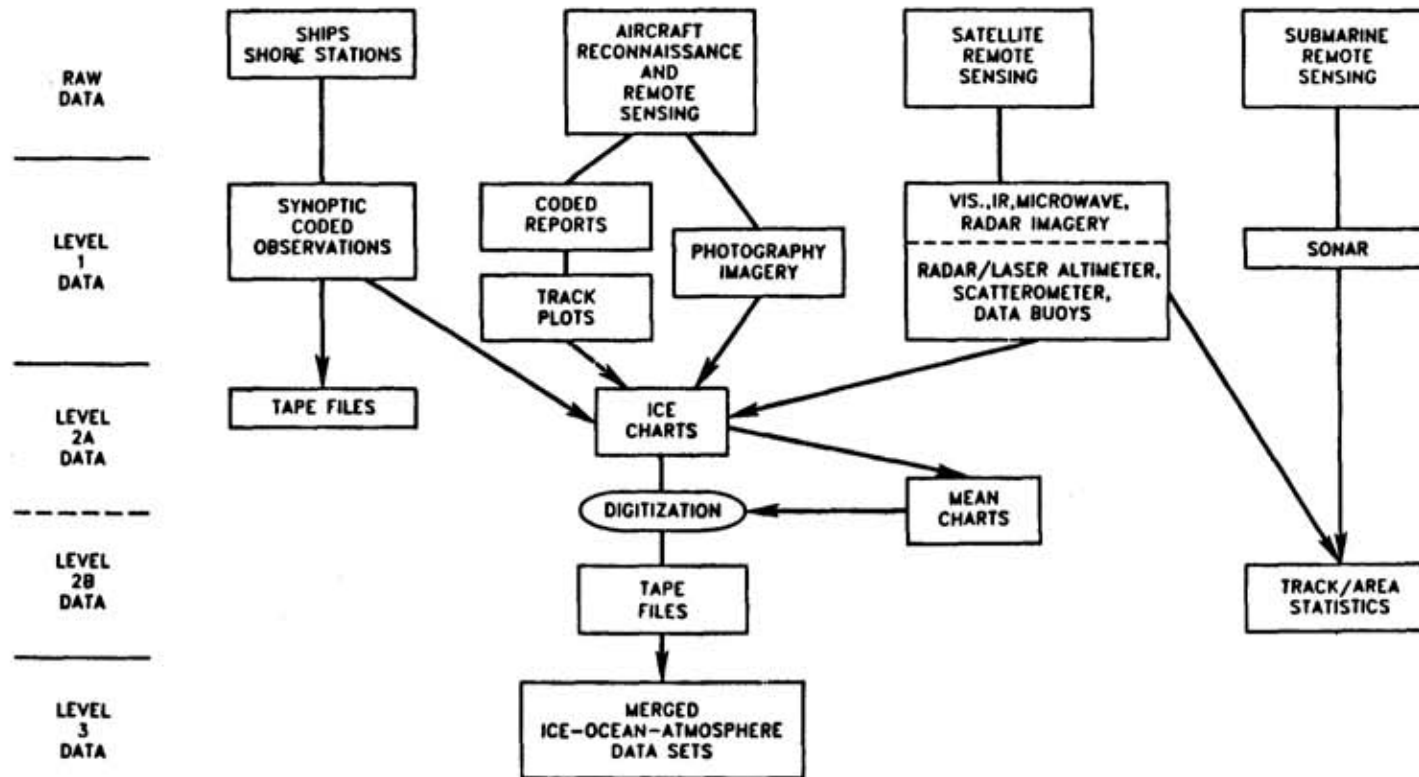


Figure 2. Schematic diagram of sea ice data streams. The levels in the left column refer to the GARP categories of data processing.

Table 3. Snow cover data for North America.

Source	Area	Stations	Variables	Frequency	Period
SCS/USDA	11 W'n States	1600	Depth, Water Content	Monthly (Winter/Spring)	1910s/30s ->
Calif. Dept. Water Res.	California	> 400 (Snow Courses)			1930->
SCS/USDA SNOTEL	W'n States	>500	Water Content Precip., Temp.	> Day	(1979) ->
USPS Westwide Network	W'n States (Mountains)	50-60	Depth, Snowfall	Daily	1950s/60s ->
NOAA Weather and Corp Bulletin	USA	Map	Depth Contours, Point Values	Weekly (Monday)	1935 -> (1949-81 digitized by Walsh et al. 1982)
Minnesota State Climatology Office	Minnesota	Map	Depth Contours	Weekly	1977/78 ->
NOAA NWS (Gamma Radiation)	USA/Canada	800 flight- lines	Cover, Water Content	> 1/mo.	1980-1985
NOAA Co- operative Observers	USA	5,000	Depth (some precip.)	Daily	1890-1982
AES. (and Provinces)	Canada	1800 (snow courses)	Depth Water Content	Monthly	1955-79
J. Walsh	Canada	140	Depth, Snowfall	Monthly	1950s/60s->

densities of station networks. Austria has about 760 stations going back to 1901. Sweden has about 400 stations with records since 1931 (and earlier for some stations). In Germany, there is a rather sparse network of 70 synoptic stations, although other agencies at provincial levels operate stations that also measure snow depth. These records were compiled up to about 1960 (Caspar, 1962) and supposedly were on punched cards, but those may no longer be available. So all that may remain from that prodigious effort is the statistical summaries.

For sea ice there is a similar set of data streams from ships and shore stations, aircraft, satellites, and submarines which are at present largely kept separate (Figure 2). The satellite situation is increasingly complicated with the advent of data at very different scales of resolution. Visible and IR satellite data typically have a resolution of about a kilometer. Passive microwave data have 25 kilometer resolution, whereas radar will provide resolution of a few meters. The problem of interpreting and merging these data and making use of the measurements is going to be a major challenge for the next five to ten years.

Existing global sea ice data sets are essentially satellite-derived from the operational products of the Navy/NOAA Joint Ice Center. These began in the early 1970s on a

weekly basis. The data on ice concentrations have been derived from the Nimbus 5 ESMR and since 1978 from the multi-frequency SMMR on Nimbus 7. However, these were research and development satellites, not operational ones. The snow cover charts have been produced by NESDIS since 1966 but with more reliability from 1973. Time series of these variables indicate substantial variability, both from year to year and between decades, that we do not yet understand (Matson and Wiesnet, 1981; Kukla and Gavin, 1981; Zwally et al., 1983). However, there is as yet no convincing evidence for the existence of trends (Barry, 1985b).

In terms of climate research programs and especially the developing IGBP/global change initiative, it is apparent that there is a strong case for improved access to the existing snow and ice data. We need consolidated archives of synoptic-scale snow cover, for example.

Research is needed on ways to combine data from the different sensor platforms and ground observations into a standard system. How do you merge surface observations of snow cover with low resolution passive microwave data? Currently, a USGS/NASA group is trying to cope with this problem by collecting surface measurements in the upper Colorado River Basin. The whole area is covered by only a few pixels of passive microwave data, whereas the snow depth and snow water equivalent are highly variable due to the complexities of surface terrain and surface cover type.

This background of data management issues that require attention shows that the focus of the WDC has shifted away, temporarily, from glaciers to snow cover and sea ice. This reflects the availability of data and user interest. In 1979, a survey was made of potential user interest in data. It identified data on climate as the primary interest and glacier research as second (*Glaciological Data, Report GD-3*). Snow cover and sea ice were fairly well down the list. This has not been borne out in the user statistics. Instead, sea ice is one of the largest areas of data and information requests.

Organization of WDC-A for Glaciology Activities

The organizational framework for the WDC is illustrated in Figure 3. There is a Panel on World Data Centers under the auspices of the WDC-A Coordination Office, National Academy of Sciences, which establishes policy on international data exchange for the International Council of Scientific Unions. Additionally, the IUGG/IAHS International Commission on Snow and Ice (ICSI) is responsible for snow and ice matters, although the links between ICSI and the WDC-A have been largely informal. On the national level, policy guidance is provided through the Geophysical Research Board, Committee on Geophysical Data and the Polar Research Board, Committee on Glaciology. In 1979, I proposed to the latter committee that it would be helpful to establish a specific panel to advise us. An annual verbal report to the Committee on Glaciology was an insufficient mechanism for obtaining feedback and guidance. The idea was endorsed by the Polar Research Board and so the Panel on Glaciological Data was established in 1980. Two years later, the National Snow and Ice Data Center was designated by NOAA. This gave us greater flexibility to archive data sets, such as avalanche data and Great Lakes ice data that were not of global interest. We could also designate the DMSP imagery collection as a national archive because it would be impracticable to copy the million pieces of transparency imagery on request! More recently, contract funds for operation of the DMSP archive have been provided through the National Climatic Data Center's Satellite Data Services Division. Other contracts for specific activities have also been provided by NASA Polar Oceans Program and the Office of Naval Research as discussed below.

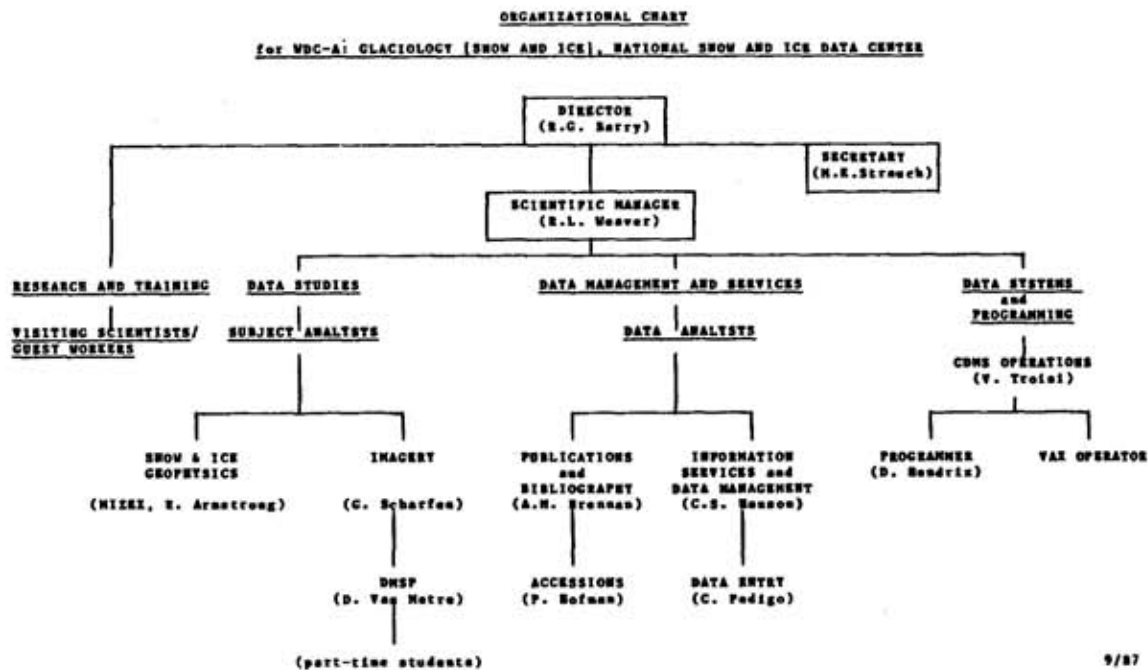


Figure 3. Organizational framework of WDC-A for Glaciology.

The First Ten Years

In 1977, the WDC essentially comprised the library collection and glacier photographs received from the Glaciology Project Office at Tacoma. Those activities still continue and the Information Center now utilizes a computerized data base. We began in 1977 to publish bibliographies and information on glaciological data. The first issue of *Glaciological Data* concerned avalanches and subsequent ones have dealt with nearly all of the other aspects - snow cover, sea ice, permafrost, ice cores and so on. We separated out the *New Accessions List* (originally contained in *Glaciological Notes*) and added contributions by scientists identifying problems in data management. In the late 1970s, we moved from purely bibliographic activities into data inventory through the initiative of the EDIS Director T. Austin. A study was made of ice core data and subsequently snow cover and sea ice information and data sets. We held workshops on those topics and published two related *Glaciological Data* reports. The one on Ice Cores (GD-8) was heavily used by the Advisory Panels to the NSF Division of Polar Programs and the Climate Program. These efforts also provide a basis for planning for future data archives from the Ice Coring program.

In the first years, we had funds to support visiting scientists (Robert Vivian, Bill Stringer, Austin Post, and Geoffrey Boulton). Unfortunately, this is one area we have been unable to continue due to the impact of inflation on the limited base funding. Other areas have grown to offset this loss, however, through contract funding; these include the DMSP imagery as well as project data management for Marginal Ice Zone Experiment (MIZEX). We have also held several workshops to plan for new data products. Figure 4 summarizes the WDC/NSIDC's growth in terms of funding, staff, and user requests. We began with 1.5 FTEs and a \$50,000 annual budget and we currently have 10 FTEs and a budget an order of magnitude greater. In 1977-78, there were about 50 user requests as far as we can document them. Currently, we are running close to 500 formal data requests but there are many other users of the library and telephone calls for information. Our income from data sales was \$30,000 in 1986. The information requests are diverse, both interesting and sometimes amusing. They have included inquiries as to "the best place to be in the world when we get to an ice age," and "the best place to be buried so that the site will not be inundated." A tire chain manufacturer wanted to know how ice properties on an ice rink differed from those on frozen lakes and whether the ice on a rink would be similar to that encountered on highways. A cattle breeder in Iowa wanted to know whether it would be colder in the 1990s because he wanted to convince his bank to provide a loan to breed longhaired cattle!

Why are snow and ice important? The interest is not merely scientific but also economic. Snow melt runoff is the main source of irrigation and water supplies in most of the western United States. For example, snowfalls may cause disruption on highways. We have recently completed a bibliography of Snow and Ice Hazards on Highways in conjunction with the University of Colorado Natural Hazards Research and Applications

TRENDS IN NSIDC/WDC OPERATIONS

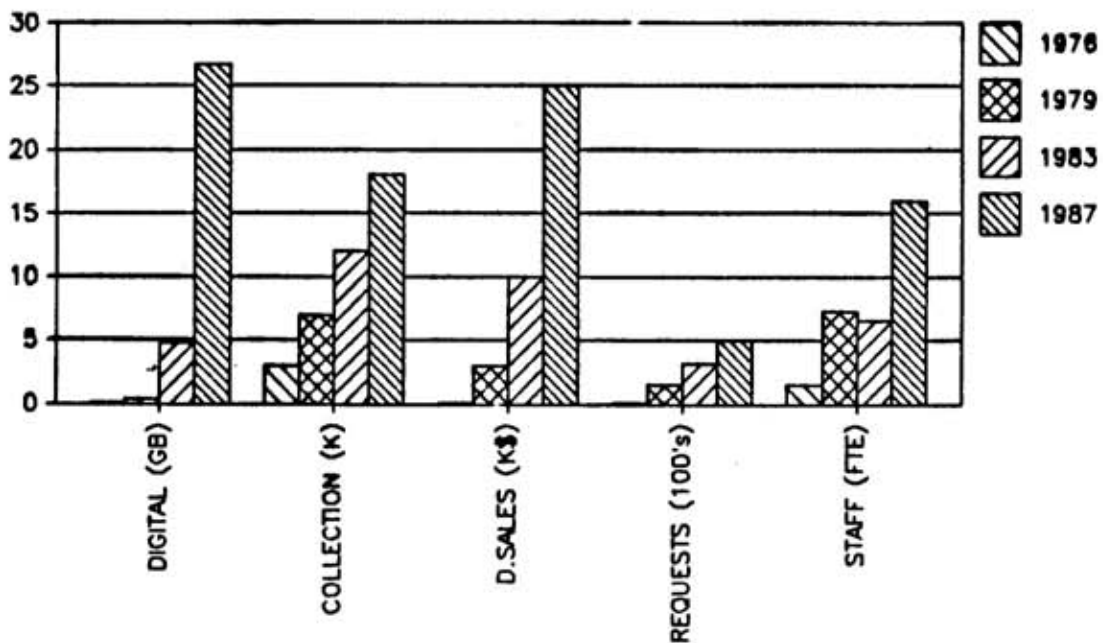


Figure 4. WDC/NSIDC growth since 1976 - funding, staff, user, requests.

Information Center. Avalanche hazards are topical in the mountain states each winter. Sea ice is increasingly important with respect to the Arctic Research Policy Act for naval

operations, commercial shipping, and offshore exploration. Iceberg hazard is similarly critical to drill rigs and ships. Glaciers are of scenic as well as scientific value, and in many parts of the world hydropower is a significant energy source. Permafrost occurrence greatly complicates resource development and engineering in arctic and subarctic regions. Parenthetically, it is interesting to note that WDC-B does not include permafrost information within the scope of their center's activities.

Recent Activities and Future Plans

The Information Center, the original core of our operation, now contains over 20,000 items indexed in a computer data base. From this data base, supplemented by literature searches of other data bases, we compile topical bibliographies. We have recently prepared updates on avalanches and permafrost and are currently preparing one on passive microwave data. We have organized a number of workshops on ice cores, radio glaciology, snow cover and sea ice data, and on Antarctic climate data. We also assisted in organizing the Snow Watch '85 conference and most recently held a users workshop on the DMSP Special Sensor Microwave Imager (SSM/I) data. Our work, supported by NASA Ocean Sciences, will implement a data management system to process, archive, and distribute passive microwave products from a future DMSP satellite (launched June 1987). This is an activity of the NSIDC, like many of our other associated research projects, but the WDC benefits greatly through the availability of our VAX-750 computer and the eventual communication networks we can utilize and be reached through by our users. Figure 5 illustrates this Cryospheric Data Management System (CDMS). Currently, we are entering the SMMR data (supplied by NASA-GSFC) in the SSM/I data format. We hope eventually to be able to overlay and merge some of the other sea ice and snow cover data sets on similar grids, both digitally in the computer and using the Image Display and Analysis System. In the future, other similar data, as well as data from the Arctic Drifting Buoys and MIZEX Project data, can be incorporated in the same data management system.

Some of the new directions that we see following the implementation of the CDMS and the Global On-Line Data (GOLD) catalog include the archiving of products from aircraft and satellite synthetic aperture radar (SAR) sensors over the polar ice sheets as well as sea ice. Here we are looking mainly to the ERS-I to be launched about 1990 with a SAR and a radar altimeter. Another area to explore is the development of a computing system for snow and ice data to complement the CLICOM (Climate Computing) system developed by National Climatic Data Center for the World Climate Research program. The data program CLICOM is a PC-based means of handling climate data and preparing statistical products. A similar processing package for snow and ice data could be developed in the future. We are also interested in improving the user access to the WDC through communication networks. Finally, in view of recent space probes to the outer planets, what about extraterrestrial ice information? There is ice on Mars and ice on other planets or their moons. If that is to be archived, perhaps we should become a Center for Galactic Snow and Ice Data!

Cryospheric Data Management System

DATA FLOW

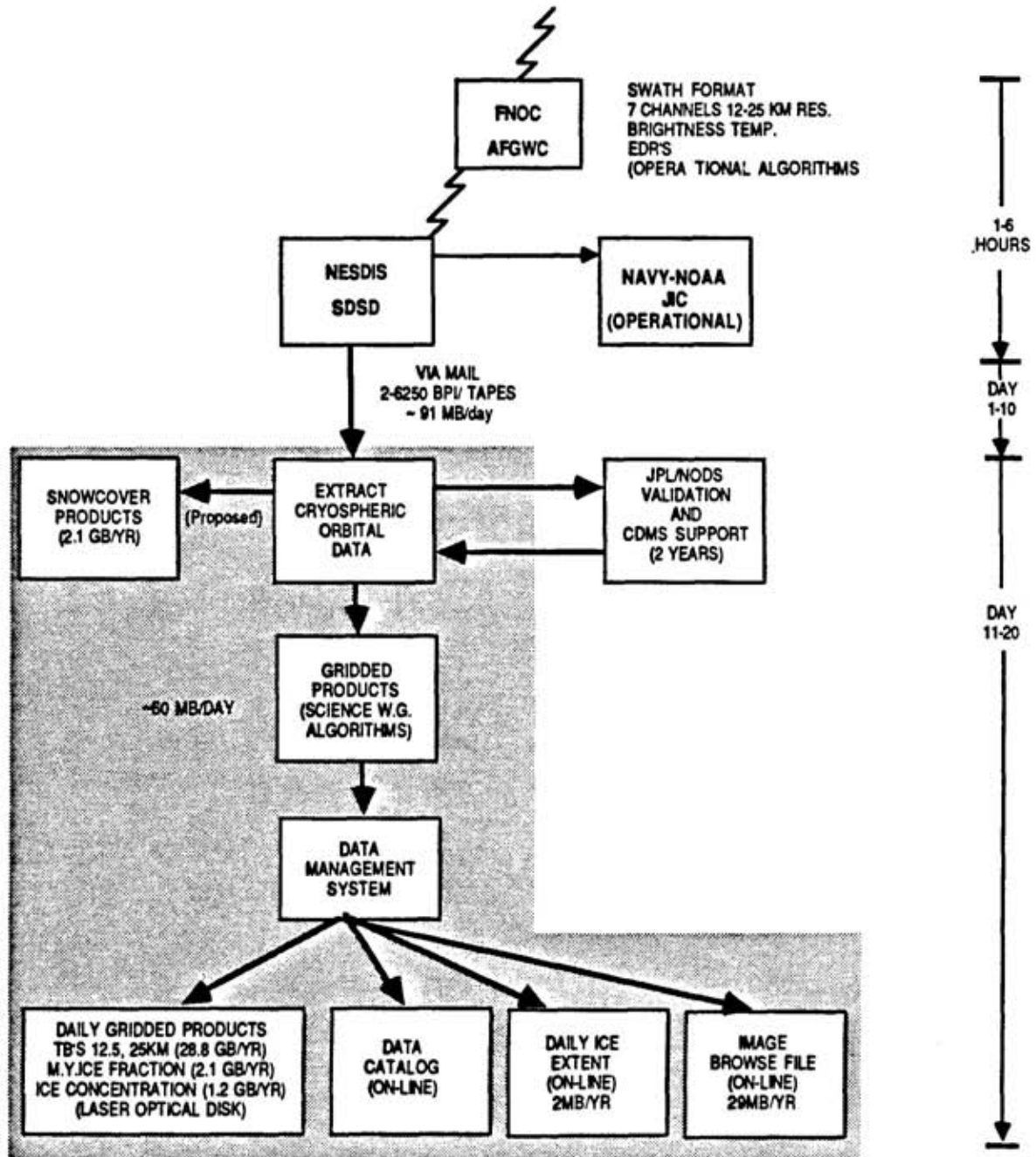


Figure 5. Schematic diagram of data flow from the DMSP Special Sensor Microwave Imager (SSMI) and the planned Cryospheric Data Management System data products.

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PASSIVE MICROWAVE USERS WORKSHOP BOULDER, COLORADO, 9-10 OCTOBER 1986

Introduction

More than 100 participants attended a Passive Microwave Users Workshop held in Boulder, Colorado on October 9-10, 1986. The focus of the meeting, hosted by the National Snow and Ice Data Center (NSIDC), was the use of passive microwave data from the Special Sensor Microwave/Temperature (SSM/T) and the Special Sensor Microwave/Imager (SSM/I). The SSM/T, currently flies on the Defense Meteorological Satellite Program (DMSP) satellites and measures atmospheric temperature profiles. The first SSM/I instrument was launched June 19, 1987 also on a DMSP satellite. Figure 1 gives a general overview of the DMSP system.

In association with the Workshop, the SSM/T Mission Sensor Exploitation Workshop and the SSM/I NASA Calibration Validation Team Workshop were held in Boulder on October 8, 1986.

NSIDC has been collaborating with the NASA Ocean Data System (NODS) group, Jet Propulsion Laboratory, Pasadena, California to develop and implement a SSM/I data management and distribution system for polar gridded data, the Cryospheric Data Management System (CDMS). NSIDC will be the center for distribution of SSM/I data and products to non-operational users through this system. The purpose of this workshop was to ask users how they think NSIDC can best implement this system. The major areas of discussion were:

1. Plans for SSM/I (also ESMR and SMMR) data distribution, especially to ensure that NSIDC plans are appropriate to the user community's needs.
2. Current status of SMMR and SSM/I sensors. At the time of the workshop the exact launch date for SSM/I was not known and there was concern that the SMMR on Nimbus 7 might fail before SSM/I was launched. Subsequent to the workshop SSM/I has been launched and the SMMR scanning mechanism has failed.
3. Discussion of types of products planned for the CDMS. The NASA Sea Ice Science Working Group (*Passive Microwave Remote Sensing for Sea Ice Research*, December 1984) made assumptions about the types of data products the general user community might want. These products were reviewed and comments from users noted.

The general snow and ice recommendations developed at the Workshop follow. A more detailed version of the presentations is available upon request.

AGENDA

Passive Microwave Users Workshop
and
DMSP-SPO SSM/I Sensor Workshop

October 9, 10, 1986
National Snow and Ice Data Center
Boulder, Colorado

October 9, 1986
Room 620, Research Building Three (NOAA Building)
30th and Marine Street

- 8:00-8:30 Registration, Coffee
- 8:30-8:45 Welcome (Roger Barry, NSIDC; Ken Jezek, NASA)
- I. SSM/I System Description and Status (Session Chairman: R. Weaver)**
- 8:45-9:00 System Status, projected launch date (J. Bohlson, DMSP/SPO)
- 9:00-10:00 Sensor System Requirements
- Hardware Description (J. Peirce, Hughes Aircraft)
- Software Description (R. Savage, Hughes Aircraft)
- Discussion
- 10:00-10:30 Coffee Break
- II. Data Distribution, and Archival Plans (Session Chairman, R.G. Barry)**
- 10:30-12:00 DoD operational plans (Dr. N. Baker, Aerospace Corp)
- NOAA/Navy Shared Processing System (M. Mignogno, NESDIS)
- NASA/NOAA sponsored plans
- NOAA/NESDIS NOAAANET overview (M. Courain, NESDIS)
- NESDIS/SDSD (M. Mignogno, SDSD)
- NODS & NSIDC plans for Cryospheric Data Management System, CDMS (C. Morris, JPL; R. Weaver, NSIDC)
- 12:00-1:30 Lunch

III. Data Products

1:30-5:00 Parallel Sessions

(afternoon coffee break depends upon session chairman)

SESSION A: Sea Ice and Snow Cover Products: Plans and User
Needs (Session Chairman: F. Carsey, JPL)
Room 620, Research Building Three (NOAA Building)
DMSP (AWS, FNOC) product set (B. Godwin, Hughes Aircraft)

Sea Ice Products (C. Morris, JPL/NODS)

Snow Cover Products (R. Barry and R. Weaver, NSIDC)

Discussion of User Needs (D. Robinson, Lamont-Doherty)

SESSION B: Soil Moisture, Ocean Waves, Precipitation Products

(Session Chairman: R. Savage, Hughes Aircraft)
Room W179, Research Building Six)

DMSP (AWS, FNOC) Product Set

Soil Moisture (M.J. McFarland, Texas A&M)

Ocean Waves (A. Milman, ERIM)

Precipitation (J. Weinman, U. of Wisconsin)

Integration of SSM/I and SSM/T Data for
Precipitation Filtering (N. Grody, NESDIS)

Discussion of User Needs (TBA)

Evening: Informal writing groups to draft report and recommendations
by Session Chairman and participants

October 10, 1986
Room 620, Research Building Three

7:30-8:00 Registration - Coffee

IV. Reports of Concurrent Sessions to Entire Workshop

(Session Chairman: D. Robinson, Lamont-Doherty)

8:00-8:45 Summary of SSM/I data products sessions

Snow and Ice (F. Carsey)

Soil Moisture, etc. (R. Savage)

8:45-9:30 NASA Sea Ice Algorithm Working Group (SAWG)
validation program (C. Swift, D. Cavalieri)

9:30-10:00 Coffee

10:00-10:30 Other Validation Efforts

Dod validation program (McFarland)

Canada, Norway (I. Rubenstein)

10:30-11:00 SSM/T sensor system, brief overview and summary of SSM/T
workshop held October 8 (J. Johnson, NOAA/ERL/PROFS)

V. Wrap-up, Open Discussion (Session Chairman, R.G. Barry)

11:00-12:30 1. Recommendations to NSIDC, NODS, NOAA/SDSD for archive systems

2. New research areas

3. Information sharing

12:30 Lunch: Individual basis

1:30-3:00 There will be demonstrations of the NSIDC/NODS-SSM/I data
management system for those who are interested.
(Room 255, Research Building Two.)

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Sea Ice and Snowcover Products: Plans and User Needs
F.D. Carsey, Session Chairman

Session Summary and Recommendations

The SSM/I sea ice and snowcover group discussed the long-term NSIDC and SSM/I roles in scientific research and research in operational development issues. The overall conclusion was that the NSIDC-NODS-SSM/I effort is essential and unique in developing the spaceborne microwave data for both scientific and operational users. The NSIDC role is unique: it is not beholden to projects, nor limited by specific agency viewpoint, nor subservient to the research interests of a specific PI, nor committed to routine processing for operational users. This uniqueness gives NSIDC its strength, and its history of effective support of investigators provides the basis for believing that this strength will be put to optimum use.

Working group recommendations on future planning are:

- 1) The group sees the nascent NSIDC-SSM/I activity as very valuable. This activity should be vigorously supported; in particular the DMSP SSM/I launch delay should not dampen the enthusiasm for this work.
- 2) Extension of the NSIDC archiving role for SSM/I to SMMR and ESMR should be accomplished, although this is not seen as an urgent project. The further extension to reprocessing of SMMR-ESMR should be reviewed by the scientific community.
- 3) In general, retrospective (re)processing of satellite data is desirable if it contributes to the establishment of long-term self-consistent geophysical data sets. Such data sets are absolutely essential. Reprocessing should be carefully monitored by knowledgeable scientists. It should be done economically.
- 4) NSIDC should take the lead in working with the operational users at the Navy/NOAA Joint Ice Center in developing the next generation of SSM/I ice algorithms. The existing algorithms, both in the NODS and FNOC environments, are not specialized in the most suitable manner for operational users. A good example, and the initial task that the committee recommends, is the development of a Bering Sea ice (or ice/wind) algorithm. This work should be the integration of NOAA/PMEL, University of Washington, University of Massachusetts, NASA GSFC, and NASA JPL specialists with a view to processing on the new equipment at JIC. Other specialized processing approaches are needed for near-shore data utilization, summer ice conditions, and high-resolution applications.
- 5) NSIDC should serve as a host/organizer for validation programs in a fashion analogous to Item 3. Here the neutral-site aspect of NSIDC is valuable.
- 6) From the evidence presented, snowcover observations of either a global or national nature and from both on-site and spaceborne sensors are rather poorly handled and not at all well understood (see Kukla, *et al.*, 1985). Ten years of microwave research at a number of institutions has amply demonstrated that snow water equivalent provides a strong signal in the SSM/I wavelengths and studies are still in progress for the large-area geophysical microwave snow analysis as well as for fundamental snow processes. This research should be exploited. Overall, NSIDC should be in a good position to assist in these problems. The snowcover group recommends that NSIDC plan a substantial role in generating national/global snowcover parameters. This activity needs scientific advice in initiation and scientific monitoring; it needs to be collaborative with NOAA, NASA, USGS, USA CRREL, and other investigators. This matter has been reviewed in other specialists meetings with recommendations more detailed and

specific; these should be dusted off and the job moved forward.

Clearly in all of the above, scientific overview of NSIDC-SSM/I work is a basic necessity, as is strong collaboration with investigators funded by the diverse agencies. This implies a need for future workshops or sessions at AGU type meetings. Equally pervasive is the financial aspect of the agencies which would gain directly from NSIDC activities have a responsibility to support their work when it is properly planned, managed and performed.

An item not thoroughly addressed here is the interrelationship of modeling and observations. A major problem is the difficulty of updating the model diagnostics on spacecraft timescales. This issue should be the basis of future thinking and planning.

The group emphasizes that this is a decade or longer of opportunity; a well-designed microwave instrument with very useful observational channels is planned for flights over an extended period with a rapidly processed, public-domain data set which is well supported by scientific work at universities and government laboratories. This situation must be exploited.

Reference

Kukla, G., Barry, R.G., Hecht, A., Wiesnet, D., eds. (1985). *Snow Watch '85*, Boulder, CO World Data Center-A for Glaciology. *Glaciological Data, Report GD-18*, 276 p.

Soil Moisture, Ocean Wind, Precipitation User Special Session
Richard Savage, Session Chairman

Session Summary and Recommendations

The session began with a presentation by M.J. McFarland of Texas A&M. McFarland carefully distinguished between soil moisture and the Antecedent Precipitation Index derivable from it, which can be estimated from passive microwave measurements. Dr. McFarland's illustrations from historical SMMR data, compared with climatological data from the Central Plains, gave good confidence in the algorithms. He also illustrated the distinctive change in signature due to snow. The discussion by McFarland and others suggests that the physics of microwave sensing of surface moisture and snow is well understood, and that a post-launch calibration and validation effort applied to SSM/I data will soon result in useful algorithms.

The discussion of surface wind effects, and sensing by microwave radiometry, was led by A. Milman (ERIM). Milman's presentation was salutary in pointing out the difficulties of any wind algorithm - varying correlation between wind and foam, the signal noise introduced by atmospheric vapor, clouds, and rain, the possible non-linearity of response. It was regretted that John Wilkerson, who will lead the DMSP Cal and Val effort, was not present to discuss results from the Naval Research Laboratory airborne radiometers. Although Milman advised caution, based on SMMR results, J. Rubenstein (Ph.D. Associates) was optimistic that better results than those described by Milman were attainable.

J. Weinman (University of Wisconsin) led the discussion on estimation of precipitation. There are many complications in the physics of such an algorithm - mixtures of ice and water species, beam-filling effects, radiation transfer through cloud edges, vertical motions, and other uncertainties. Weinman also stressed the difficulty of obtaining corollary data for forming an algorithm; digital radar data from the U.S. and Canada will be used. Because of the uncertainties in surface emissivity, the calibration and validation effort will begin with oceanic data, where the background is more uniform. An unusual and innovative aspect of Weinman's approach is the attempt to combine the different sized footprints with the resolution of the higher frequency channels, rather than smoothing data to the lowest resolution. The precipitation parameters are probably the most challenging ones discussed during the afternoon.

Beth Godwin of Hughes-Denver described work done so far using SSM/I data to discriminate SSM/T footprints containing rain. Such conditions produce brightness temperatures that are not representative of the temperature structure of the atmosphere. N. Grody of NOAA/NESDIS commented that comparison of radiances with surrounding radiances can be used to identify and eliminate such cases, without consideration of SSM/I data. The method relies on relatively simple spatial filtering, and is the preferred method in NOAA's processing.

Grody also described work he has done in categorization of surface characteristics, a goal also being pursued by the Hughes software team. Grody felt that most - perhaps all - necessary distinctions could be made from comparison of two brightness temperatures at scattering and non-scattering frequencies (e.g., 19 GHz vs 37 GHz). The Hughes approach uses several frequencies, combined in a clustering algorithm; cloud effects, best seen at 85 GHz, are believed to have a significant effect on lower frequency channels, especially over snow.

A summary of the groups finding may be divided into three parts:

I. Several necessary activities appear to be receiving appropriate attention:

A. It is gratifying that a Calibration and Validation effort is in place, especially in light of the SMMR and SSM/T experience. There appear to be overlapping efforts by NASA and

DoD, but the reviewer (R. Savage) does not have a large enough overview to comment on this.

B. It is also gratifying that there is a software Configuration Control effort in place, directed by DMSPO, implemented by FNOC and AFGWC, and assisted by Hughes. Brightness temperatures, calibration methods, and parameter values can be expected to be stable, and new techniques can be compared to them.

C. The conference was a good idea; appreciation is expressed to DMSPO, NSIDC, and PROFS for organizing it. It has been a remarkable collection of interested and knowledgeable people extending across many organizational and disciplinary boundaries. However, for a future meeting:

1. more input from numerical modelers is perhaps needed;
2. atmospheric specification by itself is very important;
3. many planned and possible parameters were not discussed - water vapor, cloud algorithms, surface characteristics.

D. The need for a geostationary microwave sensor was considered, but there was not strong recommendation. It was pointed out that there are other low altitude microwave sensors in the works, such as AMSU and NASA's (proposed) tropical rain experiment. We should wait until we have experience with coverage by the polar orbiters before claiming a geostationary sensor is needed. Cal Swift rightly pointed out the very long lead time in getting any new sensor underway.

II. There are a few weaknesses:

A. Although SSM/I is called "the microwave imager", plans to display microwave images seem very incomplete. Fleet Numerical Oceanography Center plans to display SSM/I data on both SPADS and NEDS. However, the AFGWC Satellite Data Handling System (SDHS) will not handle SSM/I data for some time to come. We are not aware of NESDIS plans to display SSM/I images.

B. There is a lack of visible and IR data coincident with the SSM/I data for the Calibration and Validation effort. Hughes will attempt to provide software for this capability through the Support & Services Contract. This will be discussed at the DMSP Calibration and Validation meeting at Naval Research Labs, November 5-6. (N.B. software for IBM-AT environment has been written by Hughes-Denver and is available from NSIDC to qualified recipients. Ed.)

III. We (especially AFGWC and FNOC) are concerned to support the mission sensor effort within the meteorological and oceanographic community. We recognize the necessity to demonstrate operational use of SSM/I data. We plan to start using the data and parameters in which we have greatest confidence as soon as possible, and to proceed more slowly on the parameters that are more difficult to use or in which there is less confidence.

A. FNOC will concentrate on supply of the following data:

1. Ice data to the Joint Ice Center, Suitland, for display on their PROFS system.
2. Tropical data (oceanic rain, surface wind) to Joint Typhoon Warning Center. The aircraft reconnaissance fleet is being reduced, and these data should prove useful.

B. AFGWC will concentrate on the following:

1. Recognition of snow cover on the ground (used in the AFGWC snow model).
2. Estimates of cloud amount over snow backgrounds.
3. Estimates of surface moisture (antecedent precipitation index).
4. Imagery display for use in the weather forecasting section.

THE NASA SSM/I VALIDATION WORKSHOP
8 OCTOBER 1986

The purpose of the NASA Validation Workshop was to discuss and expand upon a draft NASA SSM/I validation plan for sea ice. The participants are members of the NASA Sea Ice Algorithm Working Group (SAWG). It was used in the NODS/NSIDC archive of sea ice concentrations derived from SSM/I data (see Swift and Cavalieri, *EOS*, Vol. 66, No. 49, pp. 1210-1212, December 3, 1985). The NASA validation effort is aimed at testing the pre-launch algorithms and improving them where appropriate. In addition, there is significant research interest in validating specialized algorithms for specific geographical regions, thin ice, and snow over ice.

Potential validation activities were discussed in the workshop, including aircraft flights of opportunity. Sources of comparison data were identified such as arctic buoy data and satellite images. Discussions stressed the importance of coordinating the NASA validation effort with the planned validation activities of the Canadians, headed by R. Ramseier. Based on the input from the Validation Workshop, a revised draft of the NASA Validation Plan will be completed in the near future.

CRYOSPHERIC DATA MANAGEMENT SYSTEM

SSM/I Successfully Launched

On the evening of June 19, 1987, the Defense Meteorological Satellite Program successfully launched the Special Sensor Microwave Imager (SSM/I) from Vandenberg Air Force Base in Monterey, California. The SSM/I is a passive microwave radiometer which will provide near real-time data for near-operational use. The instrument operates at four frequencies: 19.3, 22.2, 37.0, and 85.5 GHz. Vertical and horizontal polarizations are provided for each frequency, except the 22.2 GHz channel which has only vertical polarization. The 19.3, 22.2 and 37.0 channels will have a resolution of 25 km, and the 85.5 GHz channel will have a resolution of 12.5 km. The satellite orbital characteristics permit daily global coverage. In the polar regions, repeat coverage is possible each 12 hours due to the orbital overlap.

The launch of the DMSP S-9 spacecraft was originally scheduled for Monday, June 15, 1987. Due to strong winds and ignition problems with the Atlas vehicle, the launch was postponed until Friday, June 19, 1987. The SSM/I sensor was powered up on Thursday, June 25th, and rotation of the antenna commenced on orbit number 77 over the east coast of the United States. The SSM/I was powered down for a short while during the July 4th weekend. Temperatures reaching the upper threshold for the sensor were monitored by Hughes Aircraft Company. The solar array panel on the satellite was moved to shade the sensor which now is operating within the expected thermal range.

System Description

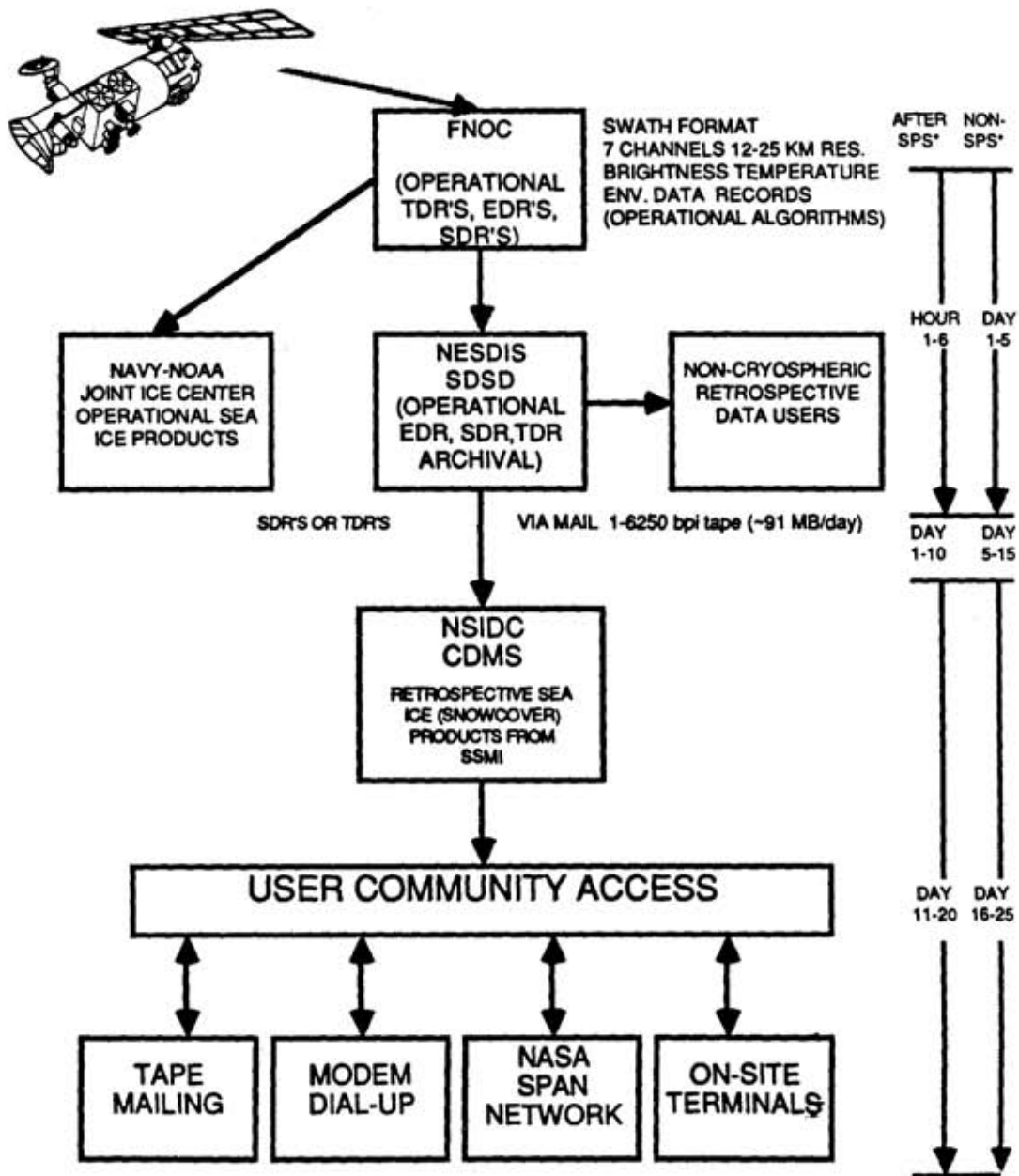
A data processing and management system to produce sea ice data products from SSM/I has been installed at the National Snow and Ice Data Center (NSIDC) with support from NASA's Polar Oceans Program. The computer-based Cryospheric Data Management System (CDMS), an enhanced version of the NASA Jet Propulsion Laboratory's NASA Ocean Data System (NODS), will extract the polar SSM/I data and make them readily available to the research community.

The CDMS design aims to provide a single focal point for snow and ice data, improved access to a subset of the currently produced digital data sets (e.g. SMMR), and analytical tools to aid data use. Rather than design a new computerized data base management system for SSM/I data, it was decided to utilize the existing NODS, which provides the functions needed. NODS is being developed as a distributed network of data centers with each filling a unique role and serving a specific community. The NODS system software was installed on the NSIDC's VAX-11/750 and will serve as a NODS node for the ice and snow community.

The NSIDC node of NODS will receive SSM/I data from FNOC through Satellite Data Services Division (SDSD) of the National Environmental Satellite, Data, and Information Service (NOAA-NESDIS) under the aegis of the DoD-NOAA Shared Metsat Processing Agreement (see Figure 1). Initially these data will be transferred on magnetic tape from FNOC to NESDIS-SDSD, where the data will be re-blocked, tape copies made and forwarded to NSIDC. When the proposed satellite data communications link between FNOC, AFGWC and NESDIS becomes operational, the FNOC to NESDIS segment of the data transfer will be over high-speed satellite channels. However, NSIDC will continue to receive data from SDSD via magnetic tape.

Once received by NSIDC, the SSM/I Sensor Data Record (SDR) will be ingested into the CDMS. The SDR data is the collection of orbital brightness temperatures from which all other CDMS products will be generated. The swath antenna temperature data will be corrected for antenna pattern and reformatted into a rapid access archive to be stored on optical disk.

CRYOSPHERIC DATA MANAGEMENT SYSTEM POST VALIDATION DATA FLOW



*SPS- NOAA-DOD SHARED PROCESSING SYSTEM

RLW 4/87

Figure 1. CDMS data flow.

The corrected SDRs will be binned into polar grids for both the northern and southern hemispheres (Figure 2). These grids will provide daily averaged brightness temperatures (BTs) at two resolutions: the 85 GHz polarizations will be binned into 12.5 kilometer square cells; the five other polarizations will be binned into 25 kilometer square cells. Three-day grids for first-year ice concentration, multiyear ice fraction, and total ice concentration will be calculated from the BT grids using the Nimbus Team Algorithm as specified by the NASA Sea Ice Algorithm Working Group. The ice concentration products will have a 50 kilometer square resolution. An archive of 100 kilometer resolution grids will be computed for each polarization from the BT grids and for each parameter from the ice concentration grids. Finally, the daily ice extent, the boundary at which the ice concentration changes from less than to greater than 10 percent, will be computed from the 12.5 kilometer BT grids. Table 1 gives a list of archived data sets.

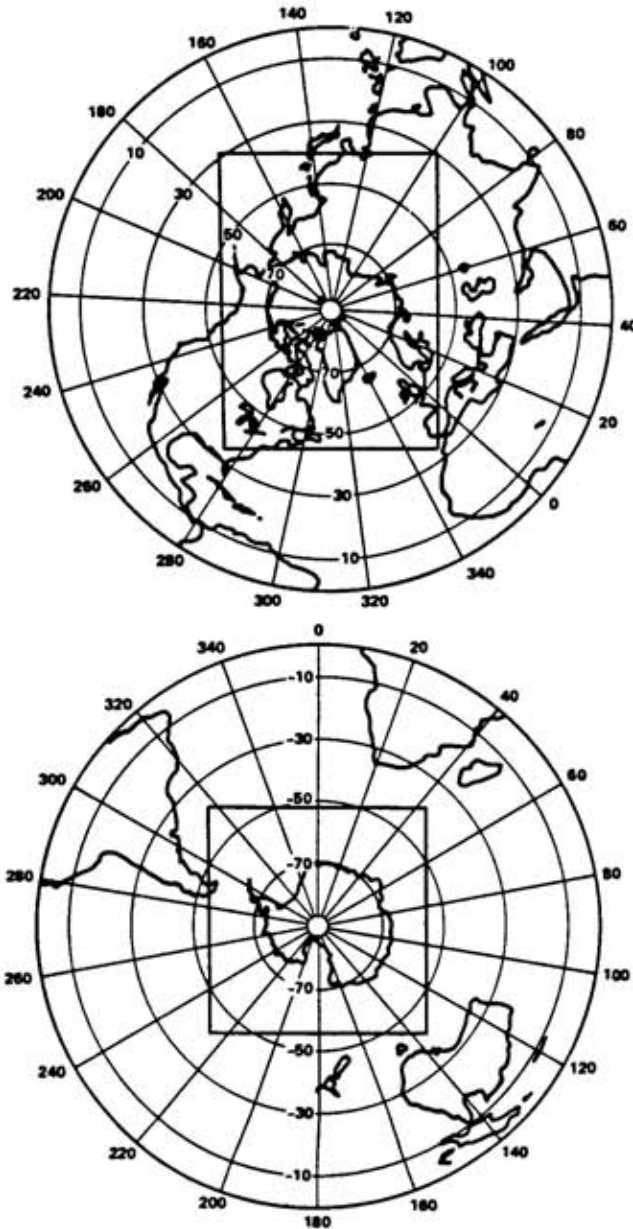


Figure 2. Geographical areas in the northern and southern hemispheres to be covered by SSM/I data.

The NODS software, used in the CDMS, utilizes a menu-driven user interface. In order to select data for extraction, the user steps through a series of options presented one screen at a time. The menu system may be circumvented by expert users wishing to utilize the NODS command line interface. Requests for data are automatically queued to the VMS operating system. If operator intervention is required, for example for a tape mount, the system requests such action and monitors the request.

A catalog and inventory of CDMS data will be maintained. The user will first query the data catalog to determine what data sets are available within selected temporal and geographical limits. The NODS software automatically extracts data selected by the user in the catalog subsystem. The hardware required to process and manage the SSM/I data currently includes a VAX 11/750 minicomputer. Magnetic disks and tape systems will be utilized for ingesting, processing, and staging of the SSM/I data sets. In order to store the projected large volume of archived data efficiently, a Perceptics' LaserSystem supports an Optical Storage International (OSI) optical disk drive. The OSI LaserDrive 1200 provides a 1 gigabyte of storage on each side of a 12-inch diameter disk.

Table 1. Archived data sets available from CDMS.

Data Set Description	Parameters	Coverage
Calibrated Brightness Temperatures (GHz)		
Sensor Data Records (SDRs)	19.35V,19.35H,22.2V,37V,37H,85.5V,85.5H	Global
Daily 12.5 Km Grid	85.5V,85.5H	N/S Polar
Daily 25 Km Grid	19.35V,19.35H,22.2V,37V,37H	N/S Polar
100 Km Browse Image (6-day)	19.3V,19.35H	N/S Polar
Daily Monitor Areas Histograms	19.35V,19.35H,22.2V,37V,37H,85.5V,85.5H	N. Pacific, S. Pacific, Amazon, Antarctic
SSM/I Sea Ice Concentrations		
50 Km Grid (3-day)	Total Ice Concentration First Year Ice Concentration Multi-Year Ice Concentration	N/S Polar
100 Km Browse Images (6-day)	Total Ice Concentration First Year Ice Concentration Multi-Year Ice Concentration	N/S Polar
Ice Edge Maps (1-day)	Sea Ice Distribution Contour	N/S Polar

Accessing CDMS

CDMS may be accessed through commercial local and long-distance dial-up services, NASA's Space Physics Analysis Network (SPAN), and the Telenet packet-switched network (via SPAN). Users may access the CDMS via telephone through two principal routes:

- 1) a 1200 baud modem directly to the CDMS VAX-11-750.
 - Dial (303) 492-2364.
- 2) a 1200 or 2400 baud modem to the University of Colorado's AT&T ISN.
 - Dial (303) 492-1900 to reach the ISN modem pool.
 - Enter ACS/KRYOS at the 'DIAL:' prompt.

The CDMS computer is connected to the University of Colorado's Campus Ethernet-Fiberoptic network. A SPAN router is connected to this network which provides mail access to the CDMS VAX-11/750 from a number of gateways including ARPANET and BITNET. The most direct way to access the VAX-11/750 is to perform a remote logon from another VAX computer via the DECnet command, \$SET HOST KRYOS. KRYOS is the node name for the CDMS host. Remote users may also access CDMS through the SPAN network with 300 and 1200 baud modems. These users are required to dial a Telenet PAD number to access the NASA Data Access Facility (DAF) security computer. Once connected, access to KRYOS is transparent. Users requiring this type of access should contact Valerie Thomas at the NASA Goddard Space Flight Center.

Two electronic mailboxes have been created on the NSIDC VAX through which remote users who have access to the NASA SPAN DECnet may send inquires. The first of these mailboxes is called NSIDC. NSIDC is intended to be a central repository for questions and information pertaining to the National Snow and Ice Data Center. Incoming messages will be previewed by a NSIDC staff member, then forwarded to the appropriate staff for review and action. The second of these mailboxes is called NEWUSER. Prospective users of CDMS may initiate a request for authorization into CDMS through this mailbox. The DECnet address for these mailboxes are, respectively: KRYOS::NSIDC and KRYOS::NEWUSER.

CDMS Notes

NSIDC distributed the first issue of *CDMS Notes* in July. This newsletter is published to provide useful information to the research community about current events at NSIDC. The focus of *CDMS Notes* will be the Cryospheric Data Management System, current ice and snow data products available at NSIDC, and the status of applications using NSIDC products. Anyone interested in receiving *CDMS Notes* on a regular basis, should send their name and address to NSIDC, Campus Box 449, University of Colorado, Boulder, CO 80309. We will be happy to add them to the mailing list.

For a more detailed description of CDMS see Weaver, R.L., Morris, C., Barry, R.G. (1987) Passive microwave data for snow and ice research: planned products from the DMSP SSM/I System. *EOS*, 68(39) p. 769, 776-777.

ACRONOYMS

AFGWC	Air Force Global Weather Central
AMSU	Advanced Microwave Sounding Unit
ANSI	American National Standards Institute
APC	Antenna Pattern Correction
ASCII	ANSI Standard Code for Information Interchange
CA	Cloud Amount
CAL	Cloud Amount over Land
CAS	Cloud Amount over Snow
CCL	Cyber Control Language
CDC	Control Data Corporation
CDMS	Cryospheric Data Management System
CPC	Computer Program Component
CPCI	Computer Program Configuration Item
CW	Cloud Water
CWI	Cloud Water over Ice
CWL	Cloud Water over Land
CWO	Cloud Water over Ocean
CWS	Cloud Water over Snow
DEF	Data Exchange Point
DEFDDA	DEF Data Description Arrays
DRD	Data Requirements Document
DMSP	Defense Meteorological Satellite Program
ERD	Environmental Data Record
EPE	Environmental Parameter Extraction
FNOC	Fleet Numerical Oceanography Center
IA	Ice Age
IC	Ice Concentration
IE	Ice Edge
km	Kilometer
LWL	Liquid Water over Land
LWO	Liquid Water over Ocean
NEDS	Naval Environmental Display System
NESDIS	National Environmental Satellite, Data, and Information Service
NODS	National Ocean Data System
NSIDC	National Snow and Ice Data Center
OLS	Operational Linescan System
PROFS	Program for Regional Observing and Forecasting Services
Rev	Revolution
RL	Rain over Land
RO	Rain over Ocean
RT	Radiative Transmissivity
SDP	Sensor Data Processing
SDR	Sensor Data Record
SDSD	Satellite Data Services Division
SM	Soil Moisture
SMI	Special Microwave Imager (Ground Data Processor)
SNE	Snow Edge
SNW	Snow Water Content

SPADS	Satellite Processing and Display System
SSM/I	Special Sensor Microwave Imager (Sensor)
ST	Surface Temperature
STS	Surface Temperature over Snow
SW	Surface Wind Speed (Ocean)
TDR	Temperature Data Record
TYPE	Surface Type
WVO	Water Vapor over Ocean

MICROWAVE RADIOMETRY BIBLIOGRAPHY

Introduction

The Microwave Radiometry Bibliography is a representative selection of references to passive microwave theory, research, and applications. The bibliography has been divided into five subject categories. An author index is included.

The subject categories are:

Theory	p. 61
Floating Ice	p. 64
Snow Cover	p. 76
Oceanography	p. 84
General	p. 87
Author Index	p. 97

The bibliography has been compiled from a variety of sources, particularly from the online data bases listed below.

COLD (Bibliography of Cold Regions Science and Technology)

Aerospace Data Base (International Aerospace Abstracts; Scientific and Technical Aerospace Reports)

NTIS (U.S. National Technical Information Service)

Compendex (Engineering Index)

Meteorological and Geostrophysical Abstracts

CITATION Data Base (WDC/NSIDC).

Because we do not have all of the original material in hand, we cannot be certain of the completeness of each citation. However, every effort has been made to ensure accuracy.

Our thanks to those who received the draft bibliography and sent additional references.

We would appreciate your comments on the bibliography -- on citations we have not included, sources not searched, or subject areas which were not adequately covered.

Ann Brennan

Compiler

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