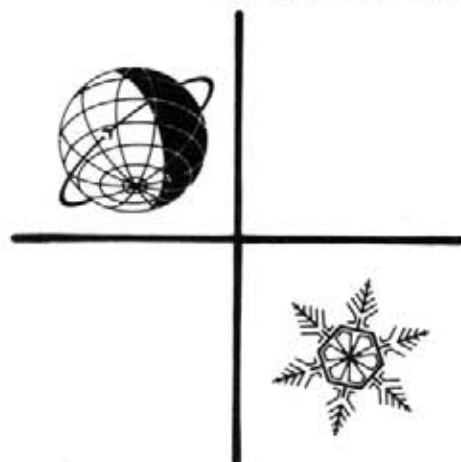


GLACIOLOGICAL DATA

WORKSHOP ON SNOW COVER AND SEA ICE DATA

World Data Center A
for
Glaciology
Snow and Ice



MAY 1979

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NOTES:

1. 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.

2. 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).

3. Inquiries and communications concerning data in specific disciplines should be addressed to the appropriate subcenter listed above.

GLACIOLOGICAL **DATA**

REPORT GD-5

WORKSHOP ON SNOW COVER AND SEA ICE DATA

May 1979

Published by:
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[SNOW AND ICE]**

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DESCRIPTION OF DATA CENTERS

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 on 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.

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

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World Data Center B
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World Data Center C
Scott Polar Research Institute
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Cambridge, CB2 1ER, England

Permanent Service on the Fluctuations of
Glaciers - Department of Geography
Swiss Federal Institute of Technology
Sonneggstrasse 5
CH-B092 Zurich, Switzerland

The World Data Centers follow the guidelines established by the International Council of Scientific Unions Third Consolidated Guide to International Data Exchange through the World Data Centres, 1973. The following description from the Guide details the form of the data accepted by the WDCs.

General. WDCs are prepared to accept raw, analyzed, or published data, including photographs. It is suggested that researchers submitting data to the WDCs do so in a form which will be intelligible to other users. 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 the Guide to International Data Exchange. Such material will be available to researchers as copies from the WDC at cost, or if it is not practical 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.

Fluctuations of Glaciers. The Permanent Service will be responsible for receiving data on the fluctuations of glaciers and will also receive such data as are generated by the International Hydrological Decade Project on Variations of Existing Glaciers. The types of data which should be sent to the Permanent Service are detailed in UNESCO/IASH (1969) Variations of Existing Glaciers: A Guide to International Practices for Their Measurement. 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.).

Projects of the International Hydrological Decade. In addition to the above, the International Hydrological Decade, 1965-74, sponsored an Inventory of Seasonal and Perennial Snow and Ice Masses, as well as a project on the Combined Heat, Ice and Water Balances at Selected Glacier Basins. A Temporary Technical Secretariat (UNESCO) For World Glacier Inventory is colocated with the Permanent Service on the Fluctuations of Glaciers.

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

To send WDCs reprints of all published papers and public reports which contain glaciological data or data analysis; one copy should be sent to each WDC or, alternatively, three copies to one WDC for distribution to the other WDCs.

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.

FOREWORD

Under a NOAA/EDIS contract, the Data Center is currently preparing an inventory of snow cover and sea ice data. The primary focus to date has been on map series and other data products describing cryospheric parameters on a regional to global scale. As part of this endeavor, the WDC arranged a two-day workshop of agency representatives and interested scientists in Boulder, 2-3 November 1978, on The Mapping and Archiving of Data on Snow Cover and Sea Ice Limits. While the attendees, with one exception, were from North America, the workshop recommendations and the material presented here are of broad relevance to problems of worldwide concern in the environmental sciences, especially climatology, meteorology, hydrology, and oceanography.

This issue contains the workshop recommendations and papers (or summaries). The next issue will comprise the results of our related survey of products containing snow cover or sea ice data.

R.G. Barry
Director
World Data Center-A
for Glaciology (Snow and Ice)

PREFACE

We would like to thank all participants in the Workshop for the papers presented, as well as for the ensuing discussions from which the recommendations were formulated. As far as possible, we have left the papers in the form they were presented, making editorial changes only for the sake of clarity, or for consistency with the Glaciological Data series. In cases where the written text of the papers was not provided by the authors, we have prepared short summaries from the tape-recorded transcript.

We would also like to thank Gloria Manzanares for the data entry of the text, Anne Gensert for the manual typing, and Nancy Mensal for assistance in proofreading.

Marilyn J. Shartran
Managing Editor

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**WORKSHOP ON MAPPING AND ARCHIVING OF DATA ON
SNOW COVER AND SEA ICE LIMITS
(BOULDER, COLORADO, 2-3 NOVEMBER 1978)**

1. BACKGROUND AND OBJECTIVES

The spatial and temporal characteristics of global snow cover and sea ice are major components of the "climate system", and its variability on time scales of weeks to decades. The need to incorporate such cryospheric data into climate models for diagnostic and predictive studies is now widely recognized, but there is a significant lack of reliable, high quality, long-term data sets. The objective of a contract funded by NOAA/EDIS to the WDC-A for Glaciology (Snow and Ice) is to begin to remedy this deficiency, firstly by developing an inventory of present data sets.

A number of types of data products, especially map displays showing snow cover or sea ice properties on a regional to global scale, are now being routinely prepared by various agencies in the United States and elsewhere. Sources for these include ground observations at weather stations or from ships, aircraft reconnaissance flights, and, increasingly over the last 10 to 15 years, satellite imagery and remote station telemetry.

The idea of holding a meeting of agency representatives and also individual scientists involved in the production of such data sets evolved during discussions that I had with G. Kukla at Lamont-Doherty Geological Observatory, E.P. McClain and F. Kniskern at the National Environmental Satellite Service, NOAA, and W.E. Markham and B. Findlay at the Atmospheric Environment Service, Canada, in spring 1978. It was considered important that, in addition to its inventory activity, the WDC should seek to facilitate the exchange of information on current data products, as well as techniques used in their preparation, and also attempt to develop recommendations on the archiving and digitization of snow cover and sea ice data.

The general questions that we have tried to address are as follows:

- 1) What data should be archived? (in terms of parameters, resolution, coverage, "levels" of data, and ancillary or supporting data)
- 2) Where should the data be archived?
- 3) When should data sets be collated, digitized, and updated?
- 4) How should the data be collected from the various sources and subsequently be made available to users?

The Workshop attracted 27 external participants (p. 5) and 17 papers were given. As shown in the program (p. 4), these were grouped into four sections dealing with hemispheric products, regional data sets, snow/ice indexing, and some current data problems. On the second day, part of the program was devoted to an assessment of future needs. Working groups evaluated 1) the archiving of existing and future data products; and, 2) their digitization and indexing. The first group was led by W.S. Stringer, and the second, by R.L. Jenne. Recommendations prepared by these groups, subsequently circulated to all participants and thereafter finalized in the WDC, have been forwarded to NOAA/EDIS; the data management group of the U.S. Climate Program Office; the Working Group on Sea Ice of the World Meteorological Organization; the United Nations Environment Program; the International Commission on Snow and Ice; and the Committee on Glaciology, Polar Research Board, U.S. National Academy of Sciences.

A supporting WDC survey of the producers of major data sets on snow cover and sea ice, detailing the sources, techniques, and products, is being prepared for publication in the near future in GD 7. Commentary on the recommendations, or related matters, and information on any sources or products that we may have overlooked, especially from other countries, will be welcomed.

R.G. Barry
Director
World Data Center A
for Glaciology (Snow and Ice)

2. RECOMMENDATIONS

A. General Recommendations

1. WDC-A for Glaciology (Snow and Ice) should seek to identify the problems that users currently encounter in accessing data sets, and explore possible solutions for the provision of more manageable data products. Strategies must be devised to facilitate access to mass data bases with time and space dimensions as primary references. With regard to future, higher resolution satellite data especially, EDIS, NASA and other agencies should format daily tapes of global data so that individual geographic sectors can be readily accessed.

2. WDC-A should help coordinate the views of the snow and ice research community on future satellite systems, their capabilities, resolution, and coverage, and communicate this information to the appropriate agencies. Such activity is timely following the failure of Seasat. The development of new systems which can provide on-board processing to generate statistics of very high resolution data for selected geographic areas is welcomed. There is an overwhelming need for compressed data from satellite systems to facilitate climatological studies covering month- to several-year time scales. The need for continued collection and retrieval of ground truth data to verify remote sensing measurements is stressed.

3. The element sizes, resolutions, and coverage needed for various cryospheric parameters have been stated in various documents (beginning with GARP Publ. No. 16). WDC-A should ensure that these recommendations are critically reviewed, and a definitive statement prepared for submission to WMO and national agencies.

4. WDC-A should collect information on special Arctic/Antarctic programs, and on meteorological, oceanographic, and other data sets pertinent to glaciology in these regions. GARP Publ. No. 19 recognizes the improvement of the global data base in polar regions as the first task of POLEX. There is a need for more accurate surface weather analyses in polar regions which could be met in part by greater use of satellite imagery in data-sparse areas. The intended disposition of satellite-readout data being received at McMurdo Station is of interest in this regard.

5. It is recommended that the U.S. Navy adopt the standard practice of reporting sea ice concentrations in tenths (not oktas), and that the AFGWC charts show snow depth in centimeters.

6. The present status of, and needs for, atlases of snow cover and sea ice should be reviewed. With regard to standardization of averaging periods, it is noted that the WMO Working Group on Sea Ice has recommended a 5-year averaging period for past and future ice archives.

B. Recommendations on Digitization

1. Data on snow/ice limits, reflectance categories, and ice concentrations on the weekly snow and ice charts prepared by NESS should be cross-checked with station data, adjusted, and then digitized. The archive should be extended backwards, after incorporating necessary cross-checking and revisions.

Estimated and interpolated boundaries should be identified. The reflectance categories should be increased in number, and each should, if possible, be keyed to a specified range of brightness. The charts should also be plotted at a scale of at least 1:30 million.

2. It is noted that SDS (NCC) will archive 2 terabit magnetic tapes per day (equivalent to 500 ordinary tapes) of TIROS-N data. The problem of user access makes it of high priority that the tapes of the basic grids, and possible selected minimum brightness values, be archived.

Since the 10-day time interval covered by the Composite Minimum Brightness charts represents almost 10 percent of the snowcover decay season, it is recommended that the question of shortening this interval be reconsidered; an additional

combined 5-day version could perhaps be prepared.

3. It is recommended that AFGWC, which currently produces daily charts of snow depth and age, should:

- a) produce a surface brightness chart, on at least a weekly basis, for archiving in WDC-A.
- b) flag climatological or predicted snow data to distinguish them from observations.
- c) develop data bases of background surface brightness (excluding snow), and of surface observations on water equivalent, daily snowfall, precipitation and maximum/minimum temperatures.
- d) provide full documentation on algorithms used to compute snow/ice parameters from radiance data for inclusion with Level II and III archives.

4. There is a wide need for "historical" series of sea ice and snow cover charts. Operational series should be carefully revised, incorporating data from all sources, before extensive and costly digitization is undertaken. Any re-analysis should be fully documented. It is important that estimated and interpolated values be flagged in data sets derived from chart series. Final digitized products should be cross-checked and their consistency documented.

C. Recommendations on New Data Sets

1. A near-IR sensor for snow/cloud discrimination is expected to be operated on a DMSP satellite in 1979. It is recommended that a data base be developed at AFGWC for subsequent archiving.

2. It is recommended that selected digital data being produced as diagnostic model outputs be preserved. In hydrology, for example, basin data on percent snow cover, daily snowfall, water storage, runoff, and energy budget components could be archived at a resolution of approximately 50 km.

3. The primary data streams that go into many operational snow/ice products are not currently preserved. Since these could be tape-archived from the teletype circuits, this possibility should be considered, especially for daily snowfall, temperature, and surface wind data at ground stations.

4. Global data sets on snow depth and water equivalent, to 0.5 cm resolution, (including snow on sea ice) will be needed for verification of climate models. Daily values and monthly averages will be required. Data on snow cover and ice thickness collected by the U.S. Army Cold Regions Research and Engineering Laboratory throughout North America over 15-20 years should be archived at WDC-A following termination of that program.

5. Climate modelling and assessment studies will require accurate data on terrain parameters, soil and vegetation cover types. Snow and ice studies may also require such data sets. Less certain is the potential need in snow and ice research for boundary layer grids and low level rawinsonde or other sounding data. This topic merits further discussion.

6. There appears to be no requirement to archive sea ice forecast/outlook charts. Operational groups may wish to re-examine this question.

References

Global Atmospheric Research Programme. The physical basis of climate and climate modelling. GARP Publications Series, No. 16, April 1975. 265 pp.

Global Atmospheric Research Programme. The polar sub-programme. GARP Publications Series, No. 19, March 1978. 47 pp.

3. PROGRAM

Introduction

J.D. Ives, INSTAAR, University of Colorado
A.H. Shapley, NGSDC, NOAA
Welcome and introduction to Institute of Arctic and Alpine Research, University of Colorado, and WDC-A for Glaciology (Snow and Ice).

R. G. Barry, INSTAAR, University of Colorado
Background to meeting and objectives.

B. Findlay, AES, Canada
Mapping and Archiving of Canadian Snow Cover Data

M.A. Bilello, U.S. Army CRREL,
Hanover-Alaskan and Canadian Snow and Ice Observing Networks

B. SNOW/ICE INDEXING

A. DATA SOURCES AND PRODUCTS

1. Hemispheric

E.P. McClain, NOAA/NESS
Climate-related Hemispheric Snow and Ice Analyses Derived from Satellite Data

F. Kniskern, NESS/Environmental
Products-Ice Products Derived from Satellite

R.H. Godin, NWS/Navy liaison
Data Sources and Ice Products of Fleet Weather Facility, Suitland

W.E. Markham, AES, Canada
Canadian Mapping and Archiving of Sea Ice Data

G. Koenig, AFGWC
Snow/Ice Data Field at Air Force Global Weather Central

A.W. Kimball, Westinghouse Electric Corporation, Baltimore-A DMSP Near
IR Satellite Sensor for Cloud/Snow Discrimination

E.R. Hoppe, Satellite Data Services Division, NCC-Environmental
Satellite Data Services for NOAA/NESS

2. Regional

S. Schneider, NESS, Environmental
Products-Satellite-derived River Basin Snowcover Percentages: A New Data Base for Hydrologists
(Paper given by F. Kniskern)

B.A. Shafer, Colorado Soil Conservation Service-Application of LANDSAT Imagery in Improving Water Supply Forecasts in Rio Grande Basin of Colorado Using Snow Mapping

G. Kukla, Lamont-Doherty Geological Observatory, N.Y.-Accuracy of Snow and Ice Monitoring

J. Walsh, University of Illinois
A Preliminary Digitization of Northern Hemisphere Sea-Ice Data

D. Barnett, U.S. Navy
Indexing Alaskan North Slope Sea Ice Conditions (1953-1977)

P.M. Kelly, University of East Anglia, England-Northern Hemisphere Sea Ice Data for the
Early Twentieth Century

C. OVERVIEW

1. Present Status

W. Stringer, University of Alaska
Fairbanks-Nomenclature for Mapping Sea Ice from High Resolution Satellite Imagery

W. Dehn, Sea Ice Consultants
Omissions in Archived Sea Ice Data

R.L. Jenne, NCAR, Boulder
Data for Ice and Snow Studies

2. Future needs, plans-Working Groups

a) archiving existing and future data products-W. Stringer
(chairman)

b) digitization and indexing of existing and future data - R.L. Jenne (chairman)

3. Recommendations from working groups and general discussion

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Snow and Ice Data Sets for Climate and Water Resource Studies with Particular Reference to North America

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R. G. Crane
P. K. MacKinnon
World Data Center A for Glaciology

I. Introduction

The material for this paper has been developed from the prefatory comments of R. Jenne to the Working Group on the Digitization and Indexing of Cryospheric Data.

Snow and ice cover play a dynamic role in the variation of albedo, the thermal and hydrological properties of the surface, and the surface roughness. (See schematic diagrams in figures 1-3.) Thus, some form of physical coefficient representation, or parameterization, of the snow and ice cover is essential for coupled models of climatological and hydrological systems. Also, the grid resolution of such models will be determined, in part, by the spatial distribution of the snow and ice data. In this respect, there is a need for snow and ice data to be made available in digital form, with the spatial resolution necessary to meet modeling needs. The following discussions focus on sources of snow and ice data sets, snow and ice gridded data products, and related hydrometeorological data.

II. Mapping and Gridding Data

This section provides a brief summary of existing snow cover and sea ice data sets. The list is not exhaustive, but is intended simply to provide an overview of the type of data available, and their sources.

Major data sets on snow cover and sea ice, including the results of both historical and current surveys, are held at the World Data Center A for Glaciology (Snow and Ice), which is colocated with the National Geophysical and Solar Terrestrial Data Center in Boulder, Colorado (appendix I). Attention is also drawn to Glaciological Data, Report GD-2, which contains a bibliography on Arctic sea ice. Detailed results of a WDC inventory of snow cover and sea ice data will also appear in a future issue of Glaciological Data.

A. Snow Cover Data

1) Global Snow Cover Analysis: U.S. Air Force Global Weather Central, (USAFGWC) (Koenig, this issue). Daily grids, including ocean areas, have been prepared by the USAF starting in 1975. Surface and satellite observed data are used to analyze snow cover on a 1/8 National Meteorological Center (NMC) mesh grid system, with 45 km (25 nmi) between grid points at 60° latitude. Snow depth at each point is given in tenths of inches, to a maximum depth of about 100 inches (250 cm). The analysis is derived from surface observations and climatology, and is cross-checked with a no-snow flag from the processing of the video data from the Defense Meteorological Satellite Program (DMSP). Methods used to incorporate the climatology have changed with time, and the accuracy of the data has improved considerably with the use of an interactive system since about January 1977.

2) Northern Hemisphere Snow and Ice Boundaries: NOAA/NESS (Kniskern, this issue). The National Environmental Satellite Service (NESS) has produced a weekly Northern Hemisphere chart showing snow and ice boundaries for three brightness levels since the autumn of 1966. The information is based on NOAA satellite data. Consistency, in terms of the reflectivity categories, is best from 1974 onwards (Kukla, personal communication).

3) Composite Minimum Brightness and Composite Maximum Temperature Images: NOAA/NESS (McClain, this issue). Computer processed Composite Minimum

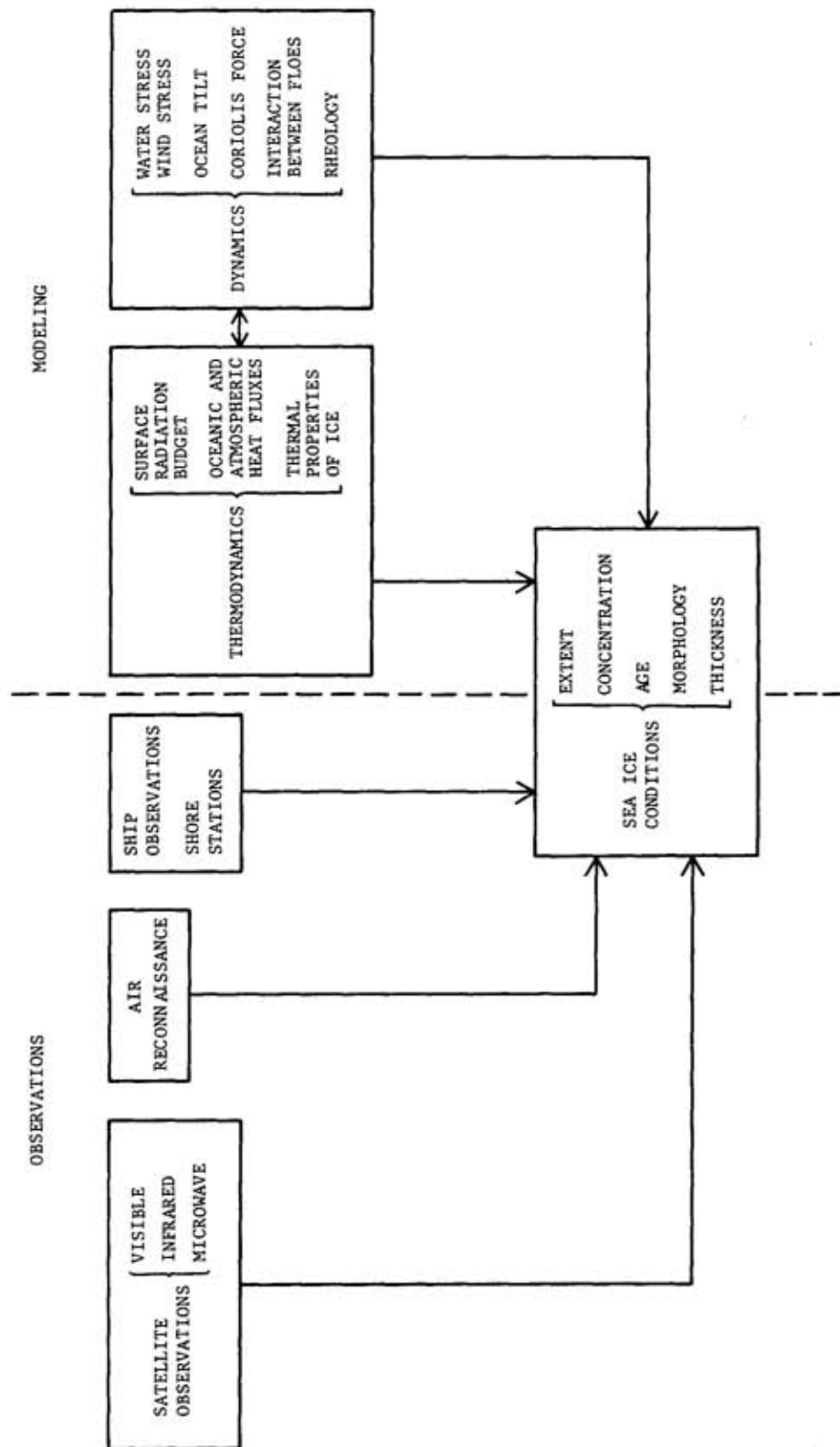


Figure 1. Observation and modeling procedures for ascertaining sea ice conditions.

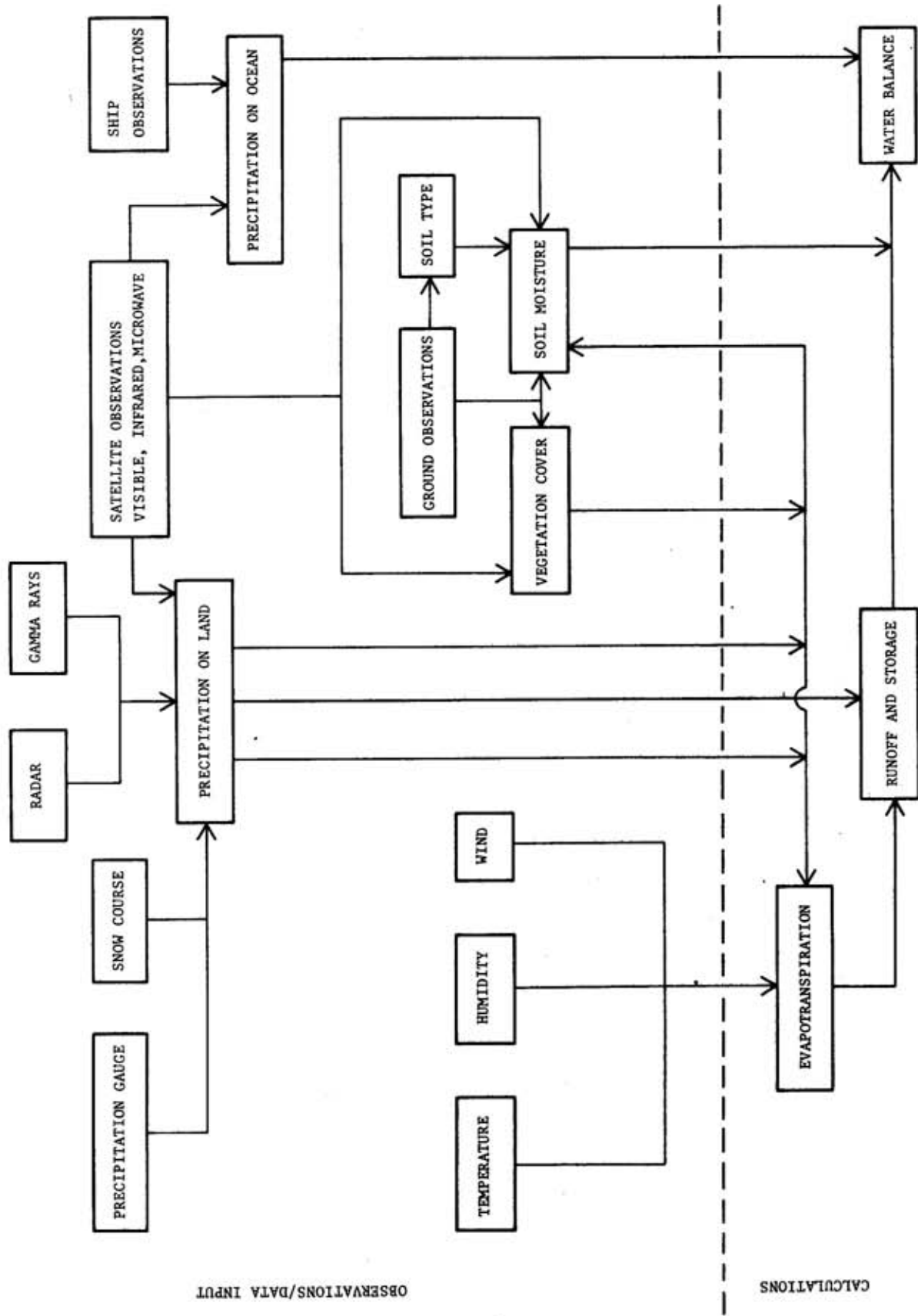


Figure 2. Observational data and physical interactions that produce a hydrological output which is constrained by atmospheric and terrestrial boundary conditions.

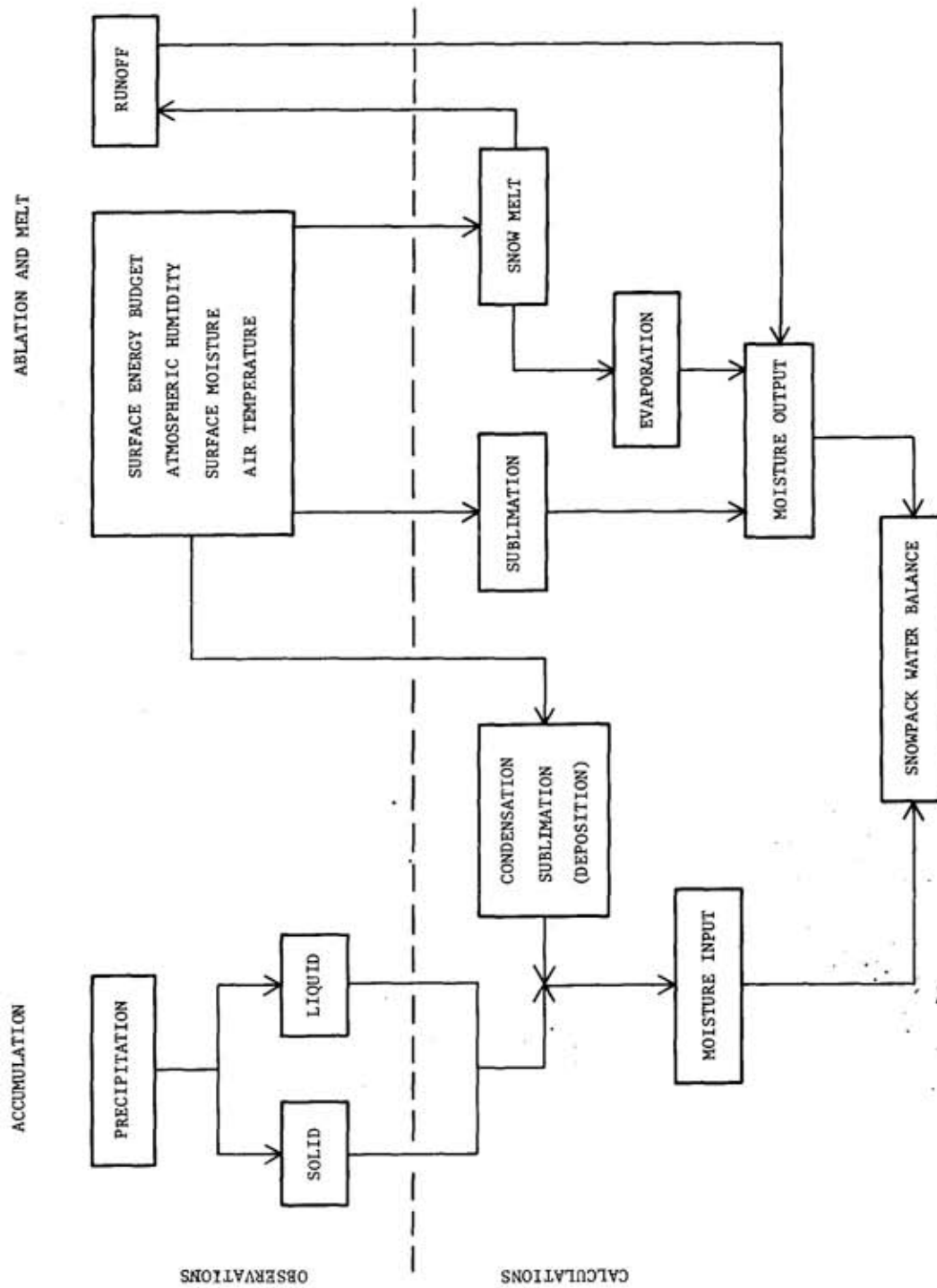


Figure 3. A simple conceptual thermodynamic model of snowpack.

Brightness (CMB) and Composite Maximum Temperature (CMT) images are produced by NESS using the 1/8 NMC mesh grid with a 45-km resolution. CMB images using 5-day non-overlapping data are available from 1968. A 10-day overlapping composite and the use of CMT images began in 1974. These images are produced daily. The original grids, however, are not saved. A 7-day overlapping composite, based on a higher resolution grid, will be introduced with the availability of TIROS-N data (McClain, in press). (See also McClain, 1978; McClain and Baker, 1969).

4) Depth of Snow on the Ground: NOAA Agricultural Weather Facility. Maps have been published in the Weekly Weather and Crop Bulletin since 1935, showing the depth of snow on the ground in the United States each Monday at 1200 hours G.m.t., December through March. The data sources are surface observations from the National Weather Service (NWS) and cooperative stations. (See also section III, below, on Selected Supporting Data Sets for Snow and Ice Studies).

5) State Snow Surveys/Snow Telemetry (SNOTEL): U.S. Department of Agriculture, Soil Conservation Service (SCS). The SNOTEL system gathers high elevation snowpack information in 10 western U.S. states. There are now 160 stations with a planned expansion to 511. The sites use hydraulic pressure cushions or "pillows" to measure the pressure of the snowpack on the surface, and 30.5-cm (12-in) rain gauges that measure precipitation as melted snow or rain. The daily data are transmitted to Ogden, Utah and Boise, Idaho by reflecting the signals from the SNOTEL sites off meteor ionization trails (Barton and Burke, 1977). The data are then transferred to a central office in Portland, Oregon.

The data from the SNOTEL sites complement monthly snow course readings now taken at nearly 1900 locations in the Western United States and British Columbia (U.S. Department of Agriculture, Soil Conservation Service, 1979). Many of these snow courses have been in operation since about 1930. These monthly readings are taken during the late winter and early spring. Additional snow depth data are supplied by regional NWS and cooperative stations.

6) Operational Watershed Snow Mapping: NOAA/NESS (Schneider, this issue). Satellite data have been used to obtain the percentages of snow coverage for 30 river basins in the Western United States since the winter of 1973. These basins occupy about 10 percent of the area of the Western United States. The data are updated at irregular intervals throughout the season, according to the rate of change in the areal extent of the snow cover (Schneider, 1975, 1976, in press; Schneider et al, 1976).

7) Watershed Snow Cover Maps: Soil Conservation Service and Cooperative Agencies (Shafer, this issue). Since the winter of 1974-75, four test sites in the Western United States have been selected for snow mapping using satellite data. The test sites are in Colorado, California, Arizona, and the Pacific Northwest. Maps are prepared for a number of river basins at each test site.

8) Snow Cover Data for the North American Arctic and Subarctic: U.S. Army Cold Regions Research and Engineering Laboratory (CRREL). CRREL-derived information on snow temperature profiles, snow density, and physical characteristics of the snow cover is available from about 30 ground observing stations in northern Canada, Alaska and northern states of the contiguous United States (Bilello, 1969). Although observations began in 1952, the length of record varies between stations. Most stations closed between 1974 and 1976.

9) Snow Cover Data for Canada: Environment Canada, Atmospheric Environment Service (Findlay and Goodison, this issue). Snow cover data for Canada are published monthly with information on snow depth and water equivalent provided from river basins and snow courses. Subjective mapping is carried out, based on the station reports. Maps show snow depth and date of formation and loss of snow cover (McKay and Findlay, 1971; Environment Canada, 1974; Findlay, 1975).

10) Snow and Related Data Available Through Avalanche Studies. U.S. data are available from a varying number of mountain stations in the Western States for the past 20 years. The data are collected, reduced, and stored by the U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station, Alpine

Snow and Avalanche Project, Fort Collins, Colorado. Typical data include mean daily values of air temperature, wind speed and direction, snow depth, and daily precipitation totals. Data at more frequent time intervals are available from a limited number of stations.

11) Aerial Gamma Radiation Snow Survey. A recent innovation in aerial remote sensing of the snowpack utilizes the natural terrestrial gamma radiation flux. In principle, the water content of soil and snow cover modulate the natural gamma radiation level emitted from the earth's surface. Therefore, difference values derived from measurements before and during the existence of a snowpack yield a water equivalent for the pack. Regional surveys are conducted by repeated flights over controlled survey lines before and during the life of the pack (U.S. National Oceanic and Atmospheric Administration, 1978). This method was developed almost simultaneously in Canada, Norway, the Soviet Union, and the United States during the 1960's. It is currently being used on a semi-operational basis in both Canada and the United States (Rango, 1977). See also a series of papers on gamma radiation techniques in Santeford and Smith (1974), and Vershinina and Dimakhsyan (1969).

National or local organizations for avalanche data exist in many alpine countries. A questionnaire seeking information related to field stations engaged in avalanche research has been circulated by the World Data Center A for Glaciology (Snow and Ice) to institutions in 43 countries. As well as other avalanche-related questions, information is also requested on the location of stations and the timing and availability of snowpack and climatological data. Results will be tabulated and published in a future issue of Glaciological Data.

B. Sea Ice Extent Data*

1) Northern Hemisphere Snow and Ice Boundaries: NOAA/NESS (section A.2, above).

2) Composite Minimum Brightness and Composite Maximum Temperature Images: NOAA/NESS (section A.3, above).

3) Sea Ice Data from Microwave Images: U.S. National Aeronautics and Space Administration (NASA) (Zwally, this issue). Nimbus-5 microwave data are processed on a 293 by 293 grid, from the pole to 50° latitude, for both hemispheres. A grid of brightness temperature data has been produced for three-day periods since 1972. The original data resolution is 25 km at nadir and 30 by 40 km at 30.5° from nadir. The mapping resolution is about 50 km (Wilheit, 1972, 1973). Sea ice conditions can be deduced from these grids (see, for example, Gloersen and Salomonson, 1975; Gloersen et al, 1974; Zwally et al, 1976; Zwally and Gloersen, 1977). The sea ice boundary around Antarctica has been mapped for December 1972 to June 1975, using the Nimbus-5 microwave data (Rayner and Howarth, 1977).

4) Global Sea Ice Limits: U.S. Navy, Fleet Weather Facility (FLEWEAFAC)-Joint Ice Center (Godin, this issue). Weekly ice analyses depicting ice boundaries and concentrations have been prepared by the U.S. Navy for the Arctic and Antarctic since 1970. These analyses have been published in atlas form, starting in 1972 for the Arctic, and 1973 for the Antarctic. Very High Resolution Radiometer (VHRR) data from NOAA satellites are the main data source employed during seasons with adequate light, while microwave data from Nimbus satellites are used during the polar night and in areas of persistent cloud cover. Whenever possible, these observations are supplemented with Landsat and DMSP images, aerial reconnaissance, and surface observations. Surface observations are retained by the National Oceanographic Data Center (NODC), Washington, D.C.

5) Shorefast Ice, Lake and River Ice Data for the North American Arctic and Subarctic: U.S. Army Cold Regions Research and Engineering Laboratory. CRREL-derived data are available from 1946 through 1977 for 40 stations in Canada, and 26 in Alaska. The length of record varies for each station. Data are available on ice thickness, concentration, age, rate of growth or

*Sea ice data sets are also compiled in Norway (for the northeast Atlantic); West Germany; Sweden and Finland (for the Baltic); Japan (for Japanese waters); and the Soviet Union (full extent of data unknown). It is hoped that more information on these will be available for inclusion in the WDC-A snow cover and sea ice extent data inventory.

ablation, and the amount and date of maximum ice thickness (Bilello, 1961, 1969; Bilello and Bates, 1966, 1975).

6) Ice Conditions in Canadian Waters: Environment Canada, Atmospheric Environment Service (Markham, this issue).

a) Data for the period 1900 through 1955 are available in atlas form (Swithinbank, 1960). The atlas documents information four times per month from 275 points between the Bering Strait and Foxe Basin, and in the Canadian Arctic Archipelago. Maps show the amount of ice present. During the autumn, the charts are less frequent and there is less information on ice extent and the age of the ice. A table showing data sources and the years data are available for each site is also given.

b) Recent charts showing ice concentration, extent, and type have been produced once a week from 1958 to the present. Charts are available for different areas of subarctic and Arctic waters in varying formats (for example, the Southern Historical charts (1958-1974), which extend up to 70°N. and are available all year, and the Northern Historical charts (1960-1974), which extend up to 80°N. or higher, and are available for 29 May to 31 October). These particular charts are on 35-mm film. Grid point data, available on card or tape, have also been prepared for the Northern charts.

Aircraft on contract operate in the Newfoundland and Hudson Bay area from January to May, then in the region of Baffin Island and the Queen Elizabeth Islands through October. Side looking airborne radar (SLAR) was installed in the aircraft in February 1978. Use is made of shore stations, ice breakers, and observers on Canadian military flights. When available, satellite data are included. Any late data are used to update the charts.

7) Sea Ice Atlases: Canadian Department of Energy, Mines and Resources (Markham, this issue). The Department of Energy, Mines and Resources, Polar Continental Shelf Project, has published two atlases covering the Canadian Arctic Archipelago and adjacent waters for the periods 1961 to 1968, and 1969 to 1974. A third atlas for 1975 to 1978 is in preparation. Maps show ice extent, concentration, age and floe size, as well as surface morphology.

8) Northern Hemisphere Ice Conditions: British Meteorological Office. Since January 1960, the Meteorological Office, Bracknell, England, has produced charts showing ice concentrations at the end of each month. The data used are primarily derived from information made available through other agencies, particularly the Canadian AES, Ice Central, Ottawa and FLEWEAFAC, Suitland (Tunnell, 1968).

9) Danish Ice Reconnaissance: Danske Meteorologiske Institut. Sea ice conditions have been reported by the Danish Meteorological Institute since 1885. Sea ice charts have been published from 1900 to 1956 for the Arctic seas, and from 1957 to 1964 for the Greenland waters (Fabricius, 1961; Danske Meteorologiske Institut, 1964). The earlier data are from ship reports. Aerial reconnaissance has been used since 1959.

C. Snow Cover and Sea Ice Extent Data Gridding

1) Arctic and Antarctic Ice Concentrations and Northern Hemisphere Snow Cover: G. Kukla, Lamont-Doherty Geological Observatory (Kukla, this issue). Weekly snow cover for the Northern Hemisphere has been digitized for the period 1967 to the present. During the period 1967 to 1971, only the area of snow cover is given. From 1971 onward, six reflectivity classes are used, but these are of poor quality up until 1973. For 1974 to the present, however, the reflectivity classes are more reliable (Kukla, personal communication). The principal chart source is the NOAA/NESS Northern Hemisphere Snow and Ice Boundaries (section A.2, above). Accuracy tests have been performed on these data. The data are digitized on a 2° by 2° grid up to 60°N., and on a 2° by 4° grid north of 60°. The original data counts were for 2° latitudinal belts in five to ten meridional segments.

Ice cover grids for the Arctic are compiled using the U.S. Navy weekly ice charts which have been available since 1972 (section B.4, above). Data included are ice concentrations, in octas, and percent of open water within the pack ice. This is extended back to 1960 on a monthly basis, using the British Meteorological Office charts (section B.8, above). Southern

Hemisphere data are available for the summer months from 1967 to 1972. Weekly charts for both summer and winter are available from 1973 (Kukla and Gavin, in press).

2) Northern Hemisphere Sea Ice Concentration Grids: J. Walsh, Laboratory for Atmospheric Research, University of Illinois (Walsh, this issue). Sea ice data are digitized at a grid interval of 1° latitude (110 km). The 1500-point grid covers the Arctic Ocean and those portions of the peripheral seas where ice is observed during all or part of the year. The grids depict the ice conditions at the end of each month from 1953 through 1977. U.S. Navy, British Meteorological Office, Canadian AES, Danish, and Norwegian data are used to obtain the ice coverage in tenths in each grid area (Walsh, 1978).

3) Northern Hemisphere Ice Limits, 1901-1956: M. Kelly, Climate Research Unit, University of East Anglia (Kelly, this issue). This is a digitization of the sea ice data of the Danske Meteorologiske Institut (section B.9, above) for the period 1901 to 1956. The same grid is used as that by Walsh (section C.2, above). An ice/no-ice indicator is given for each square in the grid. Work is currently in progress to test the reliability of these data (Kelly, 1978).

4) Arctic Ice Cover and Northern Ice Limit Antarctica: K. Hasselmann, Max-Planck-Institut für Meteorologie, Hamburg, FRG. Data sources are the British Meteorological Office monthly ice charts (section B.8, above) and the U.S. Navy northern ice limit in Antarctica (section B.4, above). The data are digitized on a 10° longitude grid in the Northern Hemisphere, and a 5° longitude grid in the Southern.

III. Selected Supporting Data for Snow and Ice Studies

Archives of climatological data exist in national and international repositories. In the United States, the NOAA Environmental Data and Information Service (EDIS) operates the National Climatic Center (NCC). This is the central U.S. repository for atmospheric data. At the operational level, the National Weather Service (NWS) is responsible for collecting and assessing real-time data.

At the international level, the World Meteorological Organization (WMO), a United Nations agency, in collaboration with the International Council of Scientific Unions, supports world data centers for climatological data. In conjunction with the WMO established Global Telecommunications System (GTS), meteorological data are channeled to the World Data Centers for Meteorology: A in Asheville, N.C., U.S.A.; B in Moscow, USSR; and C in Melbourne, Australia.* Each data center archives various global data sets. In the United States, NCC also maintains an extensive inventory on GTS sampled data.

The contribution of snow and ice to the hydrological regime is significant, particularly when viewed with respect to flood control, irrigation, and urban water supplies. Thus, many national and international agencies exist to share knowledge and experience, and develop and coordinate control schemes with respect to water resources.

The following is a selection of supporting data sets that relate in whole or in part to snow and ice studies. American inventories are considered first, followed by international programs and sources of data.

A. Surface Weather Data

Surface weather conditions are observed and reported at 1000 U.S. first-order land-based stations. In addition, a National Substation Program, comprised of cooperative weather stations, provides daily temperature extremes and precipitation totals. Precipitation includes, if appropriate, a breakdown into daily snowfall, snow depth, and in some cases snow density and water equivalent. From 1900 to 1947, the cooperative network averaged 1500 stations. Since 1947, there have been approximately 10,000 stations in the network. Ocean surface weather is also reported into the U.S. network from 2000 cooperative observers on board ships with a maximum of 500 observations reported at any one time. All these data are archived with NCC.

NCC has created a data subset of 500 to 600 stations comprised of selected

*Receives only Southern Hemisphere data.

cities and all military stations for the period 1949 to 1977. Within this subset are recorded daily temperature extremes, daily snowfall, and snow depth. Since 1965, daily sunshine and wind records have also been incorporated where available.

B. Solar Radiation Data

Since 1977, the United States has operated a network of 38 stations equipped to measure solar radiation received at the earth's surface. This network provides information on the three components of solar radiation: global, diffuse, and direct. For the period from the early 1950's to 1977, there are selected component data available for 26 hourly and 25 daily stations. There are many calibration problems among these station records. This led in part to a revitalized network established in 1977. The data are processed and published by NCC.

C. Rawinsonde Data

Rawinsondes (balloon-borne instrument packages) provide data on pressure, temperature, water vapor, and winds. U.S. controlled data are available since 1950. There are currently 128 upper-air stations in a rawinsonde network which includes the United States, Caribbean, and Central and South American nations. These data are archived at NCC. In addition, global rawinsonde data, derived from GTS teletype since 1963, is also archived at NCC.

D. International Meteorological and Climatological Programs

Various international meteorological and climatological projects are producing vast arrays of standardized modern, as well as historical, data. For example, the World Weather Watch (WWW) and the Global Atmospheric Research Program (GARP), subprograms of the WMO, are generating real-time and research data sets on all basic facets of global meteorology and climate. Meteorological satellite data derived from various national and international agencies, coupled with data from a global distribution of first-order and cooperative ground-based stations, produce a comprehensive daily "picture" of the global weather. This daily "picture" is then made available for archiving at the World Data Centers for Meteorology. During the First GARP Global Experiment (FGGE), currently in progress, it is hoped to collect meteorological data from 100,000 ground-based stations.

Solar radiation and ancillary data sets are archived at the GATE Radiation Subprogram Data Center, Main Geophysical Observatory, Leningrad. The primary data products are available in hard copy and computer compatible tape from WDC-B for Meteorology, Moscow. There are three data sets: surface radiation, direct solar radiation, and aircraft radiation (Global Atmospheric Research Programme, 1976).

As part of the International Decade of Ocean Exploration (IDOE), there has been a project to assemble in a standardized format the bucket temperatures from all available ships logs for the period 1860-1960. These data will be archived at NCC.

Many of these data sets currently being assembled or reformatted will be of value to snow and ice studies, particularly in the context of modeling, and in some cases, historical climate reconstructions.

E. Hydrological Snow Cover and Modeling

The waxing and waning of the seasonal snowpack is an integral part of the hydrological cycle. Data on the variation of the snowpack and snowmelt provide valuable input into hydrological modeling of streamflow. Several types of mapping and remote sensing systems for monitoring the snowpack have previously been discussed. Conventional field measurement techniques are reviewed in Seasonal Snow Cover (United Nations Educational, Scientific and Cultural Organization, 1970c).

The prime hydrological interest in the snowpack is to assess its role in forecasting stream discharge over time. Two basic modeling techniques are available: statistical and simulation. The statistical models are primarily used in seasonal yield forecasts. Simulation models tend to have a more complex structure and hierarchy. According to Anderson (1973), simulation models dealing with snow may be subdivided into three components: the snow cover, a

precipitation-runoff relationship, and a runoff distribution and routing procedure. In terms of hierarchy, simulation models may be distinguished between those that represent each basic component as a single relationship, and those that simulate the unit processes involved in the basic components. The practical difference is that the first category generally is used to simulate the melt season only, whereas simulation of the unit processes allows the annual cycle to be analyzed. Operational forecasts utilizing this type of simulation have been developed (Kuzmin, 1969; Anderson and Rockwood, 1970; Baker and Carder, 1977).

Research has also been directed at designing water resource projects in areas lacking adequate data. This is often the case in mountainous regions where the snowpack plays a significant role in the hydrological regime. See for example, Sokolov (1974) and Kovacs and Molnar (1974).

F. National Data Water Exchange (NAWDEX)

NAWDEX, operated by the USGS, Reston, Virginia, maintains a computer data base on surface and ground water characteristics for 300,000 sites in the U.S. The period covered by this data base extends from the late 1800's to the present, with the bulk of data arising since the 1950's.

There are currently limited snow and ice related data; however, the development of a new parameter list will incorporate snow and ice oriented studies.

Three hundred fifty organizations actively collect hydrological data that are reported to NAWDEX through a network of 53 regional centers throughout the United States.

G. International Hydrological Programs

The International Hydrological Decade (IHD), 1965-74, was conceived and coordinated by UNESCO in cooperation with ICSU, WMO, IUGG, and other organizations. One of the many thrusts within the IHD has been to assess the role the cryosphere plays in the hydrological cycle. Numerous reports, conferences, and data bases relating to snow cover, glaciers, and sea, lake, and river ice have been assembled (see, for example, United Nations Educational, Scientific and Cultural Organization, 1969a, 1969b, 1970a, 1970b, 1970c, 1972; World Meteorological Organization, 1977).

The culmination of the IHD led to a more comprehensive ongoing project called the International Hydrological Program (IHP). The IHP, in conjunction with WWW, GARP, and affiliates, is monitoring short and long term changes in, and effects generated by, the cryosphere. This includes satellite monitoring of snow and ice distribution; remote sensing of hydrological platforms; a World Glacier Inventory; hydrological modeling; and assessment of socio-economic effects of floods, irrigation, and water supplies.

As an aid to hydrologists, including those conducting research or operational forecasts involving snow and ice, the WWW has prepared a reference manual for hydrology (World Meteorological Organization, 1976). The primary purpose of this report is to increase recognition of WWW facilities.

IV. Supplementary Geographic Data

In order to simulate climate using numerical modeling techniques, or to make climate assessments, a variety of supplementary geographic data should be readily available for squares of 1° latitude-longitude or smaller. Examples include the following:

A. Elevation and Depth Data

Average elevation data are available to support most synoptic-scale atmospheric modeling needs; however, higher resolution ocean data sets are still required (table 1). At smaller scales (for example, individual river basin studies), a much greater resolution would be required. However, few data exist at these scales.

B. Surface Properties

Data on terrain features, vegetation cover or land use, and soil type are necessary for the determination of albedo, emissivity, and roughness length.

Table 1. Available elevation and depth data.

Originating Agency	Archive Location	Resolution	Parameters Recorded	Area Coverage
U.S. Air Force	NCAR	1° lat/long squares	Elevation	Global
		30' lat/long squares	Elevation	Global
		5' lat/long squares	Elevation	Europe, parts of N. America and N. Africa
U.S. Navy	NCAR	10' lat/long squares	Min., max., and average elevation	Northern Hemisphere (Southern Hemisphere completed to 30° south)
			Ridge orientation	
			% of square covered by water	
			Terrain characteristics	
Scripps Institute of Oceanography	NCAR	1° lat/long squares	% urbanization	Global
			Elevation	
			Ocean depth Elevation Base of ice caps	

Information should be included on topography, surface type (for example, bare rock or a vegetation cover), and vegetation type or land use, since these affect albedo, especially in the presence of snow cover. Similarly, albedo and surface emissivity are determined, in part, by the physical and thermal properties of the soil, the effects of which will vary with moisture content. These may be parameterized according to soil type.

Area-weighted albedo values have been calculated for 10° by 10° latitude/longitude areas based on assigning a different albedo value to each of 49 recognized surface types. Values are arranged for each of the four seasons, thus incorporating the effects of a seasonal snow cover where applicable. These data could be used to provide values for areas as small as 1° latitude by 1° longitude (Hummel and Reck, 1978).

Data on snow cover and depth, as well as water equivalent, are needed in relation to all of these terrain and vegetation or land use parameters.

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Appendix I

MAJOR SNOW AND ICE CHARTS HELD AT THE WDC-A FOR GLACIOLOGY (SNOW AND ICE)

- 1) *British Meteorological Office:
 - Monthly Arctic Ice Maps. Jan. 1962-July 1978.
- 2) *NESS/Synoptic Analysis Section:
 - Northern Hemisphere Snow and Ice Boundaries. 9-15 May 1977 to 5-10 Feb. 1979.
- 3) FLEWEAFAC, Suitland:
 - 30 Day Ice Forecast for Northern Canadian Waters. (Text: bimonthly) mid-June to mid-July 1976 to mid-Oct. to mid-Nov. 1977.
 - Western Arctic 30 Day Sea Ice Forecast (Charts: bimonthly) 2 April 1977-28 Feb. 1979.
 - Eastern Arctic 30 Day Sea Ice Forecast (Charts: bimonthly) 2 April 1977-28 Feb. 1979.
 - *Western Arctic Sea Ice Analyses. 1972-1975.
 - *Eastern Arctic Sea Ice Analyses. 1972-1975.
 - *Eastern-Western Arctic Sea Ice Analyses. 1977.
 - *Southern Ice Limit, Western Arctic. (Weekly) 22 Feb. 1977-6 Feb. 1979.
 - *Southern Ice Limit, Eastern Arctic. (Weekly) 22 Feb. 1977-7 Feb. 1979.
 - *Antarctic Ice Charts. 1973-1974.
 - *Northern Ice Limit. (Antarctica: Weekly) 3 March 1977-8 Feb. 1979.
 - Seasonal Outlook: Western Arctic Ice. 1978.
 - Seasonal Outlook: Eastern Arctic Ice. 1977; 1978.
 - Seasonal Outlook: Western Ross Sea and McMurdo Sound. 1977-1978; 1978-1979.
- 4) Environment Canada: Atmospheric Environment Service:
 - Ice Summary and Analysis: - Canadian Arctic. 1964-1971.
 - Ice Summary and Analysis: - Eastern Canadian Seaboard. 1965-1971.
 - Ice Summary and Analysis: - Hudson Bay and Approaches. 1965-1971.
 - *Southern Historicals. 1958-1974.
 - *Northern Historicals. 1960-1974.
- 5) *Dept. of Energy, Mines and Resources, Polar Continental Shelf Project (Canada):
 - Sea Ice Atlas of Arctic Canada. 1969-1974.
- 6) Danske Meteorologiske Institut:
 - *Isforholdene i de Arktiske Have. (The State of the Ice in the Arctic Seas). 1953-1956.
 - *Isforholdene i de Grønlandske Farvande. (The Ice Conditions in the Greenland Waters). 1957-1964.
 - The State of the Ice in Davis Strait. (Text: 45pp.). 1820-1930.
- 7) *U.S. Dept. of Commerce/U.S. Dept. of Agriculture:
 - Weekly Weather and Crop Bulletin (snow cover). Jan.-March 1976; Dec. 1976-March 1977; Dec. 1977-March 1978; Dec. 1978 to present.

*Descriptions of these data sets are included in the text.

- 8) *U.S. Dept. of Agriculture, Soil Conservation Service:
- Snow Surveys and Water Supply Outlook for Alaska. Feb.-June 1974; 1976-1978.

- Water Supply Outlook for:

- <u>Colorado and New Mexico</u>	Feb.-April 1978
- <u>Arizona</u>	Feb.-April 1979
- <u>Idaho</u>	Jan.-June 1978; Jan.-Feb. 1979
- <u>Montana</u>	Jan.-June, Oct. 1978; Jan.-Feb. 1979
- <u>Nevada</u>	Jan.-May 1978
- <u>Oregon</u>	Jan.-June, Oct. 1978; Feb. 1979
- <u>Utah</u>	Jan.-June, Oct. 1978
- <u>Washington</u>	Feb.-May 1972; Feb.-June 1973-1978; Feb. 1979
- <u>Wyoming</u>	Feb.-June 1978; Feb. 1979

Various other annual or short-term regional reports are also held.

9) *Snow Cover and Sea Ice Indices

- a) Digitized snow cover and sea ice data tapes for the Northern Hemisphere, 1972-1978.
- b) Digitized sea ice data tapes for the Southern Hemisphere, 1973-1978.

Both data sets have been made available by G. Kukla, Lamont-Doherty Geological Observatory.

A Northern Hemisphere sea ice data set for 1901-1956 (from M. Kelly, University of East Anglia), and for 1953-1977 (from J. Walsh, University of Illinois) will be archived at the Data Center when available.

*Descriptions of these data sets are included in the text.

Climate Related Snow and Ice Analyses From Satellite Data (Summary)

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This paper describes two products of NOAA/NESS. The first is the Composite Minimum Brightness (CMB) and Composite Maximum Temperature (CMT) charts; the second is a satellite-derived continental and hemispheric snow cover data base.

CMB and CMT charts. An irregular series of data are available for both hemispheres for 1969-79. Original composites were based on digitized video data. Scanning radiometer data were introduced at the end of 1974. From 1979 on, these charts will be based on TIROS-N, Advanced Very High Resolution Radiometric (AVHRR) Data. The use of minimum brightness (visible) and/or maximum temperature over 5- to 10-day compositing periods eliminates or suppresses all but the most persistent cloudiness. The IR data are inferior to the visible images in a number of ways; they do, however, allow analyses to be extended into the polar night, where visible data are unavailable. Using these methods, interannual variations in snow cover and ice extent are readily depicted on a hemispheric basis.

Hemispheric Snow Cover Data Base. Weekly Northern Hemisphere snow and ice boundary charts are produced using the NOAA/NESS visible-band images from polar orbiting satellites. Monthly mean snow cover charts are also produced for both Eurasia and North America. Both interannual variations of continental or hemispheric snow cover, as well as intercontinental comparisons, can be made. Twelve years of data are available from November 1966 onward.

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Ice Products Derived from Satellite at NOAA/NESS (Summary)

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The National Oceanic and Atmospheric Administration (NOAA) through the National Environmental Satellite Service (NESS) produces a variety of oceanographic products derived from satellites. With the advent of the Very High Resolution Radiometer (VHRR) aboard the NOAA series satellites in late 1972, more sophisticated ice products are produced. Accurate ice edges and even individual ice floes can be readily detected from the 1-km resolution imagery in both the visible and infrared channels. The visible channel of the Scanning Radiometer (SR) sensor, with a resolution of 4 km, has proven very useful for hemispheric snow and ice analyses. The Geostationary Operational Environmental Satellite (GOES), with a resolution of 1 km in the visible spectrum, has been widely used for the analysis of ice in the Great Lakes and sea ice along the Labrador coast.

Utilizing the above satellite imagery, the following ice products are produced at NOAA/NESS:

1. Northern Hemisphere Snow and Ice Boundary Chart - This weekly chart, which is prepared on a polar stereographic projection centered on the North Pole, provides information on the areal coverage of the snow and ice. Both high and low resolution visible imagery are utilized to detect the snow and ice fields and the differences in reflectivity of the snow and ice.
2. Labrador Sea Ice Analysis - This chart depicts the ice edge and concentration of sea ice in the Labrador Sea. The analysis has been produced both operationally and experimentally as an aid to navigation for the past two seasons.
3. Great Lakes Ice Analysis - This chart depicts the ice concentration, leads, and openings in the Great Lakes. The analysis is produced twice weekly during the ice season as an aid to navigation, and distributed by National Facsimile and mail.
4. Alaska Sea Ice Analysis - This chart, initiated in 1973, depicts the ice edge, ice concentration, age of the ice, and openings and leads in the Bering, Beaufort and Chukchi Seas. This analysis is produced weekly throughout the year and distributed by National Facsimile and mail. The ice information is used for ice advisories and forecasts to aid ships during the resupply of Alaskan ports.

All the above charts, including the originals and mail copies, are archived at NESS.

High resolution imagery has been available from the NOAA satellites over the Bering, Beaufort, and Chukchi Seas since early 1973. With almost six years of daily imagery, plus the weekly Alaskan ice analyses, we plan to produce an ice atlas of the seas surrounding Alaska. We feel the atlas should be useful to various users by showing the variability of the ice in the Alaskan region.

One other interesting ice phenomenon we have observed with the VHRR data is the movement or motion of ice. The high resolution imagery allows us to detect the movement of the ice edge, pack ice, and individual ice floes on a daily basis. The film loop which will be presented will show a 110- to 165-km ice edge movement in the Bering Sea over a period of only four days. Although this amount of ice movement is very abnormal, it does show that ice motion can be depicted from a satellite. In the future, an ice motion chart may be produced at NESS, or at least ice motion will be indicated in the regular analysis.

Data Sources and Sea Ice Products of Fleet Weather Facility/Joint Ice Center, Suitland

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Introduction

Since 1973, the U.S. Navy Fleet Weather Facility, Suitland has produced global sea ice analysis products for the U.S. Department of Defense and civilian users. Over the years, the ice products have had a wide range of utility from guiding ships through ice infested waters to numerical heat budget model inputs. In 1977 alone, over 800 naval ice messages to ship and shore facilities were transmitted; 200 users received weekly mailings; and ice facsimile products were transmitted weekly.

This paper has been developed to systematically describe and explain data sources, method of production, and products of the weekly sea ice analysis program.

Weekly Arctic Ice Analyses and Forecasts

I. General. Manually analyzed Eastern (figure 1) and Western Arctic Sea Ice Charts (figure 2) are produced weekly as a synthesis of ice data and satellite information of varying resolution and utility. Seven-day ice limit forecasts reflect anticipated trends.

II. Data sources. Conventional data are accumulated, decoded, and evaluated for timeliness and reliability as received.

A. Shore station ice reports.

1. USSR, Finland and Sweden (Baltic and Gulf of Bothnia)
2. Norway (Jan Mayen, Bear Island, Hopen)
3. Greenland
4. Alaska
5. Canada

B. Ship reports.

1. U.S. Coast Guard Ice Breakers
2. Military Sealift command vessels
3. Icelandic Coast Guard
4. Merchant and fishing vessels

C. Aerial ice reconnaissance (method of observation).

1. U.S. Navy ice reconnaissance (visual, radar, radiation thermometer, laser profilometer)
2. U.S. Navy ice observer flights of opportunity (visual, radar)
3. National Weather Service. (visual)
4. U.S. Coast Guard International Ice Patrol (visual, radar)
5. Private industry (visual)
6. U.S. Navy patrol aircraft (radar)
7. Foreign sources: Canada (SIAR, visual), Denmark (visual), Norwegian patrol aircraft (visual, radar), Japan (visual, radar)

D. Ice analyses from other domestic and foreign centers.

1. Canadian Ice Central, Ottawa (received daily by facsimile and telecopier)
2. National Weather Service Forecast Office, Cleveland (received by telecopier on request)
3. British Meteorological Office, Bracknell, England (received by facsimile)

III. Analysis tools.

- A. Eastern (85° E westward to 110° W) and Western (110° W to 85° E) Arctic work charts (U.S. Navy Hydrographic Office 2560) of 1:11 million polar azimuthal equidistant projections

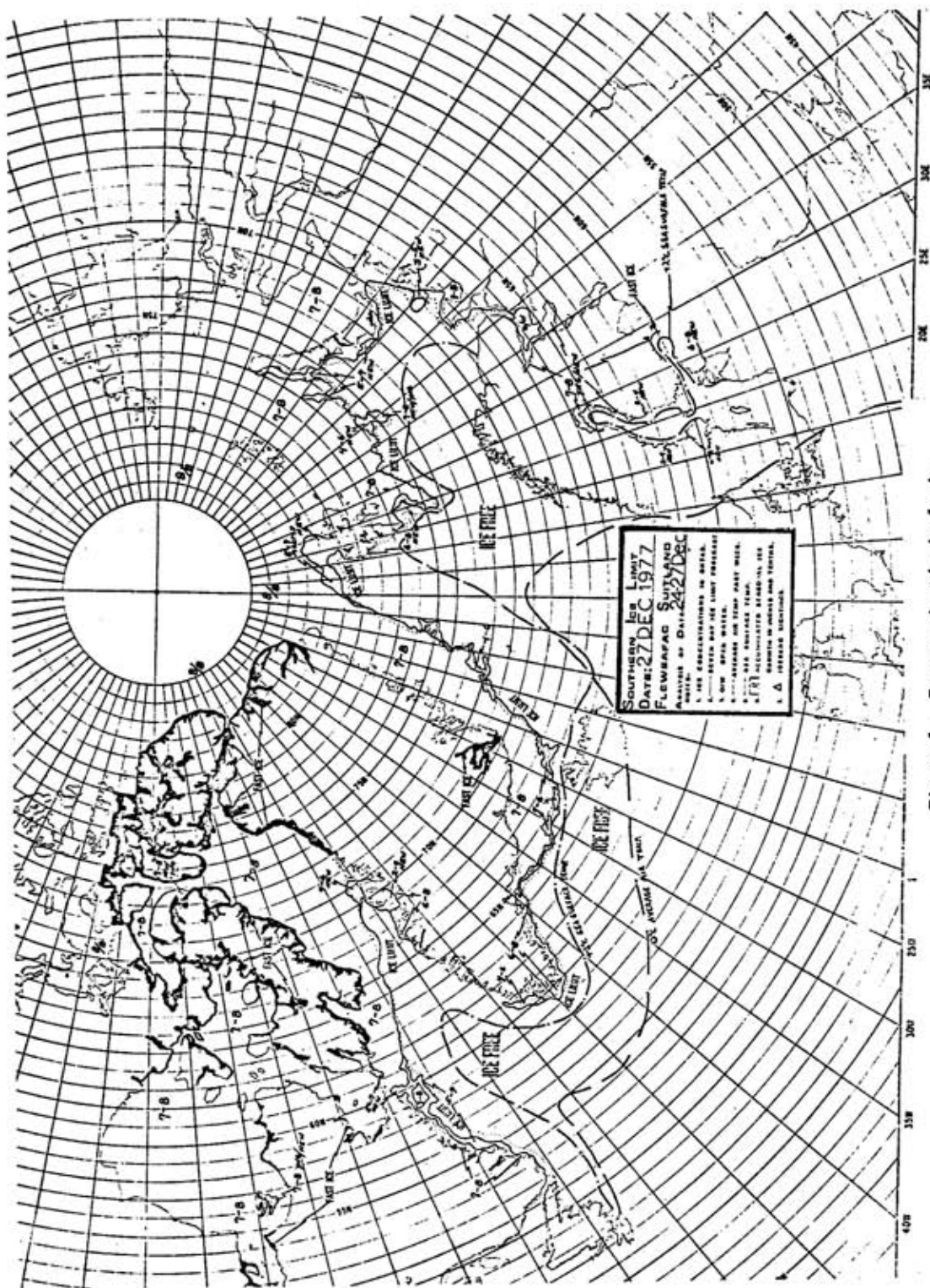
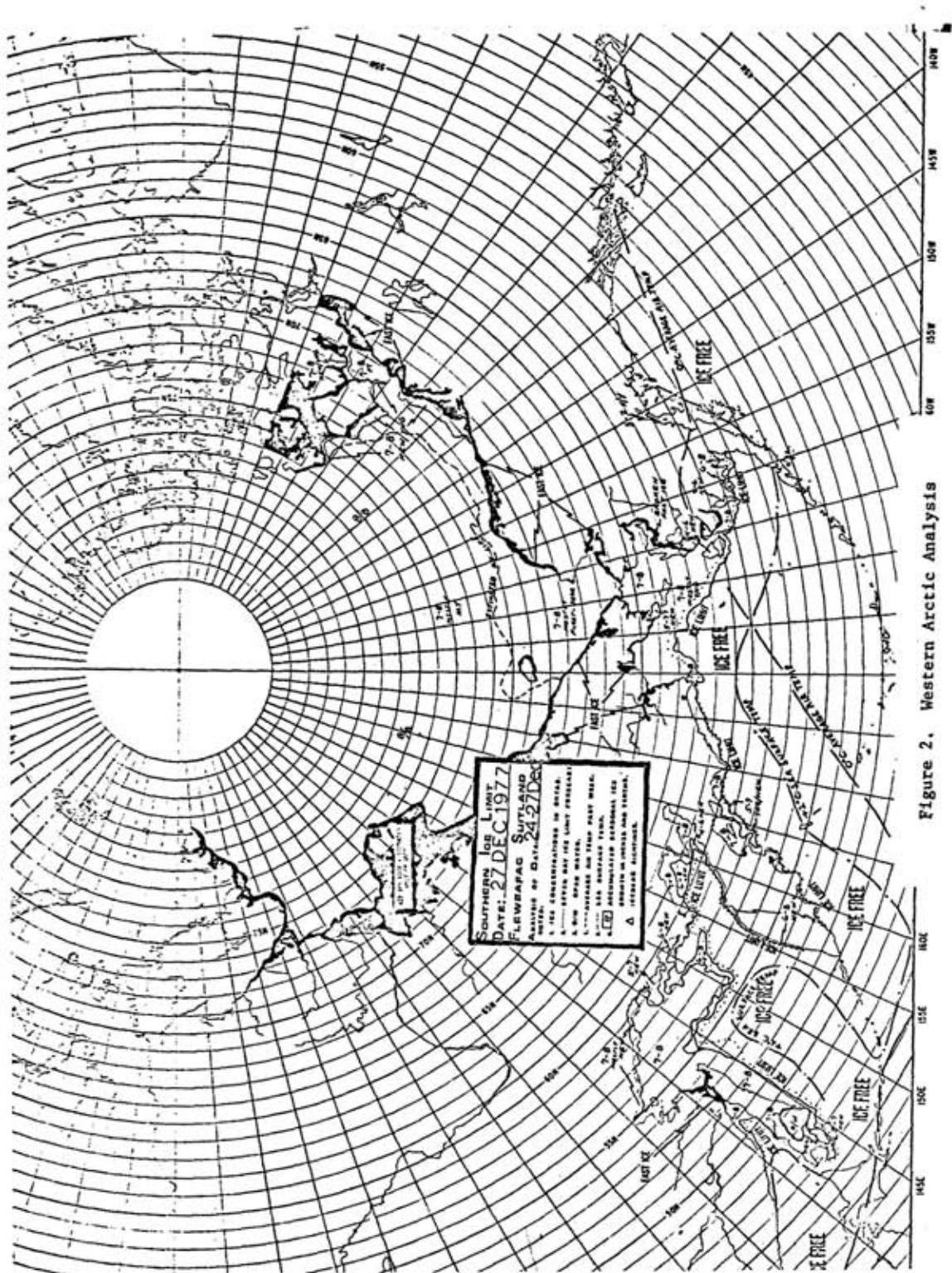


Figure 1, Eastern Arctic Analysis



B. Satellite imagery.

1. NOAA VHRR VISUAL resolution - 1 km
IR resolution - 1 km
2. DMSP hemispheric mosaic
VISUAL resolution - 4-5 km
IR resolution - 4-5 km
3. NIMBUS V ESMR resolution - 25 km

C. Automated diagnostic aids.

1. 168-hour theoretical ice drift vectors located at 207 grid point locations in the Arctic
2. Positive and negative degree-day accumulations and theoretical ice thicknesses at 62 Arctic stations
3. 15-day observed temperature trends for 62 Arctic stations
4. Daily average temperatures and synoptic temperatures at 62 Arctic stations
5. Daily Fleet Numerical Weather Central (FNWC) Northern Hemispheric sea surface temperature and atmospheric temperature analyses

D. Climatology.

1. Compilation of weekly Fleet Weather Facility, Suitland Arctic Ice Analyses from 1972 through present
2. Ice climatologies drawn from Naval Oceanographic Office publications
3. Mean ocean current data from Hydrographic Office publications and others

IV. Seven-Day Ice Limit Forecast. The forecast is intended to depict anticipated trends in ice limit positions. Available guidance is in the form of automated 144-hour wind/current ice vector forecasts at 207 Arctic grid point locations and the application of persistence, extrapolative and climatological ice movement rates. Diagnostic aids involving positive and negative degree-day accumulations and station temperature summaries are also considered.

Weekly Antarctic Ice Analysis

I. General. The weekly Antarctic Sea Ice Chart (figure 3) is produced almost exclusively from satellite information due to sparsity of conventional data and unavailability of automated diagnostic aids.

II. Data sources.

A. Antarctic shore station ice reports.

1. United States
2. United Kingdom
3. Argentina

B. Ship reports.

1. U.S. Coast Guard ice breakers
2. Military sealift, command vessels
3. Research vessels (foreign and domestic)
4. Merchant and fishing vessels
5. Argentine Navy

C. Aerial ice reconnaissance (method of observation).

1. U.S. Navy ice observer flights of opportunity and dedicated reconns (visual, radar)
2. U.S. Coast Guard (visual)
3. United Kingdom (visual)

III. Analysis tools.

- A. Southern hemispheric work chart of approximately a 1:15 million polar azimuthal equidistant projection.
- B. Satellite imagery. Same as in Arctic.
- C. Climatology. Compilation of weekly Fleet Weather Facility, Suitland, Antarctic ice analyses from 1973 to present.

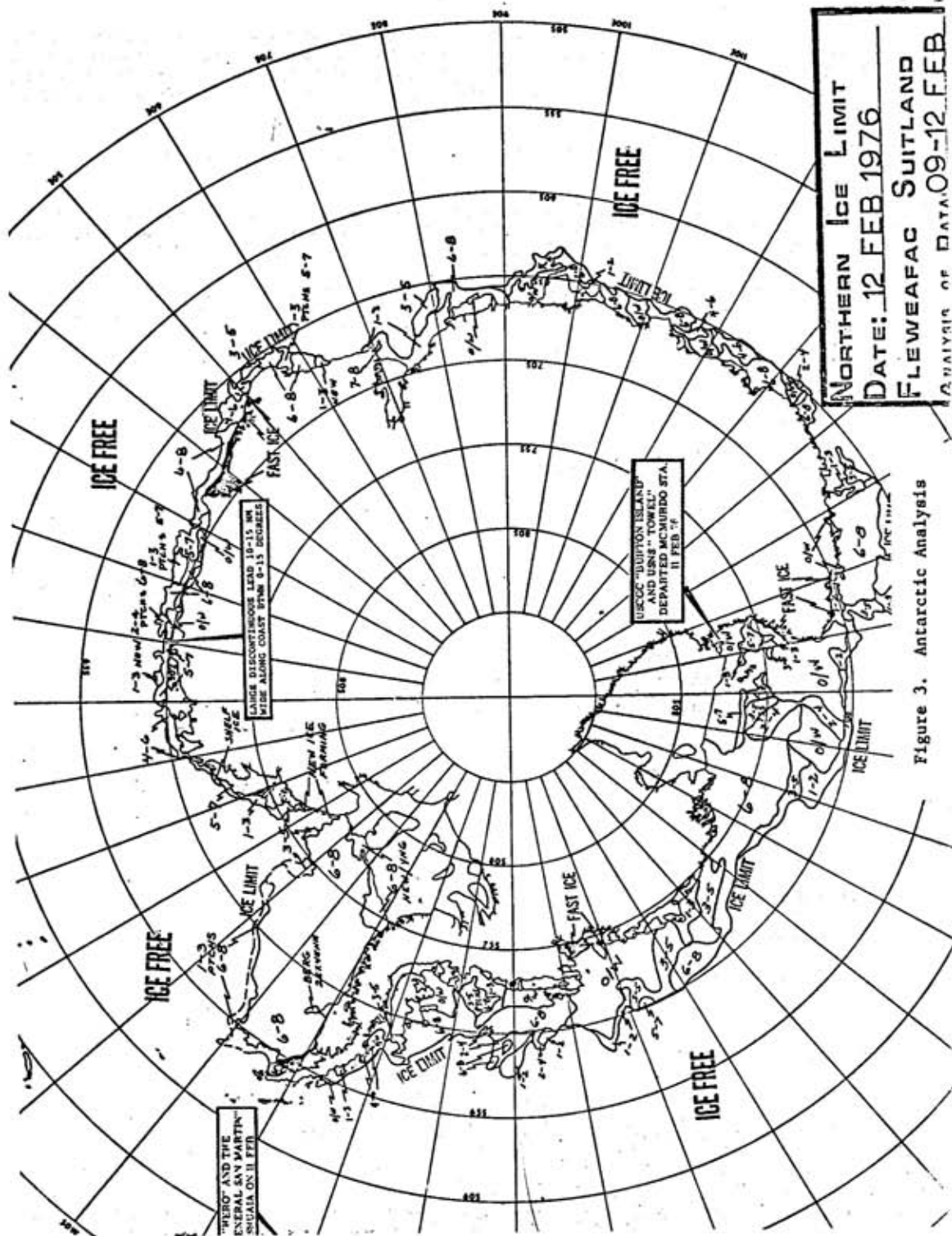


Figure 3. Antarctic Analysis

Philosophy of Analysis and Technique

The ice charts are constructed under operational time constraints and re-analysis with late data is not normally attempted. The information presented reflects an initial effort intended for operational use. The purpose of the analysis is to provide operators and researchers with reliable weekly hemispheric analyses derived principally from satellite imagery supplemented by conventional observations. In general:

- I. Shore station, ship, and aerial reconnaissance ice observations are plotted and evaluated for timeliness.
- II. Satellite imagery is analyzed for ice data content with the most recent and highest resolution imagery considered first. Comparisons are made with ice analyses from other centers (Arctic only). Synthesis of available conventional and satellite data yields the finest analysis.
- III. Where insufficient data are available to define the Arctic ice limit, the ice analysis is first made to follow continuity with the use of 168-hour ice drift vectors and other diagnostic aids (Arctic only). If data are not available during subsequent weeks, ice limits are gradually made to approach normal seasonal climatological positions.

Depiction

- I. Ice concentration.
 - A. Boundaries, in units of eight.
 - B. Open Water (O/W), less than 1/8.
 - C. Ice Free (I/F), no ice present.
- II. Ages and stages. Data sparsity in Antarctic limits description to new, young and fast ice.
 - A. New.
 - B. Young (YNG).
 - C. First year thin (FL).
 - D. First year medium (FM).
 - E. First year thick (FT).
 - F. Multiyear (MY).
 - G. Fast ice (solid black).
- III. Descriptives.
 - A. Patches (PTCHS).
 - B. Fields (FLDS).
 - C. Belts and strips.
 - D. Mostly (MSTLY).
- IV. 7-day mean position of +2°C sea surface isotherm (Arctic only).
- V. 7-day mean position of 0°C average air temperature (Arctic only).
- VI. Ice limit and boundaries. Represented by solid line.
- VII. Estimated ice limit, Represented by dashed line.
- VIII. 7-day ice limit forecast, Represented by dotted line (Arctic only).

Output (M,T,W,TH,F)

- I. Messages.
 - A. Eastern Arctic Analysis/7-day Forecast - Naval Message (Tuesday).

- B. Western Arctic Analysis/7-day Forecast - Naval Message (Tuesday).
 - C. Tailored Arctic Ship Analysis/Forecast Message (Tuesday, Friday).
 - D. Southern Ice Limit (Arctic Data Limit) Northern Hemisphere (Tuesday).
 - E. Tailored Antarctic Ship Analysis/Forecast Message (Monday, Thursday).
 - F. Northern Ice Limit (Arctic Data Limit) Southern Hemisphere (Thursday).
- II. Facsimile products
- A. Bering/Chukchi Facsimile chart #594 - Alaska Facsimile (Monday, Wednesday, Friday).
 - B. Eastern Arctic Sea Ice Analyses chart #591 Greenland/Iceland (Wednesday).
 - C. Eastern Arctic Sea Ice Analyses 62% reduced chart #596 Offutt Air Force Base (Wednesday).
 - D. Western Arctic Sea Ice Analyses 62% reduced chart #597 Offutt Air Force Base (Wednesday).
- III. Mail.
- A. East/West Arctic Analysis/Forecast (Tuesday).
 - B. Antarctic Analysis (Thursday).
- IV. Compilations of weekly ice analyses are bound into a book format and are available from the National Technical Information Service in microfiche or hard copy form.
- A. Eastern Arctic Sea Ice Analyses 1972-1975 AD-A033 344.
 - B. Western Arctic Sea Ice Analyses 1972-1975 AD-A033 345.
 - C. Eastern Western Sea Ice Analyses 1976 AD-A043 353.
 - D. Eastern Western Sea Ice Analyses 1977 AD-A056 784.
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Mapping and Archiving of Canadian Sea Ice Data

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Canada's ice program actually dates back to 1940, although prior to 1958, it was concerned only with springtime opening of navigation through the Gulf of St. Lawrence to Montreal. At least seven data reports showing the retreat and dispersal of this ice are available as publications of the government's (former) Geographical Branch (Black and Forward, 1957; Black, 1957, 1959a, 1959b, 1960, 1961; Forward, 1958). They depict ice boundaries only on a one chart per year basis.

Since 1958, the Atmospheric Environment Service (AES) has conducted ice reconnaissance in most Arctic, subarctic and Eastern Seaboard areas. The coverage is over areas south of latitude 55° N. from December to June, and in the more northern sections from July to October. There is a data gap in most years relating to the spread of the ice cover southward from Davis Strait to Belle Isle Strait.

Reconnaissance hours have increased gradually over the years and now exceed 3000 h/yr using principally Electra aircraft along with DC-3's in the Great Lakes area during the winter. Since 1971, each aircraft has carried cameras, a laser profilometer, an infrared line scan system, and an airborne radiation thermometer for use in appropriate situations. A real aperture sideways looking radar was added to one aircraft in February 1978.

Satellites have been used continuously since the mid-1960's, and the rapid advance of technology in this field has made them a major data source for the past five years. Both NOAA visual and infrared imagery and Landsat data (in summer only) are available in real-time.

Besides the above, the Polar Continental Shelf Project has flown ice reconnaissance in the arctic since 1961, principally in the Queen Elizabeth Islands. Their results are published in two Canadian Arctic Ice Atlases -- the first covering 1961-68 and the second, 1969-74. These publications present the results of the observations rather than an analysis of them. Since 1966 their data have been integrated into the AES historical chart series.

The products of the AES ice service which are archived are as follows:

1. Thousands of original ice observers' charts. These are at a scale of 1:2,000,000 up to 1977, and recently, 1:1,000,000. Although they are on microfilm, the large number precludes copying and distribution.
2. Composite ice charts at a scale of 1:4,000,000. These are issued weekly for the Great Lakes in winter, Hudson Bay, Eastern Arctic, and Western Arctic in summer; and three times weekly for Eastern Seaboard from January to June. The period covered is 1972 to date and copies can be purchased from: Ice Climatology Division, Trebla Building, Dept. of the Environment, Ottawa, Ontario K1A 0H3.
3. Historical ice charts at a scale of 1:6,000,000. A weekly series, mid-May to end of October, for the area north of latitude 65° N., and another on a year-round basis for the Eastern Seaboard, Hudson Bay and Foxe Basin. There are, however, few data north of latitude 55° N. in this series from 1 December to 15 May. Both series cover the years 1959-74, and work is progressing slowly on the more recent years. The charts are on microfilm and are available as above.
4. There are bound copies of Ice Summary and Analysis - Eastern Canadian Seaboard, Hudson Bay and Approaches, and Canadian Arctic for the years 1964-72 (1973 is in press). These add meteorological parameters to the ice charts on a weekly or two-week basis, but the actual ice data come from the historical series noted above. Copies are available from the Ice Climatology Division. An incomplete similar series of ice observations for the same period is available at AES Headquarters.

5. Ice thickness data measured weekly at most coastal weather stations north of latitude 55° N. have been published yearly since the early 1960's. An analysis - Ice Thickness Climatology was prepared in 1974. Copies are available at AES headquarters.

6. Freezeup and breakup data are collected at many Canadian weather stations. These have also been published at intervals. Copies are available from AES headquarters.

Existing Canadian atlases of sea ice are as follows:

Ice Atlas of Arctic Canada - C. Swinhank, 1960. Covers all data on record 1900-55 (including ships' logs). The data are analyzed at about 275 points four times per month and depicted in summary in chart form. The input record by year and location is also included.

Canadian Arctic Ice Atlas - Polar Continental Shelf Project, 1961-68 and 1969-74. Actually a publication record of their ice observations.

Ice Atlas - Eastern Canadian Seaboard - in press. Covers the area from the Gulf of St. Lawrence to latitude 55° N. based on years 1962-73.

Ice Atlas of Canadian Arctic. This is being developed at present by AES. Expected publication date is 1980.

In addition to the above, I would like to point out that the World Meteorological Organization is presently working on three projects in this area:

1. A set of purely numerical symbols for use on ice charts receiving international distribution or broadcast.
2. A questionnaire concerning national practices in ice reconnaissance and services provided to shipping.
3. A catalogue of ice data archives held by various nations, and eventually, a recommended system for archiving ice data in digital form. This is intended to lead to regional (or national) preparation in computer compatible format of the total ice archive in five-year segments, both for the past and as an ongoing program for the future.

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Snow/Ice Data Field at AFGWC (Summary)

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The Air Force Global Weather Central (AFGWC) Snow Cover Analysis Model was described with respect to the data input, analysis procedures, problems, possible improvements and potential uses of the model. The hemispheric model became operational in 1975. It uses hourly surface synoptic data, meteorological satellite video brightness data, and climatological data to determine the depth and age of snow on the ground on a hemispheric grid with 46-km (25-nmi) spacing. Improvements are currently being made to the climatological data used (such as manually bogused inputs) to increase the accuracy of the model's output. The resulting daily analyses provide a Northern and Southern Hemisphere data base which is stored on high speed computers and available for meteorological and other scientific applications.

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A DMSP Near IR Sensor For Cloud/Snow Discrimination

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Abstract

This presentation describes an instrument built to fly on a DMSP satellite. Sensing reflected sunlight in the $1.5 \mu\text{m}$ region, it is designed to operate in conjunction with the visible channel of the primary sensor to demonstrate feasibility of automatic recognition of clouds over snow fields. The theoretical basis for the instrument is discussed briefly, and salient radiometric characteristics of the instrument described.

Instrument Purpose and Description

This DMSP Supplementary Sensor was conceived and has been configured to demonstrate that information from a relatively narrow (approximately $0.1 \mu\text{m}$) band centered at $1.55 \mu\text{m}$ may be used for automated separation of snow and cloud scenery under sunlit scene conditions. Radiometrically, bright but noncloud scenes could be discarded during automated processing of visible spectrum cloud data. A second purpose was the generation of a data base which could be used to generate threshold (cloud/not-cloud) algorithms for application to bright scenes otherwise not computer separable. General preservation of the detailed snow information from such combined channel data was not an initial consideration.

The initial design baselines were generated from a relatively meager background of published experimental (measured) data. From that available, the work of Blau, et al. (1966) and Plummer (1969) was used for estimation of cloud radiances in the general spectral region of interest. Advance information from O'Brien, et al. (1975), supplied by Air Force Cambridge Research Laboratories (AFCRL), was used for snow radiance in the same spectral region. A sample of the data used is shown in the curves of figure 1. These data are selected as reasonably conservative. Older snow will have lower reflectivity, and most stratus and large cumulus clouds are expected to be of higher reflectance than those chosen. The data have been "normalized" by the writer to solar zenith angle 50° and nadir view so the sources of the data should not be charged with responsibility for any errors resulting therefrom. From such data were chosen the spectral limits of 1.5 to $1.6 \mu\text{m}$ as providing adequate aperture radiance, while limiting the band to the region of maximum contrast. During the period of instrument design, a short series of instrumented aircraft flights were conducted by AFCRL to investigate the near IR radiance characteristics of clouds and snow. A ground processed contrast plot is shown in figure 2. The agreement with our calculations seems to be quite good, and has been taken to confirm our spectral band selection.

The instrument design has been described in detail by Stebbins (1978). Briefly, a 48-element line array of intrinsic Ge detector elements lies in the image plane of a 40.2 degree wide angle lens designed to provide constant angular field of view per array element (14.6 mrad along track, 9.61 mrad along array on 14.6 centers along array), as well as an element illumination loss from center to end of only 12 percent. The instrument field of view will extend from subtrack perpendicular to the track and toward the sun, covering about 650 km on the earth's surface. Channel outputs will be sampled in the pushbroom mode every two seconds, individually digitized to six bits and read out over 2 seconds into the primary sensor data stream in standard supplementary sensor format. With the primary data, they will be recorded on the spacecraft and played back over the DMSP Control and Readout Stations, shipped to AFGWC, deformatted, and recorded on tapes, together with standard time and ephemeris information. The sampling rate has been designed to provide essentially contiguous coverage at the spacecraft subpoint with some overlap as the array looks out from the track. Detector footprints on the earth surface are shown in figure 3. Finally, to compensate for the variation in scene illumination from near subsolar to the terminator region (and to permit gain variation for enhancement of specific types of low radiance scenery), 16 gain states, spaced at 2.4 dB, are available and may be commanded from the primary sensor memory at specified programmed times along the orbital track.

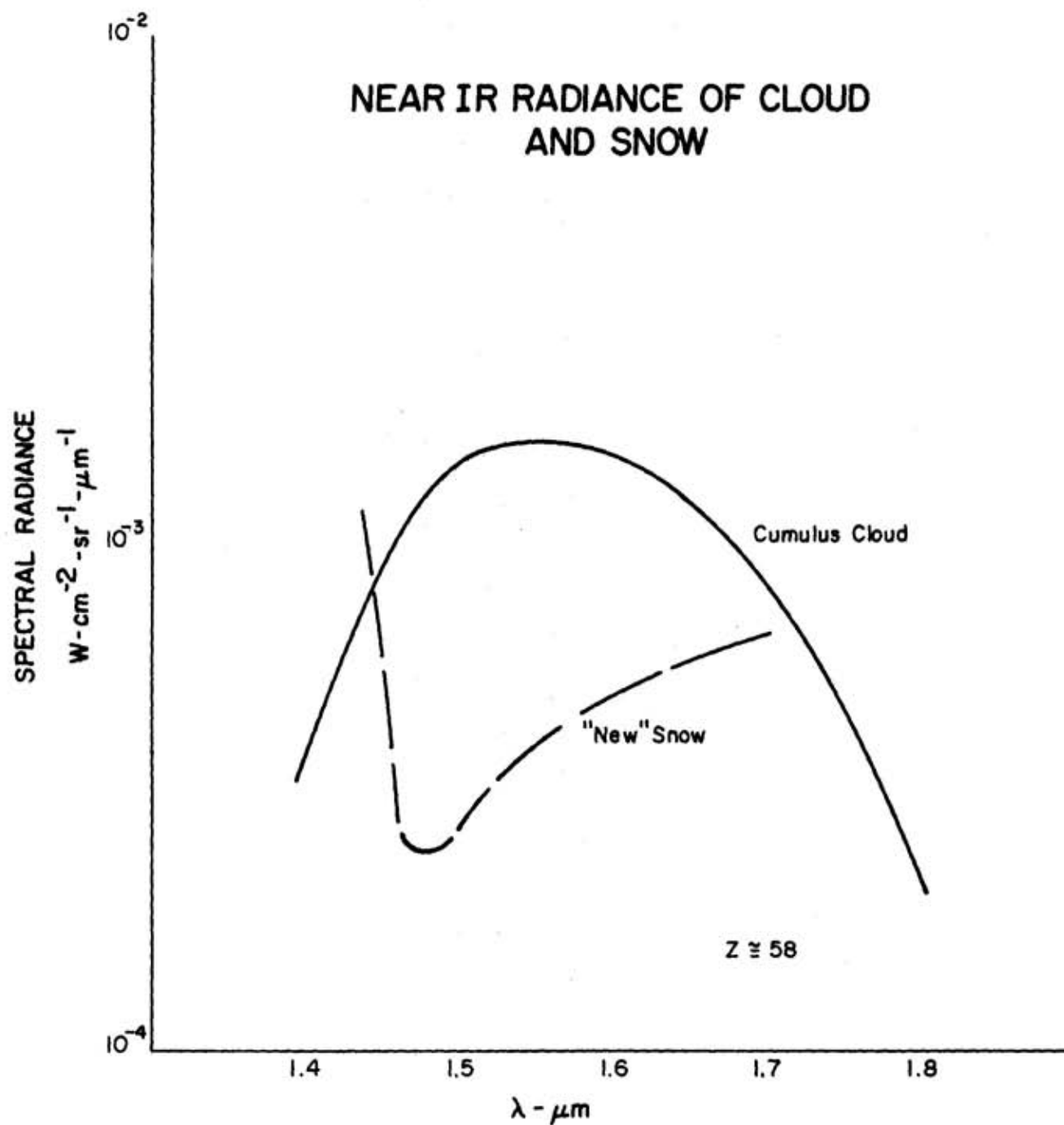
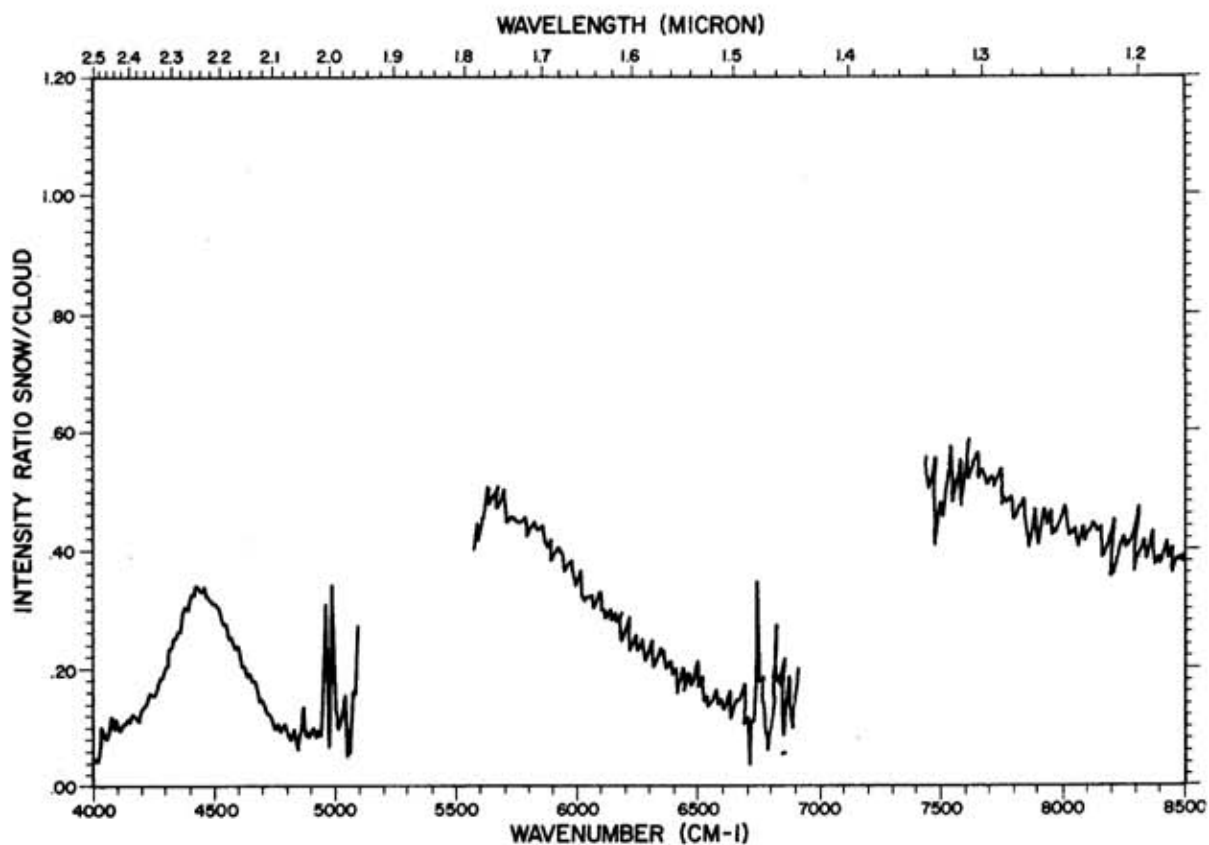


Figure 1. Near IR radiance of cloud and snow.



TR9/I/2 SNOW/CLOUDS 33K FT R306/8 0

Figure 2. A ground processed contrast plot.

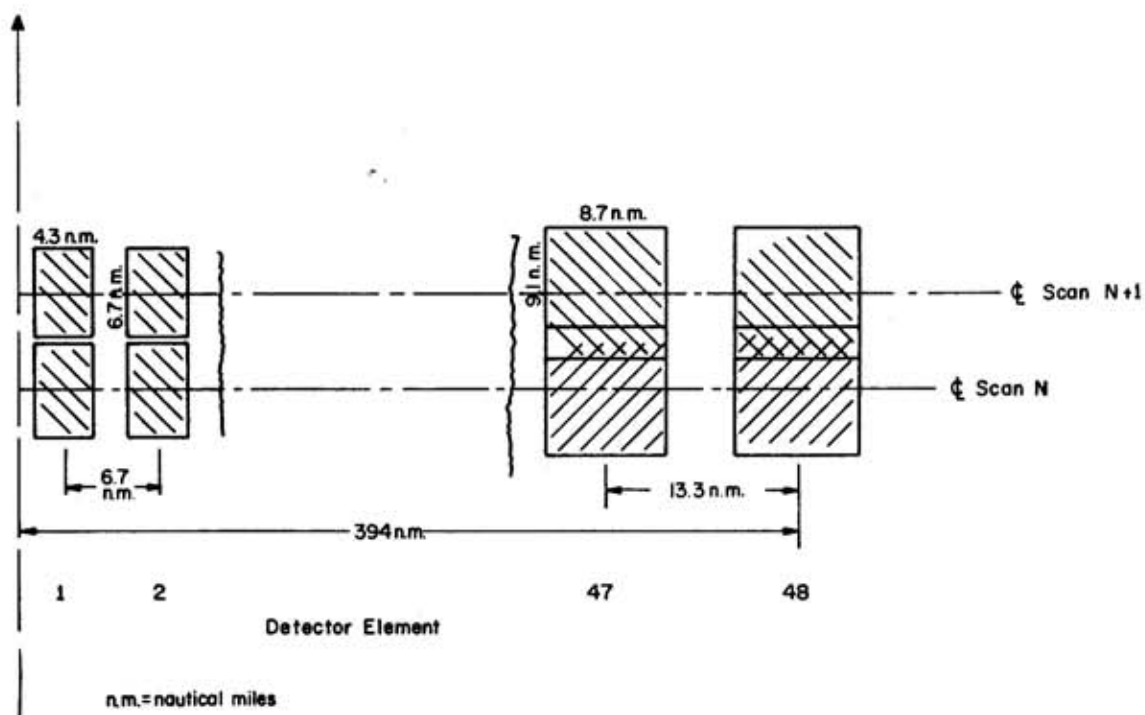


Figure 3. Detector footprints on the earth's surface.

Design Considerations

As noted previously, a purpose of the instrument is generation of a data base for discrimination algorithms. Accordingly, the instrument has been designed to provide adequate signal to noise ratios down to expected input radiances from snow scenes a few degrees from the terminator. To optimize contrast between snow and cloud scenes from near subsolar (low latitude snow caps in summer) to near terminator regions, 16 levels of commandable gain are provided. Economics did not permit individual calibration of all detector elements, so an alternative approach of accurate calibration of element 24 (near center) and frequent relative response measurements of the other detectors relative to this element was taken. The calibration was accomplished through use of the 75-cm integrating sphere used for the DMSP primary sensor after a special near IR calibration in our standards lab. The calibration point selected was full scale output (5.0 volts, level 63 digital) for a radiance input corresponding to a subsolar cloud of $\rho = 0.3$. The gain level at this point is step 3, or 7.3 dB above minimum gain, allowing for lowering if scenes are brighter than predicted. A total of 28.8 dB gain increase in 2.4 dB steps will permit maintenance of full scale output from clouds down to about 2° solar elevation. The gain state is a part of the data stream for each line.

Again, economics on several scales did not permit fine scale compensation of detector differences and illumination variation due to optical effects. Some effort was expended in this direction, however, with the relative response results shown in figure 4. As noted above, element 24 was chosen for calibration and has unity relative response. With the exception of a "weak sister", the responses are reasonably uniform and should be adequate for our purpose.

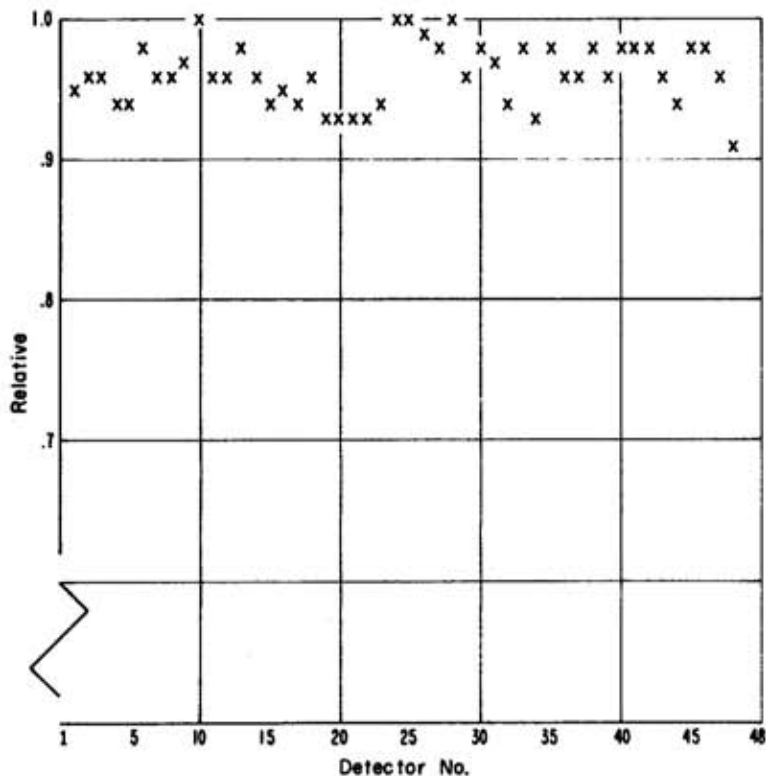


Figure 4. Detector array response.

Two red LED's (light emitting diodes) are incorporated into the optical system for functional checking during ground testing. Although they obviously do not fill the field for all detectors, the expected pattern of response, given no other illumination, is known and has been seen many times during spacecraft testing. Provision has been made for commanding these LED's on during spacecraft darkness to give some indication of sensor health.

On Orbit Evaluation

It is planned that primary data reduction and evaluation will be accomplished at AFGWC, using sensor output and corresponding scene information from the primary sensor visible spectrum (0.4 to 1.1 μm) channel. Detailed planning and areas of coverage will, of course, depend on the precise orbit selected and time of year of the launch. In general, primary objectives will be as noted at the beginning -- verification of adequate contrast for automatic discrimination and algorithm data base accumulation. As a part of this evaluation, some data may be taken at higher than normal gain levels (saturated clouds, enhanced snow data differences). Operational use of this instrument and future applications of the data generated from it will, of course, depend upon the results it produces.

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The United States Environmental Satellite Data Archives

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Introduction

The U.S. archives of environmental satellite data represent a unique source of information for various investigations within many scientific disciplines. While primarily intended for meteorological purposes, many of the sensors orbited on the more recent spacecraft also provide data of great value to hydrology and the marine sciences. The data held within the archives consist of imagery in both photographic and digital form, and, while the archives in their present form were initiated only in late 1974, photographic images from the earliest meteorological satellites of the 1960's through the latest geostationary spacecraft are included in the files.

Organization of Files

The files within the archives have been indexed and arranged to facilitate retrieval of data to answer requests. The arrangement has been based on experience gained in the past several years from the type and extent of requests serviced. Most requests have been concerned and primarily identified with a geographical area, a specific date or period, a certain sensor or spectrum, a specific phenomenon of interest, and a specified data resolution -- in that order. Thus, our data are first separated by individual satellites with their unique areal coverage, further broken down by date and sensor type, and finally, by resolution or scale. Specific data formats, such as magnetic tape and 35-mm, 70-mm, 25- by 25-cm film, are also maintained in individual files.

Uses

During the relatively short existence of the archives, we have seen substantial increases in the use of these data by oceanographers, marine biologists, hydrologists, and other investigators within the oceanographic community. Several operational snow and ice related products are derived from satellite observations, such as the Great Lakes and Alaskan ice charts, (U.S. Navy, U.S. National Weather Service), the mapped snow-covered river basin charts (see Schneider, this issue), and the Northern Hemispheric Snow and Ice Boundary Charts (U.S. National Environmental Satellite Service). This latter chart has been archived since October 1966.

The Scanning Radiometer (SR) daily infrared and visible data, held on digital tape since 1972 in polar-stereographic hemispheric mosaic format, have been steadily gaining in use for climatological purposes. The sea surface temperature digital data contain the daily sea surface observations from the SR from which weekly isoline charts for all ocean areas are prepared. These charts are used quite extensively to chart certain fish migrations, which seem to be temperature controlled.

The addition of the Very High Resolution Radiometer Infrared (VHRR IR) sensor to the operational polar orbiting NOAA satellites provided a much better look at the sea surface temperatures over much of the ocean areas. These excellent 0.8-km resolution data are being used effectively by the fisheries industry, sea transport companies, and the investigators of oceanic currents and other marine phenomena. Our establishment of a 90-day rotating file of digital tapes of these excellent data, both visible and IR, late in 1976, provided investigators a quantitative look at sea surface temperatures for selected areas at a high resolution. The twice daily periodicity of these IR data has greatly increased their usefulness to oceanographers.

Geostationary satellites were first orbited experimentally in 1966 (ATS-1); but, since only data in the visible spectrum were received, no great impact was felt by oceanographers. However, in 1974, SMS-1 was launched with an IR sensor onboard. With the experience gained using the data during GARP (Global Atmospheric Research Program) Atlantic Tropical Experiment (GATE), the marine community began seeking uses for these data with their 1/2-hour periodicity. Even with its low resolution (8 km), it found a

definite use in following the meanderings of the Gulf Stream and the temperature variations in the Gulf of Mexico. In August 1976, a digital archive of geostationary satellite data consisting of five IR and one visible full disc image per day from each of the two U.S. satellites (GOES-East/GOES-West) was started. Since then, use of these quantitative data have been rapidly expanding. By making mosaics of the five sequential IR images per day, investigators have decreased the problem of sea surface temperature analysis due to cloud cover.

Data from the Earth Resources Technology Satellite (Landsat) with their 80-km resolution have, since 1972, allowed a very close look at ocean areas. These data disclose the presence of gravity waves, pollution, oil spills, and plankton. Even with its poor periodicity (returns every 18 days) and small areal coverage, its very high resolution has made it an exceptional tool for oceanic as well as terrestrial research.

Future Data Holdings

Our archives will hold and serve as a distribution point for nonreal-time users of the data received from the NASA research satellite, Seasat, launched 26 June 1978, which carried aloft advanced sensors specifically designed for obtaining information in support of oceanographic applications. Data from Seasat should begin to become available in early 1979.

Data from the third generation polar system, TIROS-N, launched 13 October 1978, and the first follow-on spacecraft, NOAA-A, to be launched in 1979, will be available from the archives.

Data will be received and filed from the Coastal Zone Color Scanner (CZCS) of the Nimbus-7 satellite, launched 24 October 1978. Our archives will serve as a distribution point for these unique data.

Appendix I explains in greater detail the satellite data available through the Satellite Data Services Division (SDSD) of EDIS's National Climatic Center (NCC).

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U.S. Navy. Fleet Weather Facility. Southern Ice Limit-Eastern Arctic, Suitland, Md. (weekly).

U.S. Navy. Fleet Weather Facility. Southern Ice Limit-Western Arctic, Suitland, Md. (weekly).

*As of 0200 G.m.t. on 10 October 1978, all contact with Seasat was lost due to a massive power outage of yet undetermined origin. All attempts since then to reestablish contact with the satellite have been unsuccessful. Varying amounts of data from each sensor will be available from 7 July 1978 through 10 October 1978.

Appendix I

SURVEY OF NOAA SATELLITE DATA AVAILABILITY FROM THE ENVIRONMENTAL DATA AND INFORMATION SERVICE

The SDSD was established in October of 1974 to serve as the NOAA archive of oceanographic and meteorological satellite data, and to serve as a central point of contact for users to obtain both the data themselves and information relating to their use.

A description of the major types of satellite data available from SDSD and their pertinent applications will follow, with the services available in each case noted. Other major types of data to be available in the near future, TIROS-N, Seasat, and Nimbus-7 CZCS, will also be described.

I. POLAR-ORBITING (ITOS/NOAA) SATELLITES

Polar-orbiting satellites of the ITOS/NOAA series were launched into near 1,450-km sun-synchronous (quasi-polar) orbits with equator crossings near 9:00 a.m. (descending node) and 9:00 p.m. (ascending node) local sun time. The orbital period was 115 minutes with 12 1/2 orbital passes completed every 24 hours. Sensors on board included the Scanning Radiometer (SR), Very High Resolution Radiometer (VHRR), Vertical Temperature Profile Radiometer (VTPR), and the Solar Proton Monitor (SPM). NOAA-5, the last of the series, malfunctioned on 15 March 1978, leaving only the VHRR and the VTPR sensors active and providing data. These two sensors are still operative, but will soon be replaced by the sensors on the TIROS series spacecraft. Data relay to the ground is provided through VHF and S-band frequencies.

A. Scanning Radiometer (SR)

The SR sensor is a two-channel (0.5 to 1.0 μm visual (VIS) channel and 10.5 to 12.5 μm IR channel) imaging device that continuously scans in a horizon-to-horizon cross track mode with scan steps provided by the forward motion of the spacecraft. VIS data resolution is approximately 4 km, and IR data resolution is approximately 7 km at nadir. Image data from the SR are broadcast continuously and may be acquired with relatively simple VHF receiver and display equipment, then digitized, earth located, and calibrated with inexpensive systems. The primary utility of SR data would be in support of long term studies of large scale phenomena, where global coverage and calibration accuracy are more important than high spatial resolution. Similar type data will also be available from the TIROS series.

1. Orbital Swath Images. Orbital swath images are available in the form of 35-mm microfilm or photographic prints. Data coverage is essentially from November 1972 to 15 March 1978.

2. Mapped Mosaics. These are 25- by 25-cm negatives. They include Northern and Southern Hemispheric polar-stereographic projections and a tropical (40° N-40° S) Mercator projection of SR visible, SR daytime IR, and SR nighttime IR data for each day. On 15 September 1976, the format for the hemispheric mosaics changed from a 2048- to a 1024-grid structure. Simultaneously, both hemispheric mosaics were placed on one 25- by 25-cm negative. These data are available on 35-mm microfilm or photographic prints for data from November 1972 to March 1978. Polar-stereographic mosaics, Northern and Southern Hemispheres, are also available on computer compatible tape for data from May 1974 to present.

3. Sea Surface Temperature Products. Quantitative data from the SR infrared channel, together with information from VTPR, are used to compute sea surface temperature values for grid points at roughly 100-km intervals over the world oceans. Temperature values are computed daily for grid points where the sea surface is not obscured by clouds. Where clouds interfere, values from the most recent day without cloud interference are retained to complete the daily data field. A magnetic tape containing temperature values, the age of the computed value in days, and other related statistical parameters at each grid point is prepared each day. The data may be reproduced in a number of display products for specialized applications. Daily sea surface temperature data are archived and available on computer compatible magnetic tape (CCT) at NCC/SDSD.

a. CCTs containing global Sea Surface Temperature (SST) observations for each day and a summary of the orbital passes processed are available. The coverage of

these data is from December of 1972 to the present, with each tape containing one month's data.

b. Negatives (25 cm by 25 cm) which display the latest available sea surface temperature observations, and the "age" of the observation at each data point for both Northern and Southern Hemispheres are retained. Primary use of this product is internal to NESS for daily monitoring of SST processing. The coverage of these data is from November 1972 to the present.

c. SST 10-Day Analyzed Field Tapes. Once per day, all satellite SST observations are merged into a polar-stereographic field. In addition to SSTs, this "analyzed field" contains land-sea tags, climatology temperatures, SST gradient, data age information, and verification temperatures. Ten analyzed fields from 10 successive days are written to tape. With a few exceptions, this tape is available for every day since 10 May 1973.

d. GOSSTCOMP Isoline Charts. Contour displays of the analyzed fields are available in paper copies. Contours are labelled in °C with a one-degree contour interval. Sections of the globe are enlarged in Mercator projection (Arctic and Antarctic regions in polar-stereographic projection). These charts are available weekly beginning with April 1976 to the present (June 1976 missing).

B. Very High Resolution Radiometer (VHRR)

The VHRR sensor detects energy in the visible spectrum (0.6 to 0.7 μm) and infrared window region (10.5 to 12.5 μm) with a scanning system similar to the SR sensor described previously. Visible and infrared resolutions are approximately 0.8 km at nadir. Reception of VHRR data at three stations in the United States provides regular twice-daily coverage of North America and nearby oceans. Limited coverage from elsewhere (30° geocentric arc along an orbital track, once per orbit) is available through onboard recording for reception and processing by NESS, Washington, D.C. These data are designated "VRec" (recorded) swaths. "VRec" coverage of particular areas may be requested from NESS's Environmental Products Branch. The VHRR HRPT (High Resolution Picture Transmission) and "VRec" imagery is available for 1972 through the present. Coverage is variable according to the operational scheduling.

A 90-day rotating file of VHRR visible and IR data tapes began on 1 January 1977. The VHRR Digital Tape User's Guide, available from SDSD, describes in detail the contents and format of these tapes, the calibration of the IR in terms of temperature, and other information relating to the use of the data. Copies of the full tapes may be obtained, or copies of particular segments from several tapes may be combined onto output tapes.

These data are exceptionally useful for high resolution depiction of small scale oceanographic features, such as eddies and irregularities along oceanic fronts or coastal upwelling. Close-up views of snow coverage, local showers, frontal structure, etc. can also be obtained from these high resolution data. The eight-bit quantization of these data permits temperature calibration of the IR to a precision on the order of 1/2 °C for mapping of such features. The IR imagery may be enhanced to depict subtle gradations in temperature.

C. Historical Imagery

All TIROS imagery has been microfilmed in catalog format and is archived on 35-mm microfilm reels. Data dating back to 1960 are available.

Final TIROS meteorological radiation tapes from TIROS II, III, IV, VII (1024 tapes) are archived at Goddard Space Flight Center.

The ESSA series, which followed TIROS-X, was first launched on 3 February 1966. The imagery, with the exception of ESSA-9, has been microfilmed and is archived on 35-mm microfilm reels. ESSA-9 data have been placed on both 35-mm microfilm and 25-by 25-cm negatives. These images can be obtained, but are not as readily available as the earlier ESSA data.

II. GOES PRODUCTS

The GOES operational system presently consists of two spacecraft in equatorial, geosynchronous orbit. Each carries one imager, the Visible/Infrared Spin Scan Radiometer (VISSR), and a Space Environmental Monitor (SEM) system to provide data on environmental conditions in space.

A. VISSR

The VISSR sensor scans the full disc in 18.2 minutes, viewing the visible spectrum (0.55 to 0.75 μm). In the infrared, the spacecraft scans one line on each spin creating a full disc picture containing 1,821 lines with a resolution of approximately 8 km at nadir. In the visible, eight parallel lines are scanned with each spin, creating a full disc picture containing over 14,000 lines with a resolution of approximately 1 km at nadir. Visible channel scan lines may be combined in groups of two, four, or eight to provide 2-, 4-, or 8-km resolution, respectively. Full disc photographic displays are prepared on the hour and the half-hour from GOES-East, and at 15 minutes and 45 minutes after the hour from GOES-West. Partial disc pictures at more frequent intervals may be scheduled to meet special requirements. GOES-East data are available from June 1974 to the present, and GOES-West data are available from March 1975 to the present.

GOES data offer the unique capability of tracking the movement and development of oceanic features, such as large eddies or irregularities along the Gulf Stream. The excellent periodicity of the data, enabling investigators to view short-term changes in local storms, makes these data some of the most useful held in our archives. The data are otherwise limited in terms of spatial resolution of the IR data (8 km), and the accuracy with which it can be calibrated.

1. Infrared Images. 8-km resolution, full disc, 25- by 25-cm negatives. Quantity: 45 per day per satellite; 32,850 negatives per year.

2. Visible Images.

a. 4-km resolution, full disc, 25- by 25-cm negatives. Quantity: 32 negatives per day; 11,680 per year.

b. 2-km resolution, 25- by 25-cm negatives in a quarter disc, variable location. Quantity: Up to 32 negatives per day; 11,700 per year.

c. 1-km and 2-km resolution from Satellite Field Services Stations' sectors, 25- by 25-cm negatives in a format of sectors of variable size, resolution, and location. Quantity: potential for 280 negatives per day; 102,200 per year.

3. Digital Image Tapes. Since 9 August 1976, one visible and five IR images from GOES-East, and one visible and five IR images from GOES-West have been placed on CCTs in digital format, 9-track, 1600-bpi. Resolution of both the IR and visible images is approximately 8 km at nadir. One tape per day for each satellite has been archived. Only 89° of latitude starting at 50°N and 99° longitude centered at the satellite sub-points are included in each image. In September 1978, this archive was increased to also include data every 3 hours from both spacecraft. A total of 6 tapes per day are now involved.

Copies of these tapes are available from SDSO. Also, the user may request "sectors" defined by user-specified latitude/ longitude boundaries. Refer to the VISSR Archive Tape Users' Guide available from SDSO, which includes information on the content and format of the data tapes and calibration of the data.

4. Digital Wind Vector Tapes. Wind vectors are derived by computer for over ocean areas at 2 1/2° latitude-longitude intervals, using low-level cloud tracers in two pictures, one to two hours apart. The tapes contain earth-located wind vectors over ocean areas with estimated temperature and pressure level of cloud tracers. Quantity: about 750 vectors daily per satellite; one tape per month, from October 1974 to the present.

5. TV Movies. TV movies consist of about 21 hours of IR imagery from East and West satellites, including zooms on both the East and West portions of the United States with weather map overlays. This product is archived in both negative and positive form on 16-mm film. TV movies are available for most days for the last couple of years.

III. LANDSAT PROGRAM PRODUCTS

(Requests for these data are referred to the
EROS Data Center, Sioux Falls, South Dakota, as of October 1978.)

Landsat data from the NASA earth resources satellites, Landsat-1 and -2, are archived by the U.S. Department of Commerce (DOC) at EDIS. The satellites carry two sensor systems: a four-channel Multi-Spectral Scanner (MSS) and a Return Beam Vidicon (RBV) system incorporating three cameras. Both sensors view the earth in swaths only

200 km wide so that a particular locality on earth may be viewed at intervals of 18 days, or certain areas every nine days. Landsat-1 imagery is available from July 1972 to the present, and Landsat-2 imagery, from January 1975 to the present.

The Multi-Spectral Scanner (MSS) is a line-scanning device which uses an oscillating mirror to continuously scan perpendicular to the spacecraft direction. At each mirror sweep, six adjacent lines are scanned simultaneously in each of four spectral bands; two in the visible (green, 0.5 to 0.6 μm and red, 0.6 to 0.7 μm) and two in the near IR (0.7 to 0.8 μm and 0.8 to 1.1 μm). Resolution of approximately 80 m is obtained in all four channels. Image swaths are obtained routinely on all passes over North America and adjacent coastal waters. Coverage of selected areas elsewhere is obtained as required for research studies and other projects. The data are archived in the form of 70-mm negative film covering 200 km by 200 km on the earth on continuous strip. Quantity varies from 10 to 50 image frames per orbit from each channel. Various types and sizes of photographic products may be obtained from this archive.

Other satellites in this series include Landsat-3, launched 5 March 1978, and Landsat-D, to be launched at a later date. Landsat-3 carries an MSS with four bands identical to Landsat-1, and a fifth band in the thermal IR region (10.4 μm to 12.6 μm). This IR band malfunctioned immediately after launch, and no useful data were obtained. The first four bands have similar 80-m ground resolution, whereas the fifth band was to have had a 240-m resolution. The RBV onboard Landsat-3 consists of two identical side-by-side panchromatic cameras, each viewing an area 98 km by 98 km with approximately 30-m resolution.

Landsat-D will carry two instruments onboard. The MSS will be similar to that onboard Landsat-3 (5 bands); the second instrument will be a thematic mapper consisting of five bands with 30-m resolution (0.45 μm to 0.52 μm , 0.52 μm to 0.60 μm , 0.63 μm to 0.69 μm , 0.76 μm to 0.90 μm , and 1.55 μm to 1.75 μm), and a sixth band with 120-m resolution (10.4 μm to 12.5 μm). Both sensors will image a scene measuring 185 km by 185 km.

IV. DMSP DATA

The Defense Meteorological Satellite Program (DMSP) is a military meteorological satellite system which produces very high resolution visible and IR imagery of potential interest to oceanographers. Although not generally available in digital form, and of limited quantitized precision compared to NOAA VHRR and this year's AVHRR data, DMSP data have been successfully used to depict small-scale sea surface temperature features, and may be available for parts of the world for which higher resolution VHRR and AVHRR data are not.

SDSD, through a contract with the Space Science and Engineering Center (SSEC) at the University of Wisconsin, maintains an archive from which copies of DMSP imagery may be obtained. Coverage is fairly complete dating back to 1973.*

V. SKYLAB PRODUCTS

The Skylab Program established a manned workshop in near-earth (433 km) orbit from May 1973 to January 1974. The data from several of the Skylab sensors are archived by SDSD in imagery form. Requests for Skylab data are no longer serviced by the SDSD. These data are now available through the EROS Data Center, Sioux Falls, South Dakota.

A. Multi-Spectral Photographic Camera (S190A)

The MPC is a multichannel camera used to take pictures of selected areas at 50-m resolution in support of earth resources applications.

B. Earth Terrain Camera (S190B)

The ETC provides high resolution (25 m) imagery in the .4 to .8 μm range. Each image covers approximately 110 by 110 km.

C. Multi-Spectral Scanner (S192)

The MSS is a 13-channel system, collecting data in the .4 to 12.5 μm range, covering a continuous swath 68 km in width.

VI. TIROS-N PRODUCTS

TIROS-N is the prototype satellite for the next generation of operational polar orbiters, and was successfully launched on 13 October 1978.

Of primary interest for scientific applications is the Advanced Very High Resolution Radiometer System (AVHRR), which is on board TIROS-N. This sensor system, while specifically designed for the quantitative measurement of sea surface temperature, will prove as well to be of extensive value to other scientific disciplines. The AVHRR data will be digitized onboard the satellite to 10-bit precision, offering a substantial gain in precision over the previous SR and VHRR data (8-bit precision) and the planned DMSP sea surface temperature sensor (Block 5D-2, also 8-bit precision). The spatial resolution of the AVHRR data will be 4 km for global coverage and 1 km for limited area coverage, as with the current VHRR. The AVHRR is also a multichannel sensor. The first unit (aboard TIROS-N) will have four channels as listed in table 1; succeeding AVHRRs are scheduled to have five.

Table 1. TIROS-N AVHRR channels.

<u>TIROS-N AVHRR Channel</u>	<u>Wavelength</u>	<u>Description</u>
1	.55 μ m - .7 μ m	visible
2	.725 μ m - 1.1 μ m	visible/Near IR
3	10.5 μ m - 11.5 μ m	IR(same as SR, VHRR)
4	3.55 μ m - 3.93 μ m	IR

The global AVHRR data will be processed by NESS into quantitative products of global sea surface temperature. The first level product will be a 50-km resolution grid of sea surface temperatures, which will then be further processed to produce gridded sea surface temperature analyses at the regional, global, and climatic scales. The goals for accuracy of the temperature values are 1.5°C absolute and .5°C relative, with the hope that the absolute accuracy can be refined to about 1°C in time.

In addition, the highest resolution data (1 km) will be used to produce a high resolution analysis on a 4-km grid base over U.S. coastal waters and the Great Lakes. SDSO will archive all of the TIROS-N 1-km and 4-km resolution data, received by NESS, in both digital and image form. SDSO will also archive the various products produced by NESS. Users will be able to request digital data for areas of interest at the fullest resolution available.

VII. SEASAT PRODUCTS

Seasat, launched 26 June 1978, was the first NASA research satellite dedicated to ocean science and applications. Seasat circled the earth at 800 km altitude, in a near polar (inclination 108°), non-sun-synchronous orbit 14-1/3 times daily, and its five sensors covered 95% of the global ocean area every 36 hours. Its sensors sent back information on surface winds and temperatures, currents, wave heights, ice conditions, ocean topography, and coastal stream activity. These sensors, all microwave except the Visible and Infrared Radiometer (VIR), furnished all-weather, day/night coverage of the world's oceans for the period 26 June through 10 October 1978. Table 2 lists the Seasat sensors and parameters.

In September 1978, WDC-A: Glaciology (Snow and Ice) received part of the DMSP archive from SSEC. The WDC-A data set includes both visual and IR, and consists of swath data from 1973-75, and mosaic, from 1975 onward. Resolution is 5.5 km. The data are being sorted and are available on a loan basis.

Table 2. Seasat sensors.

<u>Sensor</u>	<u>Freq/Wavelength</u>		<u>Resolution</u>	<u>Parameters</u>
Altimeter	13.5	GHz	1.6 km - 11 km	topography and wave height
Microwave Scatter-meter (SASS)	14.6	GHz	50 km	wind speed and direction
Synthetic Aperture Radar (SAR)	1.175	GHz	25 m	wavelength spectra, high resolution images
Microwave Radio-meter (SMMR)	6.6, 10.69, 18, 21, and 37	GHz	16 km - 144 km	SST, wind speed, atmosphere corrections
VIS & IR Radio-meter (VIR)	.52 mm - .73 mm 10.5 mm - 12.5 mm		9 km	clear weather SST and feature ID

SDSD will serve as the distribution point for nonreal-time Seasat data to all users. Data products will include imagery from the SAR and VIR, and digital products from the ALT, SASS, SMMR, and limited digital data from the SAR and VIR. Digital data will be in the form of earth-located, geophysical units (i.e., latitude/longitude, time, wind speed, etc.). It is expected that distribution will be at SDSD's normal prices for tapes and imagery.

VIII. NIMBUS-7 COASTAL ZONE COLOR SCANNER

Nimbus-G, now Nimbus-7, was launched 24 October 1978 and is the last in a series of NASA research satellites. The Nimbus-7 Coastal Zone Color Scanner data will be archived and distributed by SDSD.

This sensor is designed for quantitative measurement of ocean color, using four high spectral resolution (20 nm) channels centered on .443 μm , .520 μm , .550 μm , and .670 μm . Two additional channels will provide sea surface temperature capability (11.5 μm) and land-sea discrimination, sea surface anomaly detection (.750 μm). The spatial resolution will be on the order of 825 m, and the width of the data swath will be at least 1500 km. It is planned that 16 minutes of data will be recorded per orbit, or 200 minutes per day.

The CZCS data offer the possibility of mapping the distribution of ocean chlorophyll and inferring the total chlorophyll content in a vertical water column.

CONCLUSION: SUMMARY OF SERVICES AVAILABLE FROM SDSD

For all of the data listed above that are archived in the form of photographic imagery, SDSD offers a complete array of photographic services, including enlargement of selected areas, special processing to enhance certain features, production of mosaics, and assembly of film loops or movies from GOES data. The price of a typical photographic product is \$3.25 for a 25- by 25-cm (10- by 10-in) contact print of GOES, VHRR and SR. Simple special processing is done at no additional charge; the cost of more complex special processing is negotiated. Delivery of photographic products is normally 10 days from receipt of order.

For data available on CCTs, SDSD provides straight tape-to-tape copying, as well as selective copying, which involves the extraction and copying of a specific subset(s) of data from one or more input tapes. Additionally, grid prints of selected areas may be obtained, either in "psuedo-image" form where certain printed characters represent specific gray shades, or in a numerical form, by raw data value or, for IR data, temperature. SDSD supplies complete documentation with all digital data, either written by SDSD or provided by the originators of the data. CCTs are also normally delivered in 10 days from receipt of order.

In the case of both digital data and imagery, SDSD will serve as a point of contact for any request for information or guidance relating to the availability or use of the data. Inquiries should be sent to:

Satellite Data Services Division
World Weather Building, Room 606
Washington, D.C. 20233 U.S.A.

Satellite-Derived River Basin Snow-cover Percentages: A New Data Base For Hydrologists*

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Introduction

Hydrologists at NOAA's National Environmental Satellite Service (NESS) have been producing satellite-derived areal snow cover maps for selected river basins since 1973. Four basins were originally targeted for study, involving a variety of topographic, spatial, and climatological conditions (Wiesnet and McGinnis, 1973). Heightened user interest, combined with an increase in manpower and equipment resources, has allowed NESS to expand the snow mapping program. During the 1977-1978 snow season, operational coverage was provided for 30 basins in the United States and Canada.

Satellite Sensors and Imagery

The images presently used for snow mapping at NESS are obtained from the NOAA series of polar-orbiting satellites and the SMS/GOES geostationary satellites. The polar orbiter currently operational is NOAA-5, the latest in a series of improved TIROS satellites. The first, NOAA-2, was launched on 15 October 1972. The imaging system relevant to snow mapping onboard NOAA-5 is the Very High Resolution Radiometer (VHRR). It provides daily coverage over most of North America in the visible portion of the spectrum (0.6-0.7 μ m), and twice daily coverage in the thermal infrared (10.5-12.5 μ m). Spatial resolution for both the visible and infrared data is 1 km at nadir. NOAA-5 is scheduled to be replaced in summer 1979 by TIROS-N, the first in a new generation of NOAA polar orbiting satellites.

Five satellites in the SMS/GOES series have been launched thus far. The first two Synchronous Meteorological Satellites, SMS-1 and SMS-2, were NASA sponsored prototypes. The most recent ones, GOES-1, GOES-2, and GOES-3 (Geostationary Operational Environmental Satellite), were entirely NOAA funded. The satellites are termed "geostationary" because their position relative to the Earth's surface remains constant; they are stationed directly over the equator at an altitude of 37,500 km. The two geostationary satellites currently operational, GOES-2 and GOES-3, are fixed respectively at longitude 75°W and 135°W. The imaging sensor onboard the SMS/GOES is the Visible and Infrared Spin Scan Radiometer (VISSR). The sensor can provide imagery at a variety of resolutions every half hour in both the visible and thermal infrared portions of the spectrum. Maximum resolution for the visible data is 1 km at subpoint; the thermal infrared data are available only at 8 km resolution.

Methodology

Snow maps are produced by first enlarging and rectifying a visible VHRR or VISSR image to overlay a hydrologic basin map. A Bausch and Lomb Zoom Transfer Scope (ZTS) is utilized for this purpose. Registration of image to map on the ZTS involves aligning physiographic landmarks such as lakes, rivers and shorelines. After registration has been achieved, the snow line on the image is traced onto the basin map, and snow-covered areas are colored in. Percentage snow cover for the basin is then determined by using an electronic density slicer. The snow map is placed on the density slicer with a previously prepared opaque mask outlining the basin. The density slicer selectively color illuminates gray shades on the map. The colors are projected onto a display screen, and percentage values for each color are read from a digital meter.

Automated methods of snow mapping are currently being studied at NESS. One such method, involving use of a computer interactive system, is described by Gird (1977).

*Paper presented by F. Kniskern.

Program Description

The areal snow cover data and/or snow maps are provided to water resource managers in numerous federal, state and local agencies. A map of the Western United States showing many of the operational basins is presented in figure 1. A list of primary users and information on the precise location and size of each basin is given in the accompanying table 1. The basins are similarly numbered on the table and map.



Figure 1. River basins for NESS operational snow mapping.

The areal snow cover percentages are dispatched over the RAWARC teletype circuit to National Weather Service River Forecast Centers (RFC) in Sacramento, Fort Worth, Salt Lake City, Kansas City and Portland. Snow maps are sent over telecopier or through the mail to other agencies, including the U.S. Geological Survey, Bureau of Reclamation, Corps of Engineers, Soil Conservation Service and Forest Service.

Not depicted in figure 1, but listed in the table, are the St. John basin in Maine and New Brunswick, and the Northeast U.S. snow map. The Northeast analysis is first transmitted over telecopier to the Weather Service Eastern Regional Hydrologist in New York, and is then rerouted to RFCs in Hartford, Harrisburg and Cincinnati.

Basin snow maps are made on an average of once a week beginning November 1st, and terminating when the snowpack appears almost totally depleted on the imagery. The analyses can only be made when the basin is free of obscuring clouds. Accordingly, basins in the Southwestern United States and California's Sierra Nevada are mapped more often than those in the less cloud-free Pacific Northwest.

Table 1. Basins being mapped as of 1978.

River Basin	Drainage Area in km ²	Primary Users
American above Fair Oaks (15)	5,601	Sacramento RFC
Boise above Lucky Peak (11)	6,941	Portland RFC, Columbia Basin Network
Carson (18)	8,864	Soil Conservation Service, Sacramento RFC
Clearwater above Peck (7)	20,824	Portland RFC, Columbia Basin Network
Columbia River above Mica Dam (1)	21,290	Portland RFC, Columbia Basin Network, B.C. Hydro & Power Authority, Environment Canada
Deschutes (4)	27,195	Calif. State Dept. of Water Resources
Feather above Oroville (14)	9,386	Calif. State Dept. of Water Resources
Humboldt above Comus (20)	31,339	Salt Lake City RFC, Soil Conservation Service
John Day (5)	19,632	Portland RFC, Columbia Basin Network
Kootenay above Libby (2)	23,277	Portland RFC, Columbia Basin Network
North Platte between Alcova and Guernsey (22)	12,198	Bureau of Reclamation, Kansas City RFC
North Platte above Seminoe (23)	15,274	Bureau of Reclamation, Kansas City RFC
Northeast U.S. Snow Map		NE Regional Hydrologist NWS
Payette above Emmett (10)	6,941	Portland RFC, Columbia Basin Network
Rio Grande above Colo.-N. Mexico State Line (26)	19,900	Soil Conservation Service, Fort Worth RFC
Rio Grande above Del Norte (25)	3,419	Soil Conservation Service, Fort Worth RFC
Sacramento above Shasta (13)	16,630	Calif. State Dept. of Water Resources
Salmon above Whitebird (8)	35,095	Portland RFC, Columbia Basin Network
Salt (28)	16,141	Salt Lake City RFC, Phoenix RDO, Salt River Project, U.S. Geological Survey
San Juan (24)	65,273	Salt Lake City RFC
Snake above Palisades (12)	13,340	Portland RFC, Columbia Basin Network
St. John	55,167	Maine Bureau of Civil Emergency Preparedness, New Brunswick Dept. of Environment, Environment Canada, St. John Basin Task Force
Sweetwater above Pathfinder (21)	6,027	Bureau of Reclamation, Kansas City RFC

Tahoe-Truckee (16, 17)	7,665	Soil Conservation Service, Sacramento RFC
Umatilla (6)	5,931	Portland RFC, Columbia Basin Network
Verde (27)	17,094	Salt Lake City RFC, Phoenix RDO, Salt River Project, U.S. Geological Survey
Walker (19)	9,241	Soil Conservation Service, Sacramento RFC
Weiser (9)	3,781	Portland RFC, Columbia Basin Network
Willamette (3)	26,159	Portland RFC, Columbia Basin Network

Notes on Users:

1. The Columbia Basin Network includes the Soil Conservation Service, Bureau of Reclamation, U.S. Geological Survey, U.S. Army Corps of Engineers, National Weather Service, Bonneville Power Administration, B.C. Hydro and Power Authority, as well as other state and local agencies.
2. Basins being done for the Bureau of Reclamation in Denver, Colorado, are retransmitted from the site to field offices in Caspar, Laramie, and Cheyenne, Wyoming.
3. The St. John Basin Task Force includes the National Weather Service, U.S. Army Corps of Engineers, U.S. Geological Survey, Environment Canada, and other State, provincial agencies.

The snow cover data are generally provided to users within 30 hours of a satellite overpass, so they can be incorporated into watershed runoff forecast models. Quality control techniques used are described in Schneider et al. (1976). They include checks of the operational snow maps with higher resolution Landsat satellite data, computer-enhanced imagery, ground-based snowpack measurements, and aerial survey maps. The data from aerial surveys are particularly useful for quality control purposes, and are provided for basins in Arizona, Idaho, and British Columbia, respectively, by the Salt River Project, Walla Walla District Corps of Engineers, and the British Columbia Hydro and Power Authority.

Availability of Data

Snow maps listed in table 1 are available on either an operational or retrospective basis. Detailed information can be obtained from:

Stanley R. Schneider
Environmental Products Branch
NESS, World Weather Building, Room 510
Washington, D.C. 20233 U.S.A.

Acknowledgements

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Landsat-Derived Snow Cover as a Forecast Tool in the Rio Grande Basin in Colorado

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Introduction

Information on the areal extent of snowpack coverage has long been a desire of snow hydrologists for both seasonal volume prediction and flood forecasting. Until recently, this desire has been largely unfulfilled due to the expense and time required for acquiring and processing aerial photo coverage. Since the early 1970's, satellites have made available relatively high resolution imagery on a repetitive basis from which snow-covered area can be determined.

Leaf (1971) and Rango, et al. (1975) demonstrated applications of snow cover estimates in forecasting seasonal snowmelt runoff. However, use of satellite-derived snow cover was not widespread in any major ongoing forecast program. In 1974, the National Aeronautics and Space Administration (NASA) undertook the task of demonstrating the feasibility of using remotely sensed snow cover from satellites in operational streamflow forecasting programs.

As a part of their Applications Systems Verification and Transfer (ASVT) program, NASA funded four demonstration projects in the Western United States to study the ways in which Landsat-derived snow maps could be constructed and incorporated into existing schemes for forecasting snowmelt runoff. Further, evaluations were to be conducted in each study site to ascertain the potential improvement in forecast accuracy which could be ascribed to use of snow cover data. The four demonstration study centers chosen were Arizona, California, Colorado, and the Northwestern United States. This study effort within the ASVT program was designated the Operational Application of Satellite Snowcover Observations (OASSO).

In Colorado, three agencies were involved in carrying out the intent of the ASVT program. The U.S. Department of Agriculture (USDA) Soil Conservation Service was given lead responsibility, with assistance provided by the U.S. Bureau of Reclamation and the State of Colorado, Division of Water Resources (State Engineer).

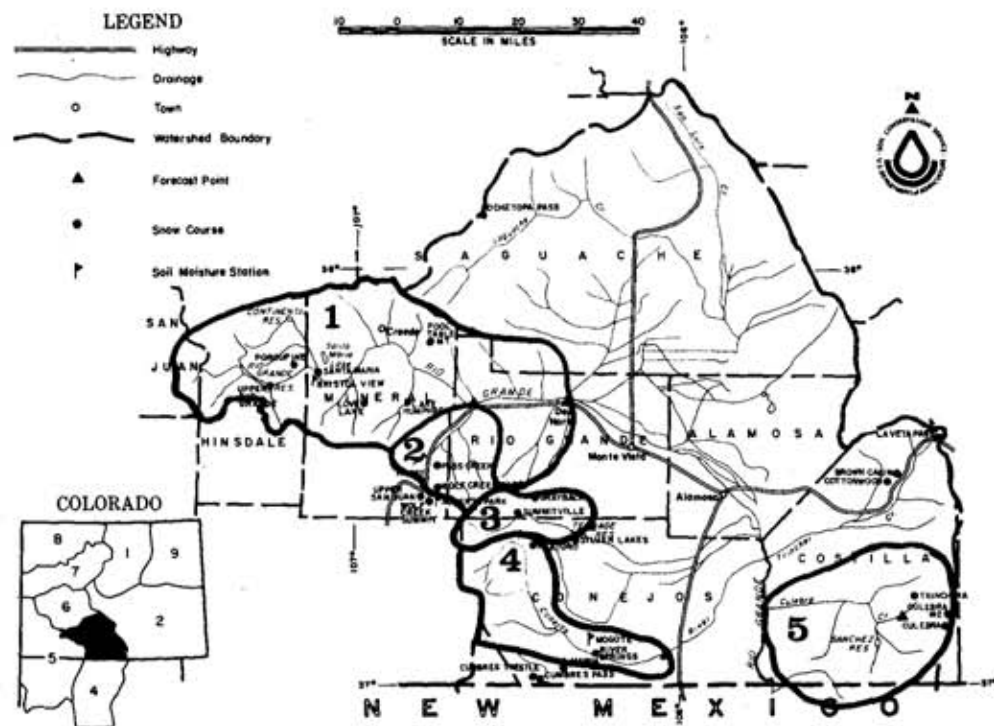
The study approach in Colorado involved a four-step analysis: 1) To identify specific drainage basins and acquire the Landsat imagery to cover them; 2) To examine various techniques of mapping the snow cover and determine which method is most useful in an operational mode; 3) To develop a methodology for including snow-covered area in a forecast of snowmelt runoff; and, 4) To evaluate the adequacy of the forecasting techniques which employed snow cover.

Study Area

The Rio Grande River Basin in Colorado was chosen as the primary drainage for the study. Within this basin, several watersheds were selected for detailed analysis. These included the Conejos River, Alamosa Creek, Culebra Creek, South Fork of the Rio Grande, and the Upper Rio Grande (figure 1). Each of these streams enter the San Luis Valley from high mountains and form the main stem of the Rio Grande.

The San Luis Valley is a virtual desert which could produce little in terms of agriculture were it not for the snowfed streams entering it. Mean annual precipitation on the valley floor, which averages 2460 m (7500 ft) in elevation, is only 17.8 cm (7 in), while the headwaters at elevations up to 4590 m (14,000 ft) average 114 cm (45 in) annually. Figure 2 depicts an average hydrograph for the Rio Grande near Del Norte. This hydrograph illustrates the seasonal nature of flow and its dependence on snowmelt. Over 80 percent of the annual flow is attributable to the snowpack contribution which runs off in the period April through September.

Accurate forecasts of streamflow are essential on the Rio Grande and its tributaries for several reasons. Agricultural interests within the San Luis Valley require planning information on their prospective water supply to manage their operations effectively. Also, waters of the Rio Grande are regulated and distributed



- 1 - RIO GRANDE AT DEL NORTE
 2 - SOUTH FORK AT SOUTH FORK
 3 - ALAMOSA ABOVE TERRACE RESERVOIR
 4 - CONEJOS AT MOGOTE
 5 - CULEBRA AT SAN LUIS

Figure 1. Upper Rio Grande watershed in Colorado. Individual basins for study

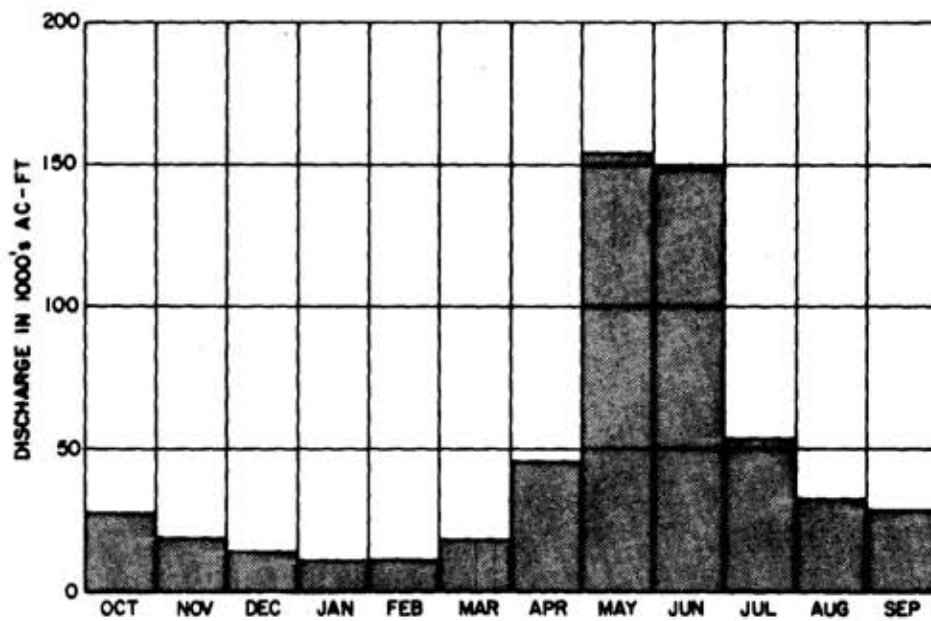


Figure 2. Rio Grande near Del Norte 1958-72 average monthly hydrograph.

according to an interstate compact between Colorado, New Mexico, and Texas. Administration of the compact agreement in an equitable and timely manner depends upon reliable estimates of streamflow both before and during the runoff season.

Although each of the watersheds in the Rio Grande Basin was studied to some degree, special emphasis was placed on the Conejos River because of its generally unrestricted flow, ease in mapping snow cover, and availability of precipitation and snow course data.

Determination of Snow-Covered Area

Through the period 1974-78, six various techniques of snow mapping were tried and compared on one or all of the watersheds in the study. Each of the techniques has advantages and disadvantages.

The zoom transfer scope was the primary snow mapping tool, and the standard against which the performance of other techniques was judged. This instrument allows the operator to view simultaneously a Landsat image and a base map of the drainage being mapped. A variable magnification feature allows the operator to compensate for differences in scale between the image and the base map. In Colorado, most of the mapping is done at a scale of 1:250,000. Snow-covered area is traced directly onto the base map and planimeted. Major advantages of the zoomscope are its relative simplicity of operation, short training time for use, and speed in which mapping can be done. A major disadvantage is the restricted field of view requiring several registrations and/or images for large drainages.

A density slicing technique was also tried. In this method, a positive Landsat transparency is laid on a light table with an opaque mask covering all but the drainage basin to be mapped. A camera records the various shades of gray, and breaks them down into 12 discrete levels which are displayed on a monitor in 12 false colors. Single or multiple colors which the operator thinks matches what is believed to be the snow-covered area are electronically planimeted and reported as a percent of the basin area. A major advantage of this system is the speed with which a basin can be mapped. Unfortunately, in basins having a dense forest cover, it is difficult to distinguish snow under trees. Errors also arise from highly reflective surfaces, such as boulder fields above timberline, which appear much like snow to the machine.

A color additive viewer, which uses four 70-mm transparencies coinciding with MSS (Multispectral Scanner Subsystem) bands 4, 5, 6, and 7, was used to map areal extent of snow. In this method, the four chips are registered with one another to produce either a false color infrared composite or a natural color composite at a scale of 1:500,000. An overlay base map is then used for manually mapping the snow-covered area. The snow extent is then either computed by hand planimeter or an electronic planimeter such as that found in the density slicer. A major advantage in this technique is its ease in setting up and producing a snow cover map. Since the 70-mm chips arrive as much as two to three weeks ahead of standard Landsat imagery, the timeliness of this technique is another significant advantage. The only major disadvantage of this system for our application was the relatively high cost (about \$15,000) of the instrument.

Several computer techniques were employed using computer compatible tapes (CCT) of Landsat scenes. The first of these computer techniques was completed at the EROS Data Center in Sioux Falls, South Dakota, on the Image 100 interactive system. A second run was made of the same scene at Colorado State University using the CDC 6400 computer to produce gray-scale maps of the snow-covered area. In both of these cases, the snow-covered area determination agreed within several percent of each other, as well as with a zoomscope map of the same scene. However, the cost in terms of money and time to obtain the tapes, process them, and interpret the output was prohibitive for our operational program.

A grid sampling method was attempted on several basins. In this technique, a grid was superimposed onto an image and the degree of snow cover in each cell was assigned a value of 1, .75, .504 or .25 according to the subjective judgement of the interpreter. The cells were totaled to provide an estimate of snow cover. This method did not prove satisfactory due to the length of time necessary to process the image and the poor reproducibility between interpreters.

Snow cover maps of the Rio Grande prepared by Stanley Schneider of NOAA/NESS were utilized to obtain an estimate of snow cover on smaller watersheds included within his mapped area. An overlay of a small watershed was superimposed on Schneider's map and snow cover traced onto it. This map was then planimeted to produce a snow cover

estimate. As expected, tests revealed that the loss of detail inherent in this technique led to poor estimates of snow areal extent for basins with drainage areas of hundreds of square kilometers.

Problem Areas

Throughout the 5-year period from 1974 to 1978, difficulties in attaining the avowed goals of the program were encountered. For instance, delivery times for standard Landsat imagery averaged almost one full month. NASA Quick-Look imagery averaged about 10 days. With these types of delays, it was difficult to implement snow cover into operational forecasts.

A high incidence of cloud cover during some years resulted in the loss of potentially valuable snow cover estimates. In 1974 and 1975 only about 33 percent and 25 percent, respectively, of the images received were acceptable for use during the main snowmelt period because of excessive cloud cover.

Changes in personnel doing the snow mapping during the study period led to obvious difference in judgement as to what constituted snow cover. Because of this personal bias, some undefined degree of error creeps into the areal estimates of snow. Accuracy in mapping snow cover is certainly desirable albeit difficult to measure. More important than accuracy, however, is consistency. Without consistent interpretation from one observer to another, any technique is bound to yield questionable results.

Snow Cover in Forecasting

Once measurements of basin snow cover were tabulated, a means was sought to use them in a forecasting methodology which could be applied in an operational time frame. Three techniques were developed, each of which was unique.

The first method is an empirical one developed by George Moravec of the Colorado Division of Water Resources. His method involves plotting snow cover depletion curves versus time, for the available years of record. Figure 3, taken from the 1977 Annual Colorado OASSO Report (Washichek, 1978), shows these curves for the Conejos River. Each curve is similar in shape and roughly parallel to the others. The next step in his technique is to scale off the relative distances between the curves in their straight line segments, and plot the scaled values versus the annual yield of the stream. Figure 4, also taken from the 1977 Annual Report, shows this relationship for the Conejos and South Fork watersheds. To forecast using Moravec's technique simply requires knowledge of which snowpack depletion curve a basin is following in a given year. The success of this technique depends upon the relationship of snow areal extent to water stored in the snowpack on a given date once the main snowmelt period is well underway. Anomalous late season storms dropping significant moisture can, however, change the snow cover on the basin, making it difficult to select the proper depletion curve from which to forecast. Just such an event occurred in May of 1978. A late storm on 8 May covered the entire basin after the main melt period had begun. It then became difficult to assess the effect of the storm, since a new depletion curve had to be established.

A second forecasting technique relies upon a statistical relationship between snow cover on a date well into the melt season and seasonal volume flow. Figure 5 illustrates this relationship for the Conejos River. The 1 May snow cover values are derived from the snowpack depletion curves of figure 3. Admittedly, the relationship is computed from only six data points, but they represent a wide spectrum of snowpack conditions. They range from a minimum of record in 1977 to a near maximum in 1975. This technique again assumes that anomalous storms near the date of the forecast will not occur.

The third technique uses a computer simulation model to make both short-term and long-term predictions of seasonal and annual volume flows. In the Colorado study, the "Subalpine Water Balance Model" developed by the USDA, Forest Service (Leaf and Brink, 1973a, 1973b) was modified to accept snow cover as a means of predicting residual water equivalent of the snowpack on a drainage basin. Satellite-derived basin snow cover, coupled with point estimates of snowpack water equivalent from snow courses and snow pillows, acts as a control to set "target" residual water equivalents which the model attempts to simulate. During the accumulation limb of the snowpack hydrograph when snow cover is often 100 percent, snow course and snow pillow data are used to guide the model. In the recession phase of the hydrograph, areal snow cover is used to estimate residual water equivalent. Figure 6, taken from the 1977 Annual Colorado OASSO Report, is a schematic representation of the way snow cover estimates interact with the model. Using the model allows a flexibility for prediction purposes, but its

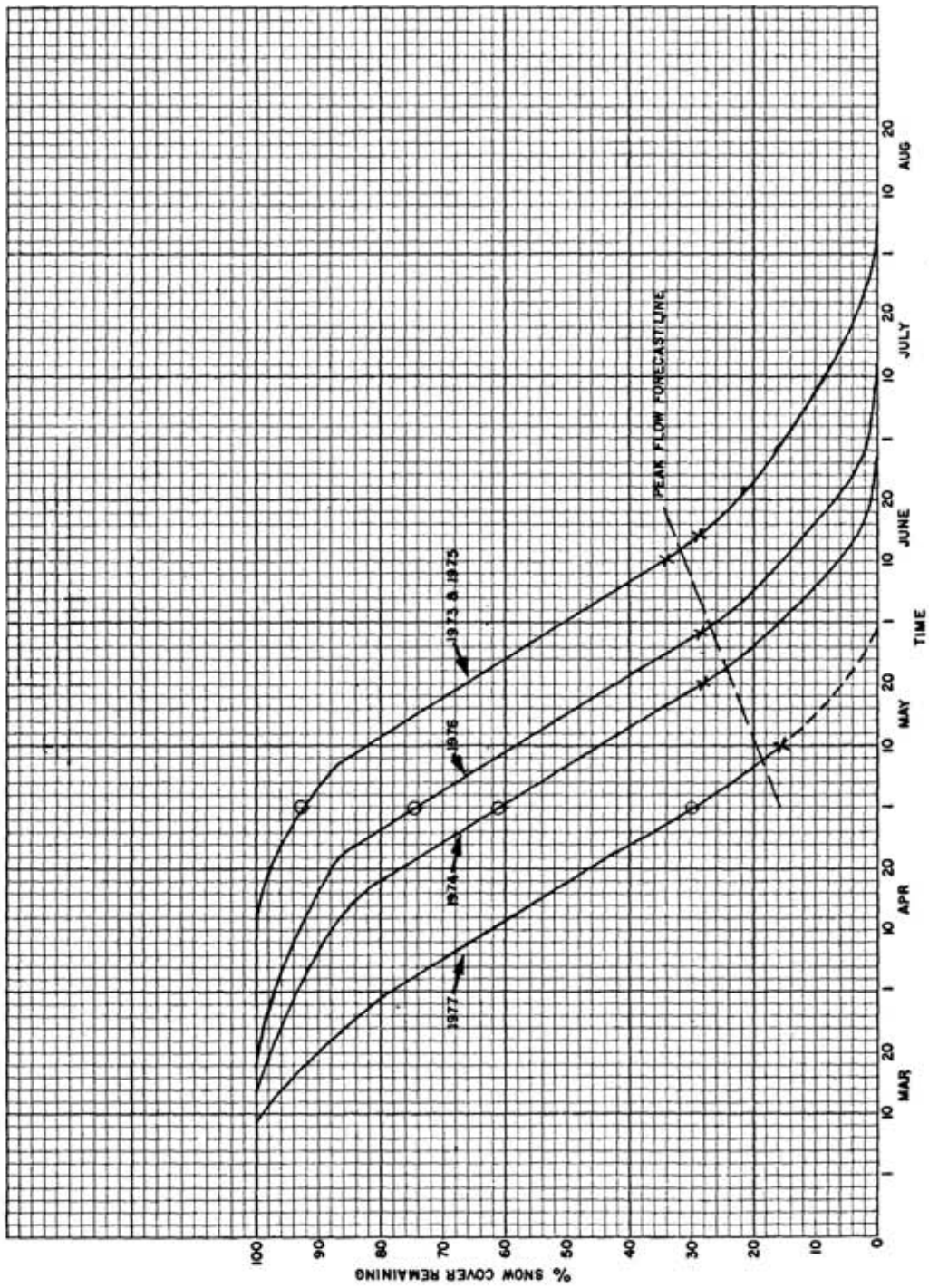


Figure 3. Moravec method.

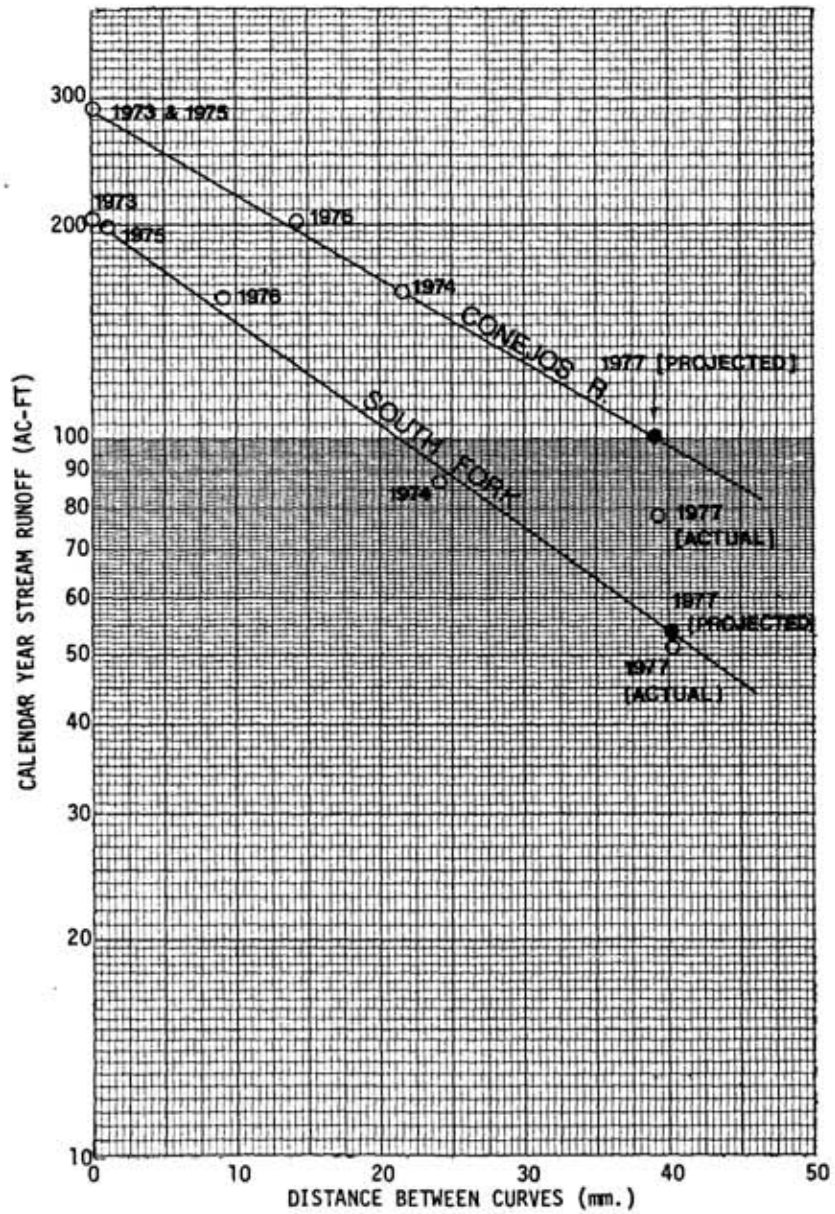


Figure 4. Comparison of annual snow cover regression curve spacing of the Conejos and South Fork drainage basins.

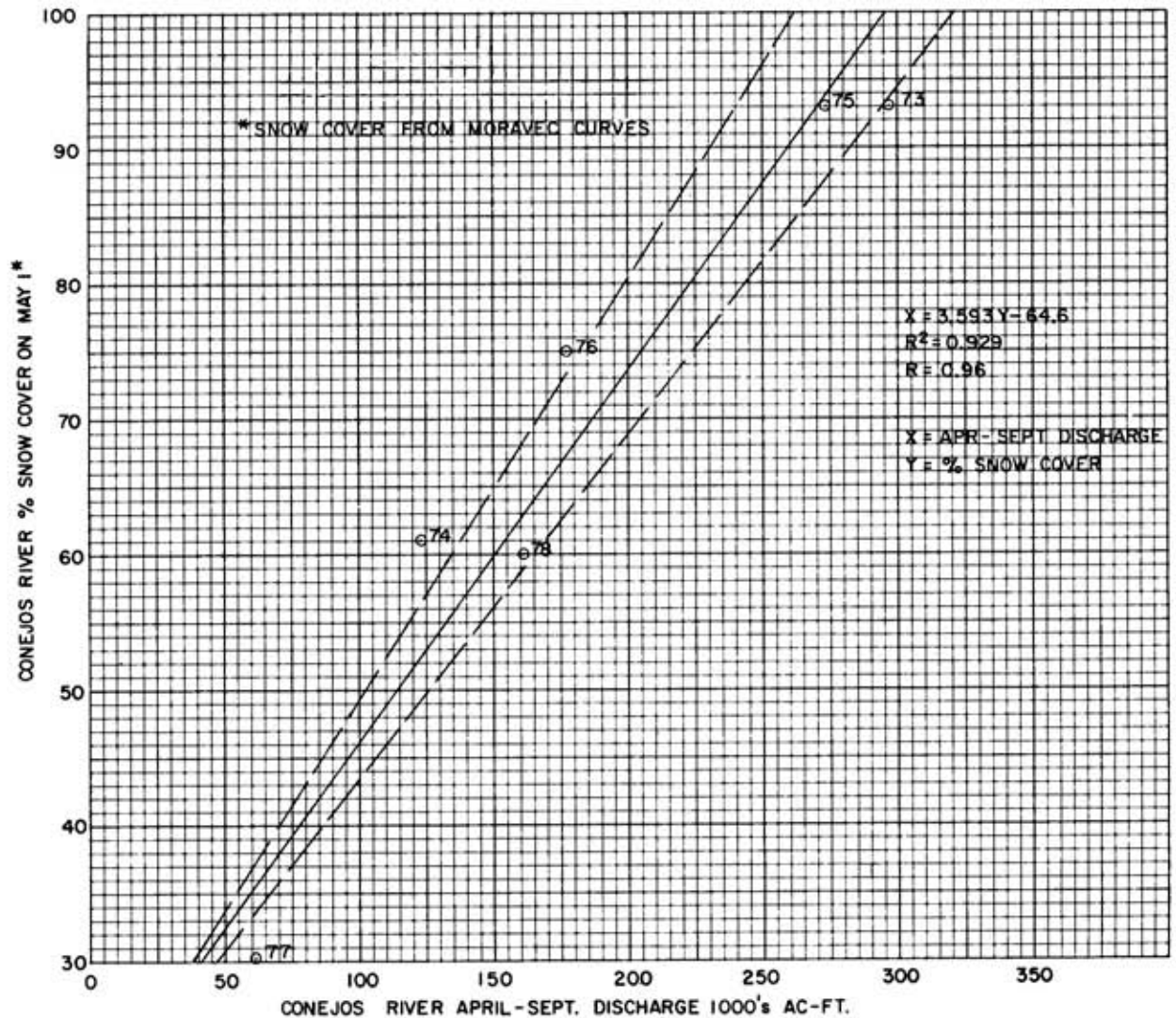


Figure 5. Conejos River forecast.

use poses a very real dilemma. The model is fairly sensitive to the climatic information entered as input. This information is not easily acquired in many instances and must be estimated.

Results and Discussion

Use of snow areal extent measurements in snowmelt runoff prediction in the Rio Grande shows promise, but with the short period which the study encompassed, it is difficult to assess its long-range impact. However, a number of conclusions can be drawn concerning the use of snow cover in forecasting in the Rio Grande Basin.

Currently available Landsat imagery is of sufficient quality and resolution for accurate snow mapping by photo interpretative means. Delay in image delivery, occurrence of cloud cover, and a 9-day interval between satellite coverage diminish to a significant extent the amount of reliance one can place in using snow cover as a forecast parameter.

Three methods of using snow cover area in forecasting have been explored and have proven successful. A statistical regression model relates snow cover to season volume flow directly. An empirical method relates seasonal snowpack depletion to seasonal and annual yields. A computerized simulation model provides short-term and seasonal forecasts using snow cover as an input variable.

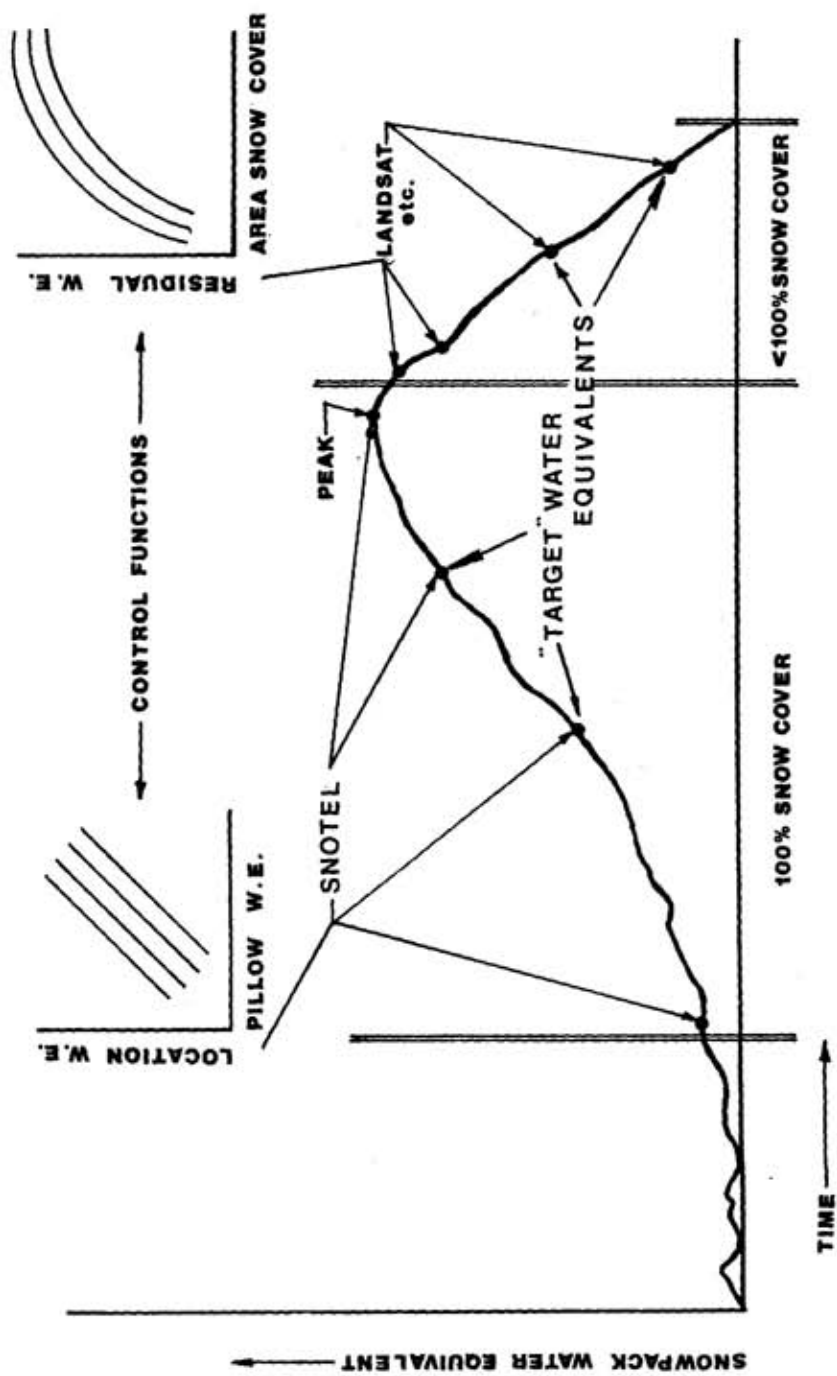


Figure 6. Colorado snow A.S.V.T. short-term forecasting system; subalpine water balance simulation model.

A significant drawback to using snow-covered area exclusively to make streamflow predictions is the lack of applicability prior to commencement of the main snowpack recession which normally occurs after 1 May. Water management decisions frequently need to be made in late March and April, necessitating streamflow forecasts before snowpack depletion gets well underway. For this reason, present forecast methods utilizing snow course and precipitation data will continue to be used. Use of snow cover area in empirical or statistical prediction techniques during late spring will be valuable as an independent method of checking the standard forecasts now being produced.

As we accumulate more years of satellite imagery covering a wider range of hydrologic and climatic conditions, we expect our forecasts to be improved through the use of snow mapping. Satellite snow mapping, together with improvements in remote hydrometeorological data collection systems, will enable us to make more frequent and accurate forecasts because of our increased knowledge of what is happening in the major water producing zone above valley floors.

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Archiving and Mapping of Canadian Snow Cover Data

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Introduction

In Canada snow remains on the ground anywhere from a few days to the entire year. Along the irregular seacoast of British Columbia and in that part of southwestern Ontario where the latitude is the same as northern California, snow cover lasts for only a few days during midwinter. By contrast, over the Western Cordillera and extensive parts of the Arctic tundra, continuous snow cover lasts for eight to ten months, or even longer over permanent ice fields.

The snow resource is documented for quantity, distribution, and timing by networks of meteorological observing stations and snow courses operated by public and private agencies. The data collected are forwarded by the many observers to central depots for synthesis, archiving, and publication. Most of these data are entered onto ledger forms by hand, but much greater automation of data capture and transmittal is foreseen for the 1980's. Archiving now makes widespread use of computer compatible methods, but some smaller agencies continue to rely on hand tabulation. This paper presents an overview of these procedures and practices, but concentrates on the activities of the Atmospheric Environment Service (AES) as a lead agency in the collecting, processing, publishing, and preserving of national snow cover information. The first two of these steps are incorporated here only to reference procedures described below.

It should be noted that when using point snow cover data, it is usual to archive and subsequently map the data, whereas with other parameters such as sea ice, mapping usually precedes archiving. With the use of remotely sensed data, especially from satellites, it is now possible to enhance basic network observations. In particular, the direct mapping of snow extent is now feasible, although currently of limited application in Canada.

Snow data are collected at differing times in a variety of ways. Remote recording snow gauges or snow pillows may telemeter data at regular intervals throughout the day or be interrogated as required by the base station. Meteorological stations routinely report snowfall up to four times a day, while remotely located snow courses may only be visited once or twice during winter. Detailed mapping may require combining data sources having a variety of formats which can ultimately lead to difficulties in interpretation and analysis. This has limited the number of products in the past, and, in Canada, the snow parameters have not yet been adequately standardized and archived to allow a satisfactory exploitation by the user community.

Data Collection and Initial Processing

The Canadian meteorological service (AES) measures snowfall at about 2500 observing stations across the country. Snow on the ground is also recorded daily at over 300 principal synoptic and airways stations, and at the end of the month, at the remaining climatological stations. As well, the AES operates about 150 snow courses (about 10 percent of the national total) in regionally representative terrain around the stations.

Provincial agencies also measure precipitation and operate snow courses. Most of the former data are archived by the AES when network standards are met. The AES also publishes summary snow course data supplied by 18 agencies from about 1500 snow courses.

Snowfall. The measurement of snowfall is standardized according to international agreement. The depth of freshly fallen snow is measured by a ruler at representative points to estimate a composite value. The water equivalent of the snow is determined at principal stations from MSC Nipher shielded snow gauge measurements, while at all other stations it is estimated using an assumed snow-water ratio of 10:1. Principal stations continuously report to regional centers, while climatological stations,

usually manned by volunteer observers, report at month-end. All stations are regularly inspected and the data are quality controlled.

Snow on the Ground. The depth of snow on the ground is reported daily by principal meteorological stations. Some climatological stations also make daily measurements. Many meteorological stations, however, are too exposed to wind for good regional measurements.

The snow course provides a better sampling of representative snow cover, but, necessarily, measurements are less frequent. In eastern Canada, representative landscapes are often chosen, while in the West, courses are sited on land types typical of many areas, for example, the natural grassland of the prairies and the alpine meadows of the mountains. In general, snow courses are located in areas not subject to interference through cultivation and other activities of man.

Snow courses are laid out and operated according to the policy of the respective agencies. The "national" network is really a composite of 18 subnetworks using a variety of course designs, frequencies of operation, samplers, and field techniques.

The snow depth and water equivalent are measured at a number of points along the course. Also, often noted are crust and ice layers; less frequently recorded are temperature profiles, crystal types, and tensile strength (hardness). The latter parameters are usually only available from snow pit measurements when horizontal rather than vertical sampling is employed. For normal vertical sampling, when the tube is fully immersed in the snow, the depth is read from the scale on the sidewall. The water equivalent is generally determined by weighing the contents of the tube. Common practice, especially at AES stations, is to record individual depths, and to collect a bulk snow sample from all points in a pail which is then weighed to determine the course water equivalent.

Snow course information is supplemented by data from storage gauges. These are most often of the Sacramento or stand pipe design. Long duration recording gauges, such as the Fischer and Porter, are also used and have been utilized as an integral sensor on data collection platforms or other telemetry systems. In areas difficult to access, snow depth may be estimated from aircraft using conspicuous vertical markers on the ground for guidance.

Recently, greater use has been made of satellite information in basin studies, particularly for flood discharge forecasting and reservoir regulation. In cooperation with U.S. agencies, a World Meteorological Organization (WMO) research project was carried out by the Hydrometeorological Research Division in two watersheds: the Saint John (Maine-New Brunswick) and the Souris (Saskatchewan-North Dakota) Ferguson and Lapczak, 1976).

This work is now expanded in the Saint John basin to include an operational satellite snow cover mapping project in support of flood flow forecasting. Presently, NOAA-5 data are being used, but direct reception of Geostationary Operational Environmental Satellite (GOES-East) imagery is expected to commence shortly at AES headquarters in Downsview, after which time GOES imagery will be used in the analysis, since a 24-hour turnaround for the product will be possible (Hoqq, 1978).

This project represents an extension of earlier work undertaken by the National Environmental Satellite Service (NOAA/NESS). The capability is to distinguish snow-free from snow-covered areas, as other snow cover properties can not yet be adequately assessed.

Quality Control. Data from meteorological stations are scrutinized during a three-stage process. Other data are mainly from water resource agencies, which, in view of the socioeconomic impacts of inadequate forecasts, would be expected to exercise similar care in verification.

Archiving and Publication

Snowfall and daily snow on the ground information has been collected and published by the AES since 1840 and 1941, respectively. (Snow cover data were collected earlier, but discontinuously.) Instruments and sites are well standardized for these parameters, and the material is published in the form of the actual, quality controlled measurements.

The AES has conducted snow surveys on an operational basis only since the early 1960's. While equipment and training of observers is comparable to that for snowfall, the data are published almost directly in Snow Cover Data for Canada. The archive

consists of handwritten ledger sheets filed by station. No microfilming is done.

Also contributing to the above mentioned publication are 17 other agencies operating snow courses. These data are published as received, in one volume per year. There is no other method of future retrieval other than hand reabstraction. Recourse to the originating agency, which often prepares statistical summaries, may be a preferable procedure for users.

Snow Cover Data for Canada began for the winter of 1960-1961, although a similar publication for eastern Canada had been available since 1954-1955. This was originally done in response to a request made through the Eastern Snow Conference which publishes a similar volume for the northeastern United States. The agencies contributing data to this annual national summary may also publish their own data, in a format designed for their respective clientele. Occasionally, summary volumes are produced, (for example: Canada, British Columbia (1975) and Canada, Quebec (1969)). These latter agencies have, moreover, computerized their archives to facilitate forecasting operations. Other agencies, such as the Conservation Authorities Branch of Ontario and the AES itself, have similar plans.

The Proposed AES Snow Course Archive

In order to maintain its mandate to publish national snow course information and to cope with metrification, it was decided in 1977 to create a modern computer compatible archive from which a hard copy could be directly produced for publication. Some of the potential benefits include:

- A) a permanent data storage facility which may be readily accessed and will grow in usefulness, particularly for statistical purposes, over a number of years;
- B) a standardized format for data collected by a variety of agencies for differing reasons. This will facilitate data utilization over broad regions;
- C) the possibility of including for publication additional physical information such as snow crusts, ice layers, environmental characteristics, sampler types, etc., which are recorded by many agencies, but not regularly published.

Input Component. For ease of computer operations, a standard input format is necessary. Presently, contributing agencies supply a variety of hard copy formats which are digested clerically for hand entry on the printing format. A universal reporting form is being prepared which will allow standardized reporting by agencies. Alternatively, computer compatible data input such as magnetic tape could be accepted. The system is, of course, bilingual in SI (Système International d'Unités) or Imperial Units, English and French.

The form (figure 1) identifies each course, its address and other vital statistics including the operating agency, period of record, course length, and number of sampling points and sampler type. The form was developed from earlier work (Goodison, 1975).

The basic information is logged onto a master file. A second section of the form registers site and environmental information. Changes to the environment may necessitate a new master record, but in general these data would not be published, although they would be available on request.

In part C of figure 1, the data are listed according to time of survey, and provision is made for recording the depth, water equivalent, presence of crusts, ice layers, and snow free points. It is possible to archive up to four surveys per month from September through June.

Data Processing. Flow charts (figures 2, 2a, 2b) indicate how pertinent master and observational data are combined. Provinces, major drainage areas, river basins and courses (stations) are all identified by numerical codes assigned at AES headquarters. The record layout is shown by figure 3; table 1 describes the data card format. The principal product of the data processing is the publication format.

Publication Format. The proposed format (table 2) is generally similar to the existing layout of Snow Cover Data for Canada. This is to ensure consistency. There is a provision for additional information as well. This includes:

- A) a classification of surface crust hardness,

CANADA SNOW COURSE REPORTING FORM

PART A MASTER INFORMATION

(1) IDENTIFICATION NUMBER # _____ (2) COURSE NAME _____ (3) PROVINCE _____
 (4) RIVER BASIN _____ (5) MAJOR DRAINAGE AREA _____
 (6) CONTRIBUTING AGENCY (Name, No.) _____ (7) LAT. _____ (8) LONG. _____ (9) ELEV.* _____
 (10) NO. SAMPLING POINTS _____ (11) SPACING OF POINTS* _____ (12) UNITS OF MEASUREMENT _____
 (13) TYPE OF SNOW SAMPLER _____ (14) WINTER COURSE ESTABLISHED _____

PART B ENVIRONMENT AND MODIFICATIONS TO SITE

(15) TYPE OF TERRAIN AND VEGETATION _____

 (16) SLOPE AND ASPECT _____
 (17) CHANGES TO SNOW COURSE OR OPERATION SINCE LAST REPORT
 DATE OF CHANGE _____ NATURE OF CHANGE _____

PART C OBSERVATIONS

WINTER 19 ____ 19 ____

MONTH	FIRST OBSERVATION							SECOND OBSERVATION	THIRD OBSERVATION	FOURTH OBSERVATION
	Day	Surface	Crust	Ice	Average	Depth	Average			
	(18)	(19)	(20)	(21)	(22)	(23)				
SEPT										
OCT										
NOV										
DEC										
JAN										
FEB										
MAR										
APR										
MAY										
JUN										

Figure 1. Canada snow course reporting form.

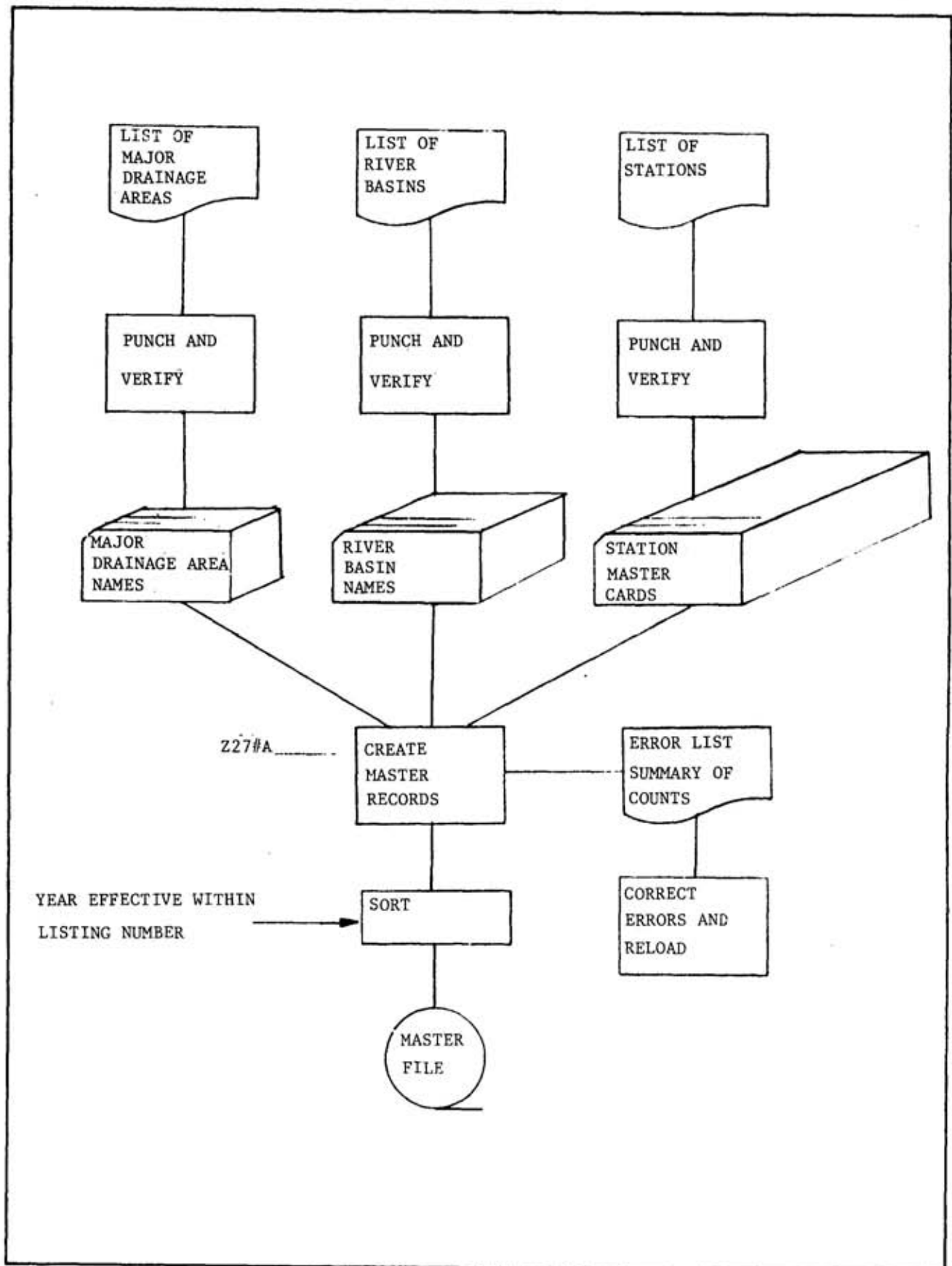


Figure 2. Snow course archival system.

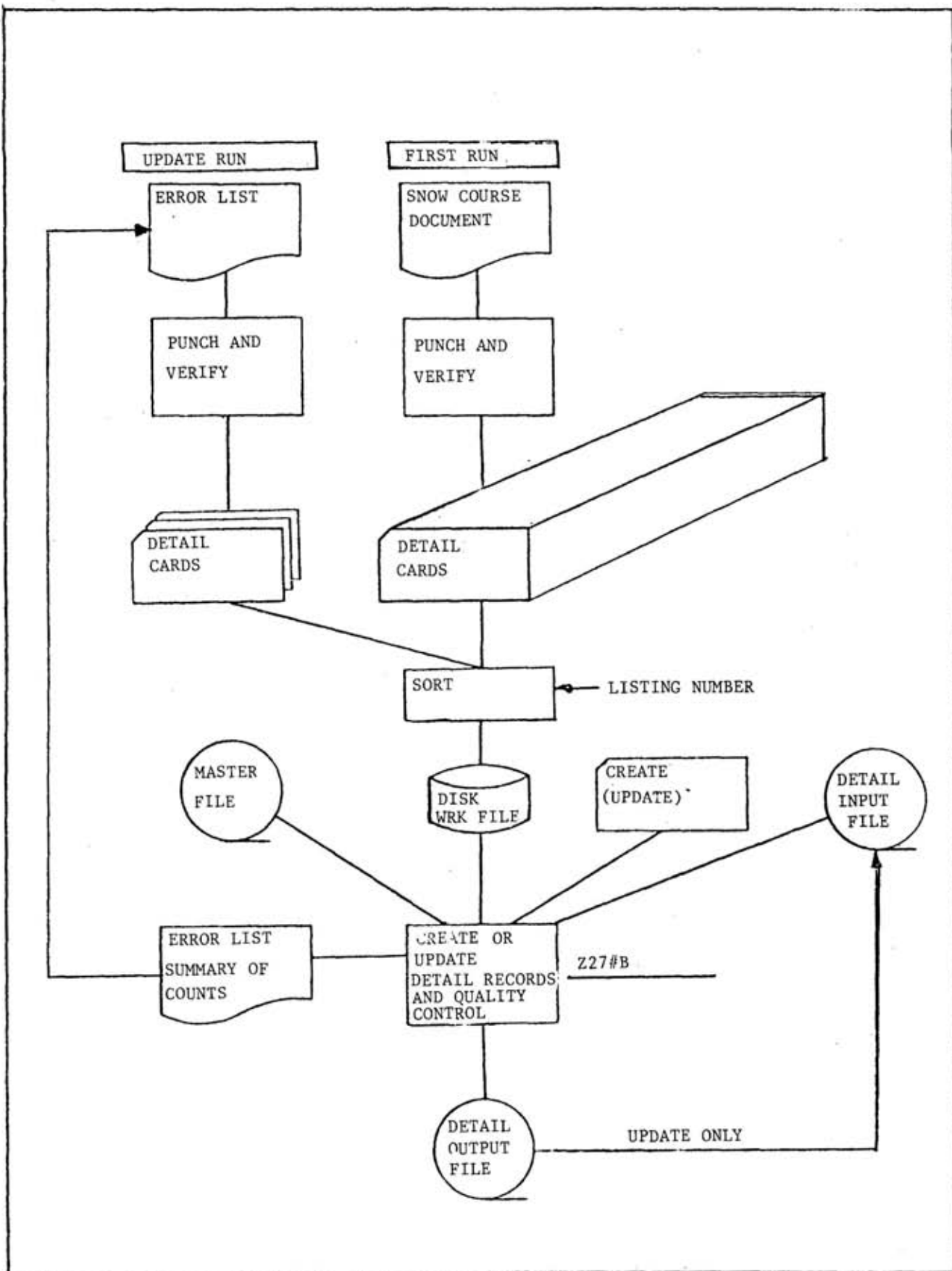


Figure 2a. Snow course archival system.

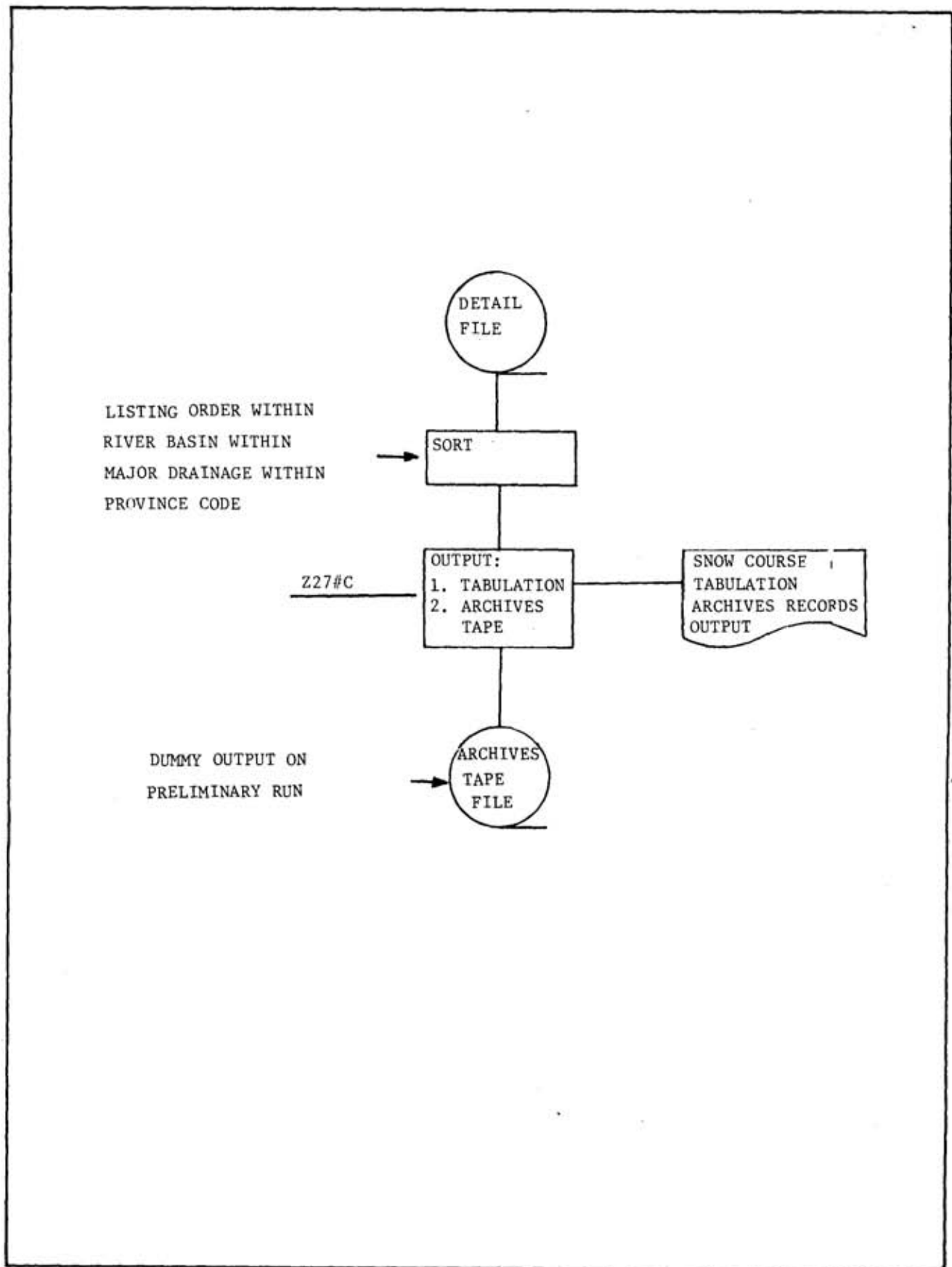


Figure 2b. Snow course archival system.

NAME CARD									
MAJOR DRAINAGE AREA NAME									
44 45 47									
80									
27	1	13	14	15					
1	2	3							

NAME CARD									
RIVER BASIN NAME									
44 45 48 49									
80									
27	2	13	14	15					
1	2	3							

MASTER CARD									
SNOW COURSE NAME									
38 39 40 41 42 43 44 45 46 47 48 49									
80									
27	3	9	10	11	12	13	14	15	
1	2	3							

DELETE CARD									
SNOW COURSE NAME									
38 39 40 41 42 43 44 45 46 47 48 49									
80									
27	4	9	10	11	12	13	14	15	
1	2	3							

AVERAGED DATA CARD									
3rd OBSERVATION									
48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80									
80									
27	5	9	10	11	12	13	14	15	
1	2	3							

ARCHIVAL RECORD									
3rd OBSERVATION									
48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80									
80									
27	6	9	10	11	12	13	14	15	
1	2	3							

Figure 3. Snow course record layouts.

Table 1. Layout of snow course data card.

CARD COLUMNS	FIELD	CARD CODE	REMARKS
1 - 2	System Information	27	
3-9	AES Station No.		Allocated by AES for Station Identification
10-11	Year		Last Two Digits of Year
12-13	Month	01-12	Month coded numerically January is 01 etc.
14	Card Number	5	
15	Units of Measurement	1	Snow depth - Centimetres and tenths Water Equivalent - Millimetres
		2	Snow depth - inches and tenths water equivalent - inches and tenths
16	Not Used	Blank	
17-32 17-18	Day	01-31	First Observation of Month Day of Month
19	Surface Crust	A B C D E Blank	No Crust Light Crust Crust Strong enough to Support Man on Snowshoes Crust strong enough to Support Man without snowshoes occasionally Crust Strong Enough to Support Man without Snowshoes Most of the Time No Report
20	Ice Layers	0 1 2 3 Blank	Nil Layers within Pack Layers at Base of Pack Layers both within and at base of pack NO REPORT
21-24	Average Snow depth	0000-9999	000.0-999.9 Centimetres or 000.0-999.9 Inches
25	Snow Depth Code	T Blank	Snow depth is trace and coded 0000 No Codes
26-29	Average Water Equiv.	0000-9999	0000-9999 Millimetres or 000.0-999.9 inches
30	Water Equiv. Code	N Blank	Used if water equivalent is missing and snow depth is reported. No Codes
31-32	Points with No Snow	00-20 Blank	Number of Points in the Course Not covered by Snow No Report
33-48		Blank	<u>Second Observation of Month</u> Coded as For first Observation No Report
49-64		Blank	<u>Third Observation of Month</u> Coded as for First Observation No Report
65-80		Blank	<u>Fourth Observation of Month</u> Coded as for First Observation No Report

Table 2. Proposed publication format for snow cover data-Canada.

PROVINCE RIVER BASIN SNOW COURSE	DATE	CHANGE	LINE	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	YRS	SA	SPACING
BRITISH COLUMBIA COLUMBIA RIVER DRAINAGE UPPER COLUMBIA RIVER BASIN	(18)	1250	1				30 A03	30 B12	26 B1	27 C1	29 C1	14 D2	11 D2	39	01	5X30
			2				269.0	302.0	638.0	401.0	311.0	305.0	254.0			
			3				818	1090	1331	1501	1689	1577	1392			
			1									28 D3	28 D2			
			2									282.0	254.0			
			3									1499	1392			
	(18)	1280	1				28 A02	28 A02	26 A11	28 B	29 C2			36	01	50X30
			2				73.6	73.6	86.4	86.4	17.8					
			3				124	124	137	178	5					
NORTHWEST TERRITORIES DISTRICT OF FRANKLIN	(17)	375	1	23 A02	01 B22	01 B1	01 C1	01 C2	01 D3	01 D2	01 E3	01 E2	01 B1	10	02	5 X30
			2	6.8	10.2	72.6	70.1	86.6	101.1	87.1	92.5	81.0	71.6			
			3	20	18	204	205	256	376	361	348	290	264			
			1	30 A01	08 A02	08 A1	08 B1	0A C2	08 D2	08 D2	08 C3	08 C2	08 B1			
			2	4.8	26.7	72.9	76.2	86.9	105.4	85.4	83.6	76.8	64.0			
			3	15	53	205	254	325	391	376	328	251	198			
			1	15 A01	15 A01	15 A01	15 A02	15 B1	15 C1	15 D2	15 D2	15 C1	15 C2			
			2	39.1	73.7	88.9	88.9	85.3	111.5	84.1	84.8	76.2	36.1			
			3	86	244	287	274	274	386	318	307	279	89			
			1	23 B02	23 B02	23 B02	23 B2	23	23 C3	23 C3	23 B1	23 A2	23 A1			
			2	45.0	62.2	91.7	91.7	85.3	106.2	87.6	91.2	80.3	12.2			
			3	117	218	371	371	267	417	381	366	356	43			

- B) the presence of ice layers in the pack,
- C) the number of snow-free points on the course,
- D) sampler type,
- E) an indicator of major changes in the course or environment.

Following is a brief description of the publication form. In the extreme left-hand columns are the identifiers for: province, drainage basin, course name, locational coordinates, and elevation above sea level. The two-digit figures in brackets refer to the operating agency.

The data are presented on three separate lines. Line one gives the day, (space), crust types, ice layers, and points with no snow (dd cip). The second line presents the mean snow depth for the course in centimeters and tenths. The third line below gives the mean water equivalent in whole millimeters. The three columns on the far right-hand side give: the years or record, the sampler type (code), and the course length and spacing, i.e., 5 x 30 indicates 5 points at 30 m apart.

Status of the Archive. The format of the archive has been generally finalized, but the cooperation of the participating agencies has not been formally sought. The archive should become operational by 1979-1980 or before.

Research and Mapping of Snow Cover

Perspective on the Present State. Snowfall and snow on the ground data have been analyzed for a number of national mapping exercises. In 1965, Potter produced a monograph on the snow depth data measured at meteorological stations, 1941-60. A number of maps of median month-end depths were drawn along with frequency diagrams for regional stations. The only comparable earlier work was a collection of hemispheric maps prepared by the U.S. Army in 1954.

Regional variability in the physical properties of snow cover was studied by the National Research Council beginning in the 1930's, and culminated at the time of the International Geophysical Year (1957/58) (Williams, 1958). These studies, which included measurements of snow density, hardness, crystal type and size, and layer temperatures, provided much useful information for a number of practical applications, including later mapping. McKay and Findlay (1971) presented a paper at the Western Snow Conference wherein national patterns of snow depth and density were related to the major vegetation and topographic divisions (figure 4). Earlier, McKay and Thompson (1968) studied the snowpack in the Prairie provinces, and summarized the difficulties of analysis and interpretation, as well as presented suggestions for practical use of the data. In 1972, at the WMO/UNESCO Banff Symposium on Snow and Ice, these authors (McKay and Thompson, 1972) further specified techniques and problems in snow cover mapping. A concrete example of the seriousness of the problem was given by Ferguson and Goodison (1974) who published a number of 5- and 10-year mean snow water equivalent maps for southern Ontario (figure 5). The difficulty of interpreting local influences and observational biases was discussed. These factors are particularly critical in shallow pack areas, as a later paper by Goodison (1975) emphasized in calling for greater standardization of sites and observational procedures.

Stratification of snow cover data against vegetation and terrain is a convenient way of simplifying the complexity of the field as studies during the 1960's in Quebec-Labrador demonstrated (see, for example, Adams et al., 1966) (figure 6). For prairie regions, Steppuhn and Dyck (1974) have rationalized local variability in a similar manner, demonstrating the statistical homogeneity of their selected data sets. Goodison (in press) has also shown that landscape stratification, based on standard snow courses rather than special traverses, is a feasible method of snow cover calculation. Remote sensing is also proving to be a useful tool for regional studies, as Loijens (1974) demonstrated for Canadian aerial gamma surveys.

Snow maps for the Hydrological Atlas of Canada published in 1978 were described by Findlay (1975). These were produced at a scale of 1:5,000,000 and printed at one-quarter size (1:10,000,000). The maps included: annual precipitation/snow cover measurement networks, annual snowfall, dates of formation and loss of snow cover, and mean maximum depth of snow and time of occurrence (figure 7). The precipitation and snowfall maps were developed from the long-term meteorological station records (1941-70). The dates of formation and loss of snow cover, and mean maximum depth of snow were derived from a combination of meteorological archive records and hand tabulated data from 230 nationally distributed snow courses. The combined data were subjectively interpreted.

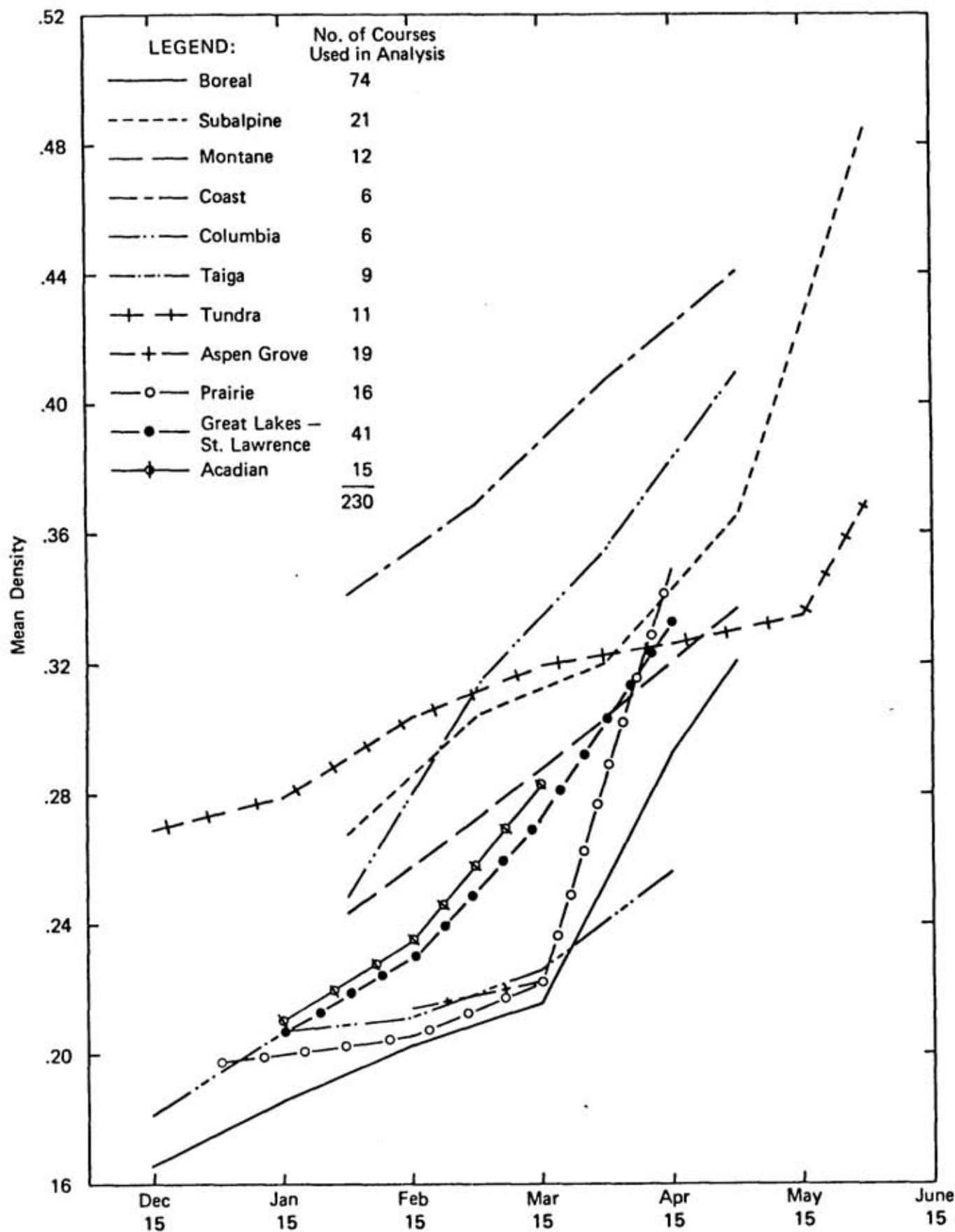


Figure 4. Time-density variations in vegetation regions.

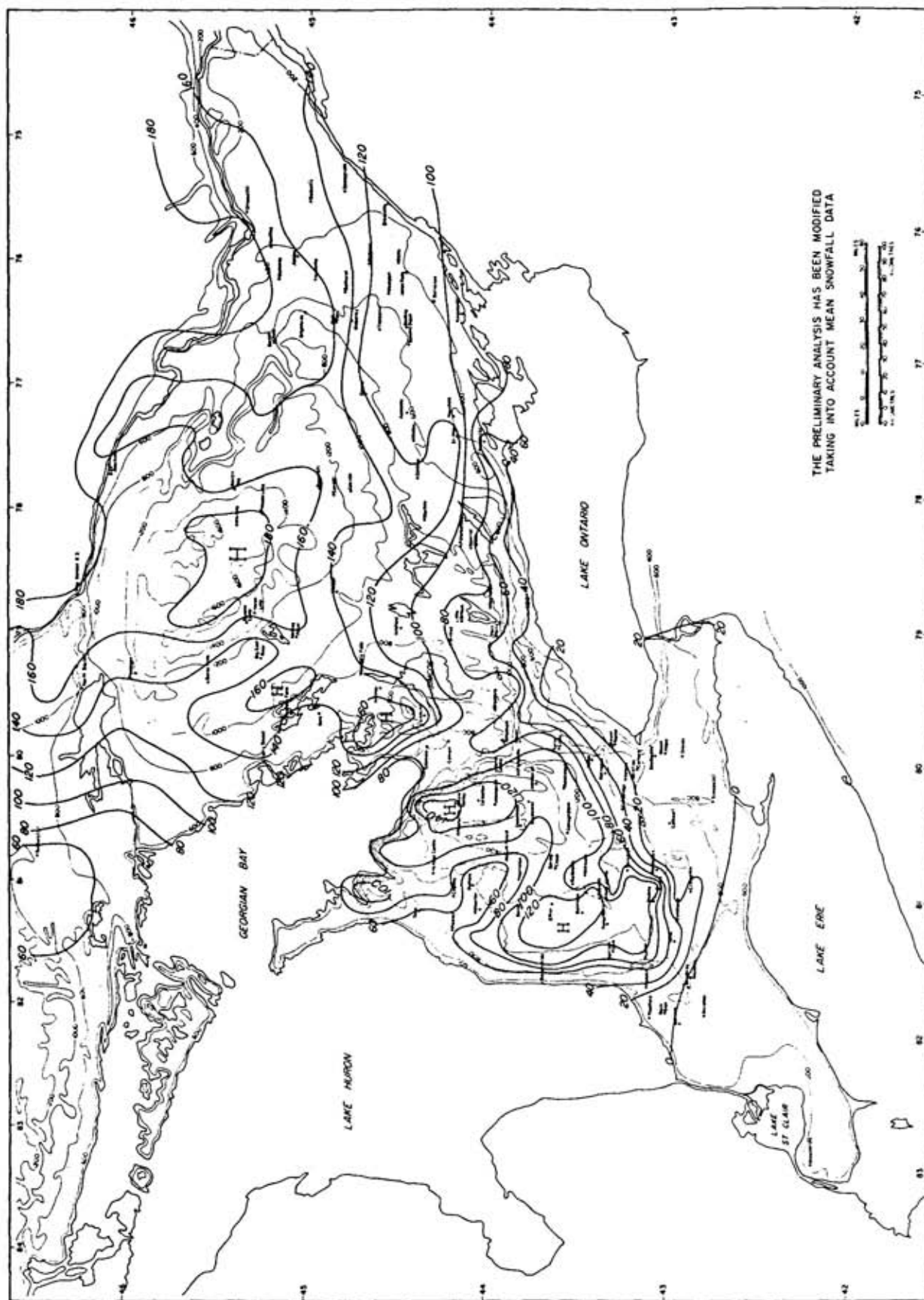
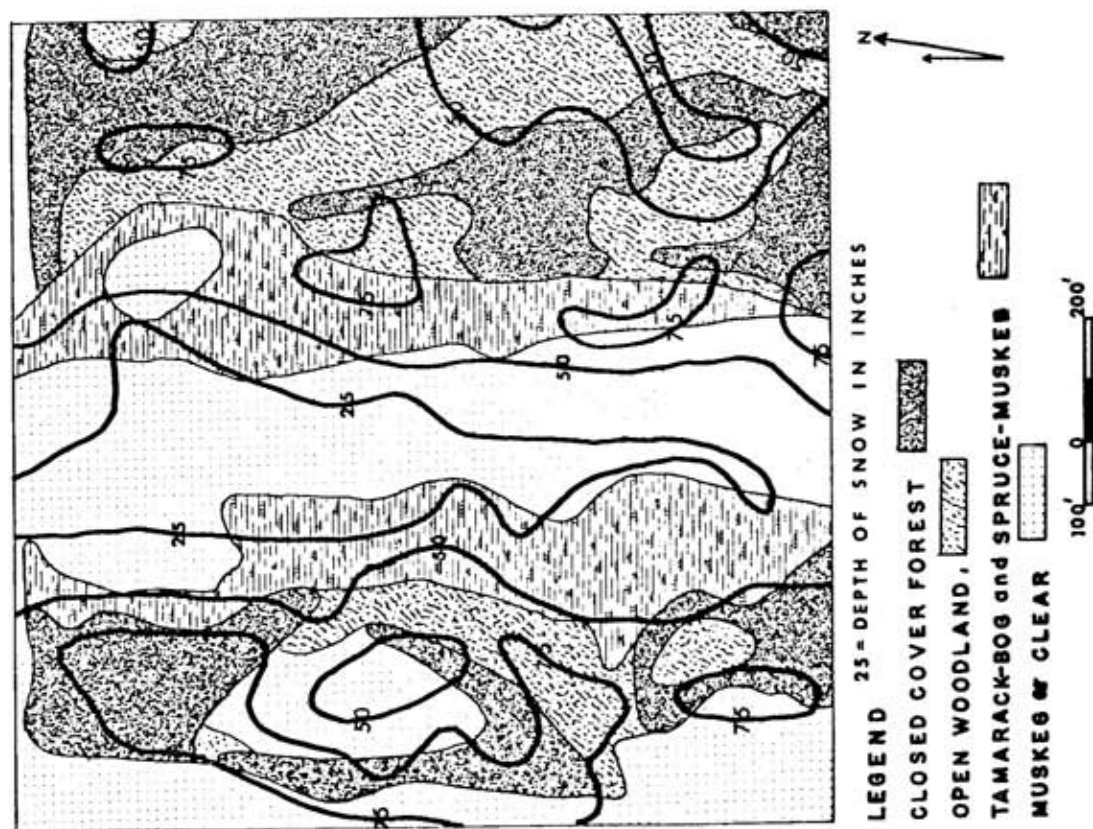


Figure 5. Five-year mean (1969-1973) snowpack water equivalent (mm) for mid-March. The preliminary analysis has been modified taking into account mean snowfall data.

SNOW COVER AND VEGETATION



WATER EQUIVALENT OF SNOW COVER

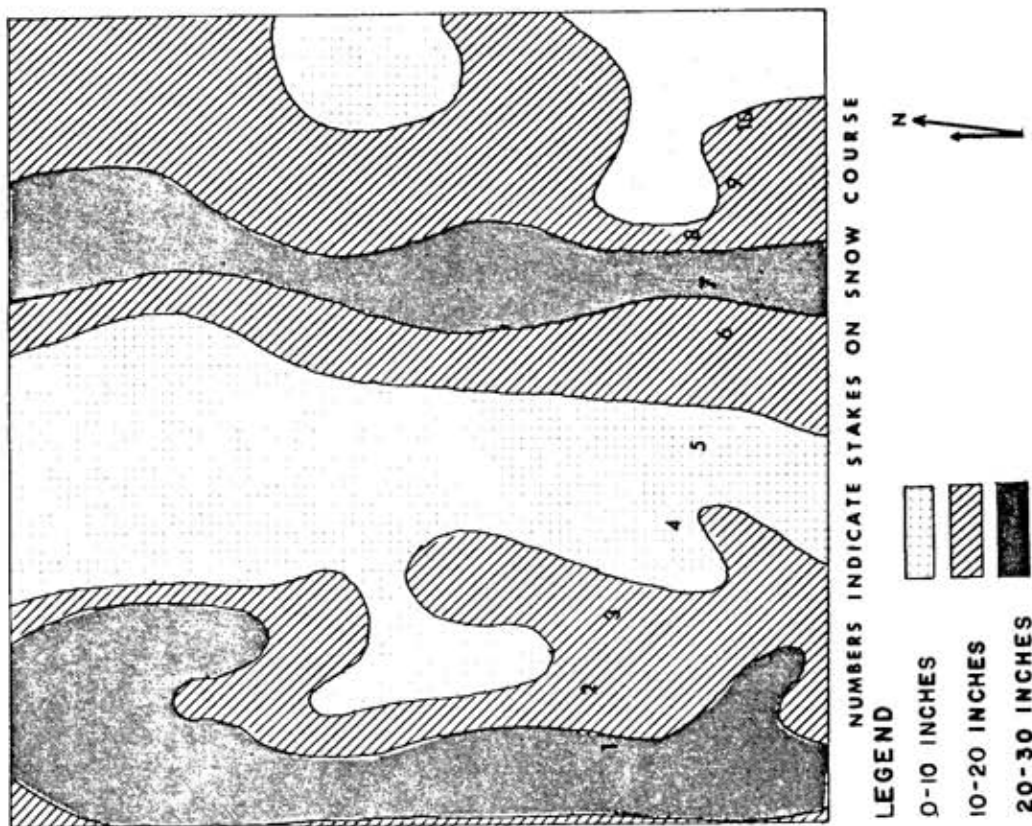


Figure 6. Snow cover and vegetation relationships near Schefferville (Knob Lake), Quebec.



Figure 7. Mean maximum depth of snow and time of occurrence.

Real-time Analyzed Products. Recently, Environment Canada has created a Canadian Climate Centre (CCC) whose term of reference has a similarity to the World Climate Programme of the WMO. The CCC coordinates research and applications to reach users more efficiently. One method is the introduction of a weekly bulletin, Climatic Perspectives, where national maps indicate the snow depth as ascertained from 1200 Greenwich Mean Time synoptic reports on the final day of coverage. In addition, information on anomalous conditions as they impact on transportation, Arctic activities, agriculture, wildlife, and recreation will be gathered, and featured in the bulletin, or otherwise be available on request.

Conclusions

Over the past few decades, considerable research has been directed towards isolating problems of instrument design and function, and specifying the type and magnitude of errors with which one must contend. As well, there has been a considerable increase in network sizes in response to user market development, including government planners and decision makers. Included is the widespread deployment of automatic data collection platforms. Such developments have exerted pressure on data handling facilities and raised serious questions regarding the type of data to be preserved and published.

In Canada, the meteorological and water services have developed modern machine handling facilities, giving efficient data storage and access retrieval to users. This is with respect to precipitation and streamflow. Regarding snow cover, however, there remains considerable scope for improvement. Research has identified the principal problems, i.e., nonstandard course siting, instruments, and measurement procedures leading to difficulties in archiving and interpretation. The snow course archive presently being developed will remove some subjectivity from climatological analyses, but it is for now a rather simple, initial step. By providing ease of access to such a data bank, it is expected that the user market will grow, particularly as examples of its use are demonstrated in the literature.

Historically, snow cover data products have been meager since much analysis has had to be done by hand. The demand for climatological information, as with other forms of environmental information, has notably increased as the values in design, engineering, planning, and operations of investment sectors, resource management, and socioeconomic concerns are brought to light.

With the increase in real-time products, the usefulness of snow cover information should gain greater appreciation among decision makers, which will in turn stimulate improved archiving and mapping facilities and an overall growth in products over the next few years..

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Surface Measurements of Snow and Ice for Correlation With Aircraft and Satellite Observations (Summary)

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The seasonal extent of the earth's snow and ice cover can easily be determined by aircraft and satellite reconnaissance. However, determination of the depth and physical properties of the snow cover and the thickness of ice on lakes, rivers, and along coastlines by these remote sensors does not provide all the necessary data. Reliable measurements are not being taken as frequently as in the past, and a significant amount of valuable data is lost, e.g., temperature measurements. There is a continuing need for data derived from a variety of sources, i.e., remote sensing, aircraft observation, and ground measurements. There is also a need to make available unpublished historical data not contained in the literature. The ice measurements made by the S.S. Manhattan (Bilello and Bates, 1972) and the U.S. Air Force ice thickness observations made between 1943 and 1951 (Bilello, Bates and Riley, 1970) are examples of data which might have been discarded.

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Accuracy of Snow and Ice Monitoring

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It is well known that snow and ice covers have a large influence on the global heat budget, mainly because of their high albedo (Hummel and Reck, 1978; Kung et al., 1964). Knowledge of the variation of these covers in time and space is essential in the attempt to reach an understanding of climate changes (Wiesnet and Matson, 1976). Today, several groups produce operational snow and ice cover charts. These maps, mostly done on a weekly basis, extend from regional to global scales. Production techniques and the charted characteristics (i.e., snow depth and relative composition; surface reflectivity, age of cover; concentration of ice) of the snow and ice cover differ (Dickinson et al, 1974; U.S. Naval Oceanographic Office, 1974; U.S. National Environmental Satellite Service, 1974-75).

Tables 1 and 2 list the charts used in our study. The week to week changes in the extent and reflectivity of the snow and ice covers in both hemispheres are measured, and the results expressed in the form of several snow and ice related climatic indices (Kukla and Gavin, in press).

Table 1. Current series of snow charts used in the study.

Chart Name	Produced By	Area	Projection and Approx. Scale	Interval	Content	
Northern Hemisphere Average Snow and Ice Boundaries	Analysis & Evaluation Branch of the National Environmental Satellite Service, NOAA	Continents of the Northern Hemisphere North of 25°-30° N. Latitude	Polar Stereographic 1:50,000,000	Weekly: 1967-Present	Boundaries of Snow and Ice-Covered Areas in 4 Classes: 1) Least Reflective 2) Moderately Reflective 3) Highly Reflective 4) Scattered Mountain Snow	*
Current Snow and Ice Depth	USAF, Air Force Global Weather Central	Northern Hemisphere 0-90° N.	Polar Stereographic 1:30,000,000	Weekly: 1976-Present	Depth of Snow and Ice for 6 Categories: 1) <2"; 2) ≥2"; 3) ≥4"; 4) ≥6"; 5) ≥8"; 6) ≥10"	*
Age of Surface Snow/Ice	USAF, Air Force Global Weather Central	Northern Hemisphere 0-90° N.	Polar Stereographic 1:30,000,000	Weekly: 1976-Present	Age of Snow and Ice in 7 Categories: 1) No Snow 2) Fresh <24 hrs. 3) New <48 hrs. 4) Aging at least 3 days old 5) Old at least 3 weeks 6) Very old at least 2 months 7) Permanent at least 6 months	S N O W
Weekly Weather and Crop Bulletin Snow Chart	U.S. Dept. of Commerce National Weather Serv., NOAA, U.S. Dept. of Agriculture & Statistical Reporting Service	Continental U.S.	Albers Equal Area 1:30,000,000	Weekly: 1934-Present	Depth of snow on ground at 7 a.m. E.S.T. for Monday, December - March only	*

*Quality Checked

The Weekly Weather and Crop Bulletin reports snow cover extent and depth from December through March in the continental United States at 7 a.m. EST on the chart date. The map is produced from telegraphic reports of selected stations across the country.

Ice cover is mapped weekly by the Navy and NOAA. NOAA reports the general extent and relative reflectivity of ice cover and assigns the cover to a reflectivity class, whereas the Navy reports the ice concentration in octas (eighths). Visible, infrared, and microwave imagery gathered during three consecutive days of each week are used to construct the charts. Data are supplemented by ship and coastal station reports.

Accuracy of Snow Charts

In order to examine the accuracy of the operational snow charts, we produced a new, independent, updated set of snow maps for three selected blocks in the United States (figure 1). The Western section, west of approximately 105°W longitude, includes the Range and Basin province. The Central section includes the flat north central Plains, principally represented by farmland, and the Eastern section represents a moderately hilly region with extensive forests. For technical reasons, the Central and Eastern sections overlap over Iowa.

Satellite information for each day was recharted and completed by incorporating reports from the ground stations shown in figure 1. The area covered by snow is measured and expressed as the percentage of the total area of the block. Selected results refer at this stage to snow area only and are shown in figure 2. Differences between the summaries found in the operational and the corresponding updated chart, in percent of the block area covered, are plotted in table 3. Day 7 is the last day of the analysed week. It is seen from the results, that:

- 1) the best fit is reached on the last, or the penultimate day of the week;
- 2) the departures tend to be smaller in the more recent charts;
- 3) the average differences are usually less than 10 percent of the area of the block;
- 4) largest differences are in the mountainous Western block.

Given the frequently irregular and sketchy character of the snow fields, difficulties in distinguishing snow in heavily forested areas, and the rapid changes of snow cover in the selected intervals, we consider the accuracy of the charts to be sufficiently high for climate-related studies on a continental or hemispheric scale.

Accuracy of the Ice Charts:

The Navy and NESS operational charts of sea ice covers were checked using a method similar to that used in the snow map analyses. Results will be reported in more detail elsewhere. In general, the quality of both sets was found to be sufficiently high for use in climate related studies. Navy charts very accurately show the proportion of open water (sometimes perhaps including a very thin ice cover) to the sea ice. They do not, however, indicate relative reflectivity.

It is our firm belief that the skill of the interpreters in individual agencies is constantly increasing, and that further improvements in the charts' quality will soon follow.

We recommend at present that existing charts be subdivided into three sets:

- 1) Pre-satellite era...A good time series for parts of the Northern Hemisphere, but only some indices are useful. Generally good for depicting the ice boundary, but data on ice type and concentrations are not very reliable.
- 2) Satellite era, 1966-1973...Relatively good representation of the general boundaries of snow and ice cover but not too much detail. Sufficient for studies on a continental scale.
- 3) Satellite era, 1973 onward...Introduction of microwave and improvement of existing methods. With more detailed information available on a global scale, this period could be used as a "normal", as sets of high internal homogeneity can be generated.

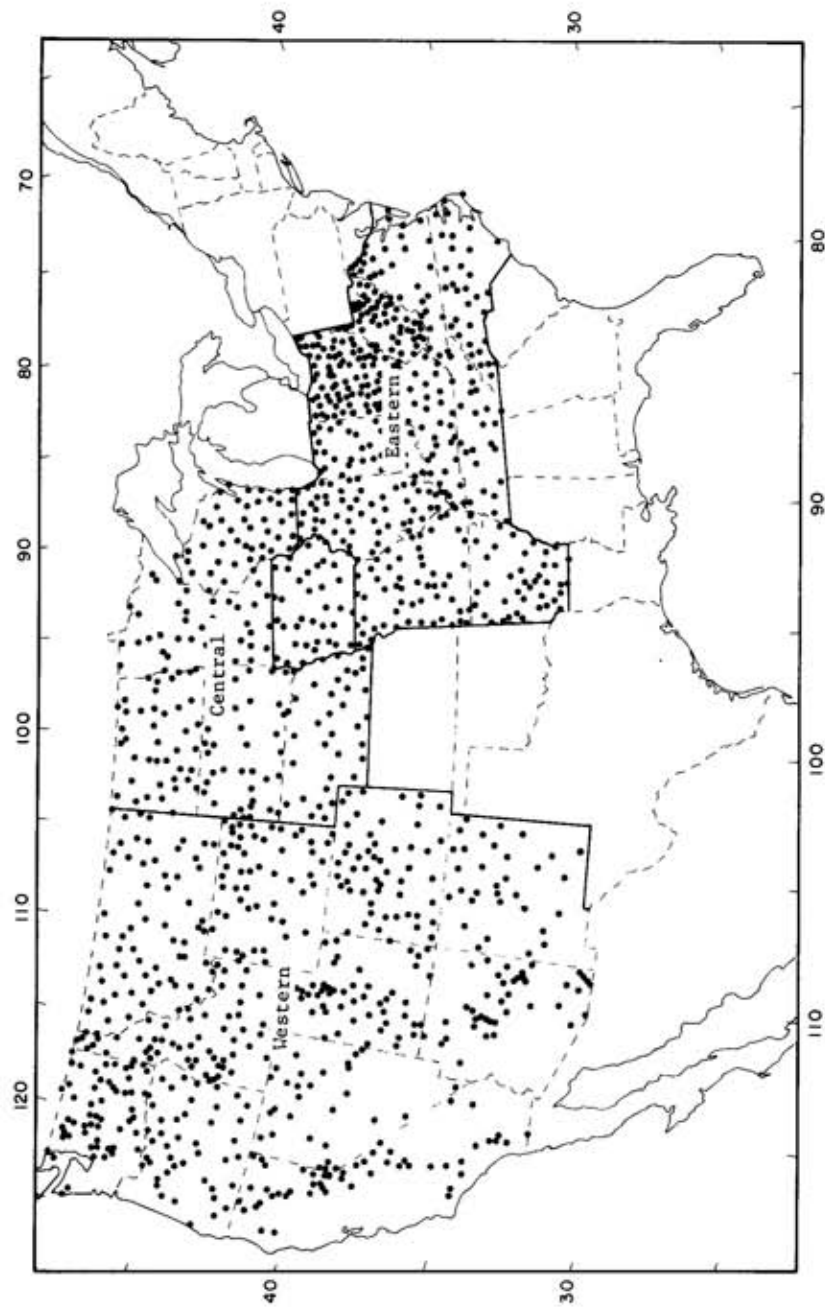


Figure 1. Location of the ground stations in the Western, Central and Eastern blocks. Iowa is included in both the Central and Eastern block. Snow reports are from monthly climatic data.

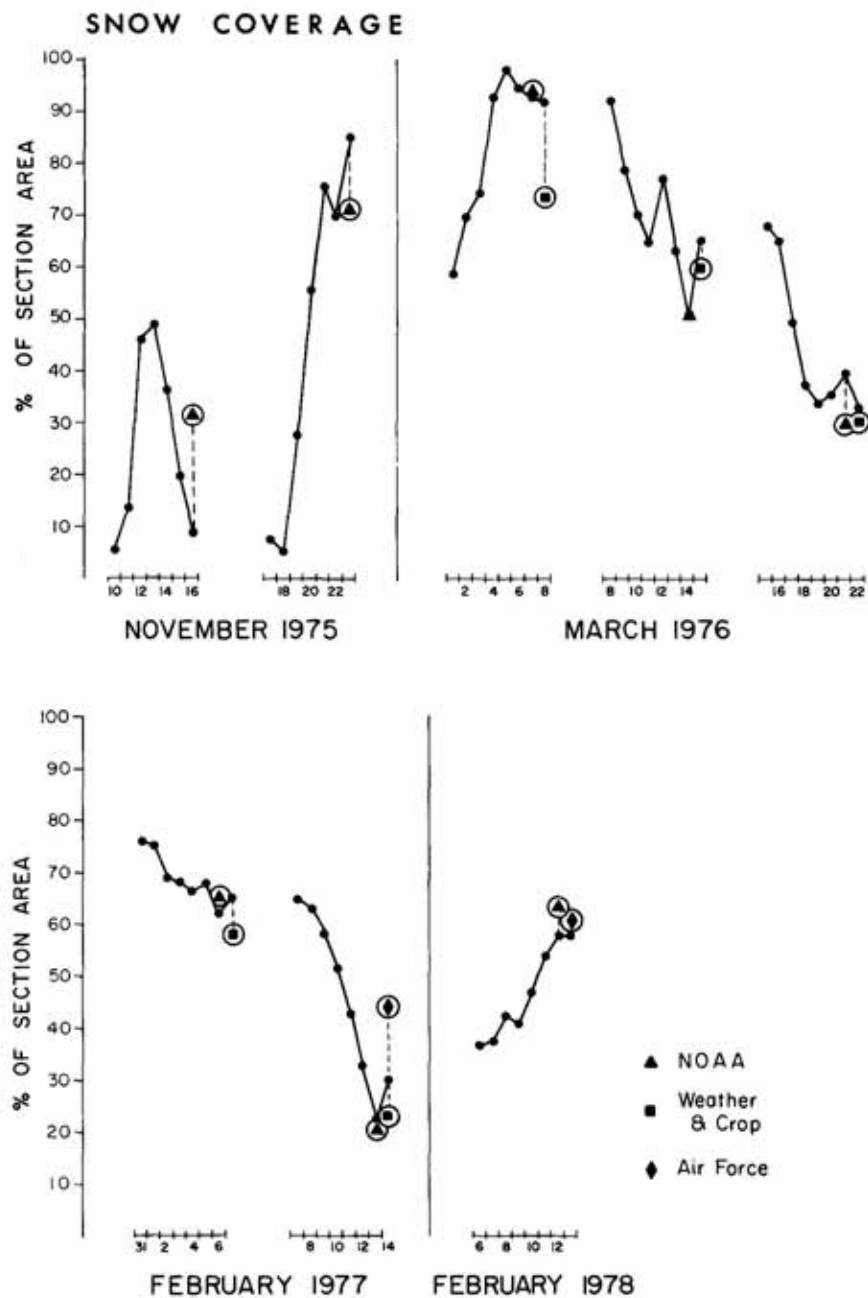


Figure 2. Percent of snow covered area on individual days at selected intervals in 1975-1978. November 1975 and March 1976 data are for the Central block (Iowa, Minnesota, Nebraska and Dakotas). February 1977 data are for the Eastern block, February 1978 data for the Western block. Circled triangles, squares and diamonds show the area shown in the corresponding operational charts.

Table 3. Snow area shown on the operational chart compared to the snow area on our updated map. Difference in the area of the block covered on each day (in percent). Negative sign shows our result to be smaller.

NESS	1	2	3	4	5	6	7
11/10-16/75	26.5	18.1	-14.6	-17.3	- 4.8	11.8	22.7
11/17-23/75	63.5	65.8	43.3	15.6	- 4.5	1.2	-13.9
3/ 1- 7/76	34.6	23.8	19.2	.6	- 4.7	- 1.2	.6
3/ 8-14/76	-41.7	-28.5	-19.6	-14.0	-26.8	-12.8	- .3
3/15-21/76	-38.5	-35.4	-19.9	- 8.0	- 4.2	- 6.2	-10.2
1/31-2/6/77	-10.7	- 9.9	- 3.6	- 3.0	- 1.2	- 2.7	3.0
2/ 7-13/77	-45.1	-43.0	-38.5	-31.2	-20.6	-12.4	- 2.6
2/ 6-12/78	26.7	26.0	21.1	22.8	16.5	9.3	5.5
AIR FORCE	1	2	3	4	5	6	7
2/ 1- 7/77	1.3	7.6	8.2	10.0	8.5	14.0	11.5
2/ 8-14/77	-18.8	-14.3	- 7.0	3.6	11.8	21.6	14.0
2/ 7-13/78	23.4	18.5	20.2	13.9	6.7	2.9	2.9
WEATHER AND CROP BULLETIN	1	2	3	4	5	6	7
3/ 2- 8/76	3.6	- 1.0	-19.6	-24.9	-21.4	-19.6	-18.7
3/ 9-15/76	-18.7	- 9.8	- 4.2	-17.0	- 3.0	9.5	- 8.1
3/16-22/76	-34.8	-19.3	- 7.4	- 3.6	- 5.6	- 9.6	- 2.8
2/ 1- 7/77	-17.1	-10.8	-10.2	- 8.4	- 9.9	- 4.2	- 6.9
2/ 8-14/77	-40.0	-35.5	-28.2	-17.6	- 9.4	.4	- 7.2

Suggestions for future snow and ice map products:

- 1) A minimum scale of 1:30,000 is needed.
- 2) Reflectivity classes should be more detailed, at least six classes. (Brightness data are preferable to snow depth for the purposes of climate dynamic studies.)
- 3) Charts should distinguish between data recorded on the day that the chart is dated, and data collected on previous days.
- 4) The proportion of snow to bare ground should be given where possible.
- 5) Where possible, areas of melting snow cover on the pack ice should be indicated.
- 6) Where possible, relative reflectivity of sea ice should be indicated in Navy charts.

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A Preliminary Digitization of Northern Hemisphere Sea Ice Data (Summary)

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A preliminary construction of a sea ice data set has been made for use in studies of short-term ice/atmosphere relationships on the hemispheric scale. The data, covering the 25-year period from 1953 to 1977, were synthesized from published sources and transcribed to a master concentration grid of approximately 1800 points, at a spacing of 1° latitude (110 km). The concentration grids have been constructed for each month of the period, the 300 grids being digitized and stored on tape at the National Center for Atmospheric Research, Boulder, Colorado.

The data structure is uniform throughout the 300-month period, but there is obviously some nonuniformity in the quality of the gridded data. This is due, in part, to imprecise concentration classifications, inconsistencies in overlapping data, and missing data. Values are estimated and 'tagged' to indicate where data are missing. Not all existing data are included, but preliminary data fields can be easily overwritten by more reliable values, if the latter are obtained. A more detailed description of this data set is presented in Walsh, 1978.

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An Arctic Sea Ice Data Set, 1901-1956

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The Climatic Research Unit, University of East Anglia, is engaged in a feasibility study of the potential for Arctic sea ice prediction on climatic time scales. The main stages in this research are summarized in appendix I. The program includes the collection of sea ice data for the Arctic covering the 20th century; the statistical analysis of these data to identify the major fluctuations in sea ice extent, both spatially and temporally; correlation with climatic and atmospheric circulation data to determine the immediate causes of these sea ice variations, not excluding the possibility of feedback; and research, both theoretical and empirical, aimed at achieving the degree of understanding of the causes of these variations in climate and sea ice which is a necessary prerequisite to any predictive effort. This paper deals with the first stage in this research: the collection of Arctic sea ice data for the 20th century.

Ongoing digitizing projects by Walsh (1978) and Kukla (personal communication) are concerned with data for the last 25 years or so, but few digitized data are available for the first half of the 20th century. Pronounced changes in sea ice extent occurred during this period, which is considered to be without a climatic parallel during the last few hundred years (Kelly, 1975; Lamb and Morth, 1978). In order to extend the existing sea ice data base, we have digitized, and are currently assessing the reliability of, the circumpolar ice limit contained in a chart series produced by the Danish Meteorological Institute (DMI) for the period 1901 to 1956 (Thomsen, 1947).

During the 1890's, the DMI published reports of ice conditions in the Davis Strait, and later between Greenland and Novaya Zemlya, in the Institute's Yearbook (*Nautisk- Meteorologiske Aarbog*). In 1900, this work was extended to cover all Arctic regions where data were available. Information was obtained from sources in Canada, Germany, Great Britain, Norway, Sweden, the United States, and the USSR. These observations originated from naval and merchant shipping, shore observers, and, in later years, aircraft reconnaissance. During the periods 1901-39 and 1946-50, the Institute published an annual report, *The State of the Ice in Arctic Seas*. This publication contained, as text, summaries of the ice extent in the months and regions for which observations were available, and, on multicolored charts, compilations of these observations for the months of April to August (occasionally September) when most information was available.

The observations were plotted on a polar stereographic projection of the Arctic. Direct observations of polar fast ice, winter fast ice, big ice floes, close drift ice, open drift ice, icebergs, and bergy bits were plotted in red, with the date of observation occasionally given. In addition, a red curve indicated observed limits between open sea and ice where available; a dashed line gave a climatological "normal" ice limit (for a period of years which changed during the chart series); and, as defined by a change from a white to a blue-green background on the chart, an ice limit based partially on direct observations and partially on supposition. This final ice limit is henceforward referred to as the estimated ice limit. It indicates the edge of the DMI classification "open drift ice". In certain regions and in certain months, the charts contain the phrase "state of the ice unknown" or "no data", although an estimated ice limit is generally given for such areas.

The number of direct observations plotted on these charts is not great, even in the later years. The coverage is reasonable around Greenland, Iceland, and Spitzbergen. Elsewhere, and particularly in the Western Arctic, the coverage is poor. The question of which information to digitize from the DMI charts posed some problems. Obviously, the direct observations, plotted in red, must be considered the most reliable; however, their variable coverage in space and time precludes rigorous statistical analysis. It was decided, therefore, to digitize the estimated ice limit initially, and perhaps to add to this at a later stage. In regions of good data coverage, the estimated limit conveniently synthesizes the direct observations, and even in regions of poor coverage, may contain some reliable information.

The latitude and longitude coordinates of the estimated ice limit were digitized at a spatial resolution of about 100 km, depending on the distance of the particular set of points from the pole. It was felt that the accuracy of the data and the coarseness of the definition of the limit on the charts did not warrant increased spatial resolution. These coordinates are currently being transferred onto the grid shown in figure 1. This grid, over the area analyzed in the DMI charts, corresponds to that used by Walsh in his digitization of recent data (Walsh, 1978). The resulting data set will give an ice/no-ice indicator for each square in the grid. At a later stage, details of ice concentration may be substituted for the simple ice/no-ice indicator where data are available. Also, various regions are to be selected for close study, and a finer grid employed.

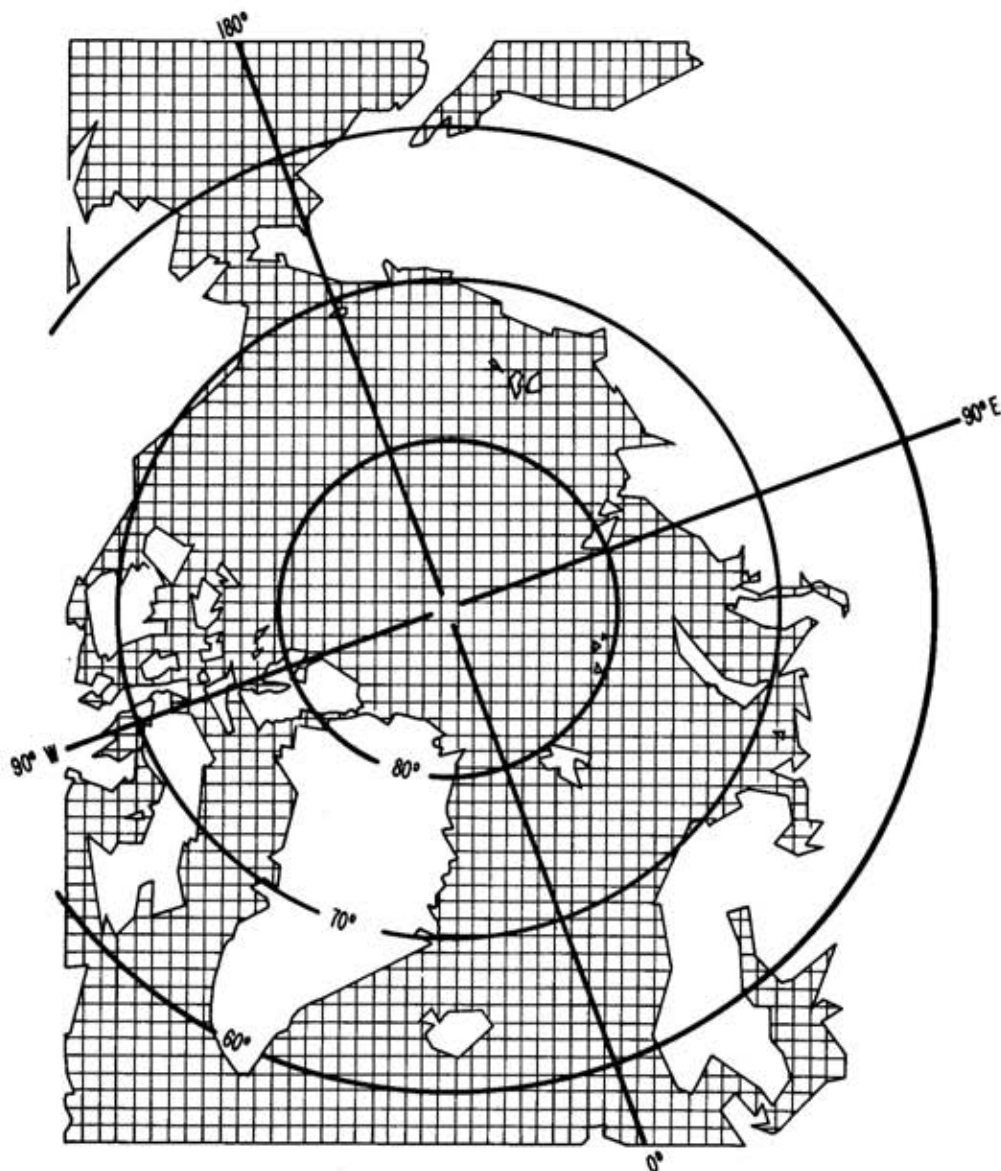


Figure 1. Standard one-degree ice data grid.

As we have digitized the full circumpolar limit, including the estimated limit in regions of little or no data, the question of data reliability or homogeneity is of great importance and is currently being assessed. The following points are being studied:

1. How does the Danish sea ice terminology correspond to recently developed conventions?
2. How reliable were the original shipping and shore observations of sea ice?
3. How, and by whom, were the charts compiled from the direct observations?
4. How was the ice limit estimated in regions of scarce or nonexistent data?

This final question is perhaps the most important. It is obvious that at certain times and in certain regions, the estimated ice limit follows the climatological "normal" also given on the charts. At other times, this is not the case; an extrapolation has somehow been made. There are three fairly obvious possibilities:

1. Extrapolation in space, from adjacent areas where data were available;
2. Extrapolation in time, using data from previous months;
3. Using auxiliary information; perhaps unplotted ice data or possibly climatic or atmospheric circulation data.

The reliability of these estimation methods depends to a great extent on the experience of the chart analyst, and, given the wide variations in sea ice extent during the present century, upon the period of years on which this experience is based. Hence, the importance of determining how, and by whom, the charts were compiled. The preparation of the reports was undertaken by four people during the period 1901-56 -- V. Garde, C.J.H. Speersneider, H. Thomsen, and M.V.L. Lorck -- well-known names in the history of sea ice investigations.

In order to resolve these problems, two approaches are being taken. First, information pertaining to the compilation of the charts is being sought from the Danish Meteorological Institute and in the relevant scientific literature. Second, various statistical analyses are being undertaken. Principal component or eigenvector analysis is being used to identify the most important spatial patterns of variability in the sea ice and climatic data sets. This technique can also be used to highlight gross errors (Kelly and Chance, 1978). A number of long series of sea extent data at various locations have been collected (see table 1) and these, if based on independent data, will be used to verify the DMI data set. The data set produced by Walsh (1978) overlaps the DMI data set during the period 1953 to 1956 (although it is not strictly independent), and will also be used for comparison purposes.

After this assessment is complete, gross errors will be removed from the DMI data set, the data will be flagged with a reliability rating, and will then be made available to other investigators. A detailed description of the data set will be prepared for publication at that time.

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Table 1. Sea ice data for the Northern Hemisphere.

LOCATION	PARAMETER	PERIOD	SEASON	SOURCE
Arctic Ocean (eastern)	Weighted total of ice in Greenland, Barents and Kara Seas.	1895-1924	April-August	Brooks and Quennel (1928)
Arctic Ocean (eastern)	Index of ice severity in Greenland and Barents Sea and around Spitzbergen.	1897-1938	January-December	Walker (1947)
Kara Sea (a)	Area	1895-1915	April-August	State of the Ice in Arctic Seas: Supplement (1917) Nazarov (1947)
(b)	Severity index	1868-1946		
Barents Sea (a)	Area	1895-1915	April-August	State of the Ice in Arctic Seas (1917) Maksimov, Smirnov and Vorob'ev (1964)
(b)	Area	1900-1960	April-August	
Greenland Sea (a)	Area	1877-1915	April-August	State of the Ice in Arctic Seas: Supplement (1917) Kirillov and Khromtsova (1972)
(b)	Area	1924-1968	April-August	
Iceland	Weeks per year with drift ice on coast	1600-1975	October-September	Lamb (1977), Koch (1945), Thorarinnsson (1956)
Baltic (a)	Date of final opening of Port Riga	1530-1958		Lamb (1977), Betin and Preobazensky (1959), Speerschnneider (1915, 1927).
(b)	Maximum area	1720-1957		
(c)	Number of days with ice.	1763-1926		
West Greenland	Northward extent of "Storis"	1821-1939		Koch (1945), Lamb (1977)
Newfoundland	Index based on maximum eastward and southward extent of ice	1920-1973	April	Miles (1974)
Western Atlantic: icebergs (a)	Severity index	1886-1939	March-July	Walker (1947)
(b)	Number of icebergs south of 48° N.	1900-1976	September-August	U. S. Coast Guard
Baffin Bay	Date of clearing	1952-1974		Keen (1977), Dunbar (1972)
North Slope, Alaska	Severity index	1953-1976	Summer	Barnett (1978)
Okhotsk Sea	Anomaly of drift ice period (days) at (a) Abashiri (b) Shana	1892-1945		Sawada (1957)

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Appendix I

A BASIS FOR FORECASTING THE ARCTIC SEA ICE OVER A FEW MONTHS TO MANY YEARS

The project, which is funded by the U.S. Office of Naval Research, commenced in September 1977. The objective is to lay the foundations of a scientific forecasting ability for the Arctic sea ice on time scales of a fraction of a year to decades.

This is to be accomplished in three stages:

- (A) The collection and digitization of available sea ice data for the Arctic extending back to the 19th century.
- (B) The identification of past variations in sea ice extent and associated fluctuations in climate and the atmospheric circulation.
- (C) If feasible, the development of a forecasting scheme based on a thorough understanding of the mechanisms underlying the variations in sea ice, climate and the atmospheric circulation.

Inadequacies in Archived Sea Ice Data

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Introduction

Needs are increasing rapidly today for sea ice data to support shipping, under ice operations, oil rig structures and terminal design, studies of air and water pollution impact and control, and to determine the effects of sea ice in climatic prediction and modification.

Since ice predictions were initially provided by U.S. Navy activities in support of surface shipping, several factors have operated to make difficult the establishment of a coherent body of quality data. Firstly, only since 1953 has the United States conducted regular reconnaissance and a forecasting service. Hence, codes, definitions, and nomenclature have developed slowly since that time and have not been altogether suitable for numerical, exactly defined, components of a data base. For example, ice thickness data have been based on differently defined categories and groupings. The same applies to floe size distribution; concentration, amount of ice, or stages of development types versus the amount of open water available; ridging or roughness -- both surface and subsurface, etc. Secondly, development for both airborne and satellite technology in remote sensors and sea ice interpretation spurred in NASA's vigorous programs has resulted in a constantly increasing sophistication in terms of spatial, thermal, and other types of resolution in defining key ice features and processes with a constantly greater degree of exactitude. Thus since 1962, the user of ice data and information has had to deal with combining his traditional, largely estimated, visual observations with the electromagnetic and optical (laser data on ice topography) data in formulating data bases for real-time extrapolation or forecasting and for development of "normal" concepts of ice features, conditions, and distribution and their time-space variation.

In the following discussion, however, what are primarily emphasized are not so much the largely insurmountable problems, but the correctable inadequacies existent in today's processing and use of data.

The following examples are not the only errors or omissions in published accounts of historical sea ice data, and are presented simply as examples: mistakes in plotting data, ineptness in the interpretation of satellite imagery, failure to incorporate other data, and a failure to maintain continuity and a constant watch on changing conditions. In the cases presented, an understanding of sea ice distribution and the meteorological/oceanographic influences, combined with a constant watch, the use of all possible data sources, and the exercise of quality control could have prevented the inadequacies.

1. One of the most dramatic short-term changes in the extent of sea ice occurred in the Bering Sea during the period from 4 March to 8 March 1970. During that period, the Bering Sea ice pack expanded some 330 km southward over a 72-hour period. This expansion was a result of freezing (formation of new ice) and ice drift. The formation of new ice accounted for over 75 percent of the expansion. On 4 March, the air circulation was generally east to west, which would tend to maintain the pack edge in position with only limited new ice formation south of the thicker ice. On 5 March, the airflow had backed to the north, and much colder air moved from the Arctic with associated strong winds. Just south of the pack, the water temperatures were very near the temperatures necessary for new ice formation, and the advection of the much colder air caused almost immediate freezing at an accelerated rate. In 24 hours, about 110 km of the open water south of the existent ice edge froze to a thickness that enabled the satellite (ESSA series) to make detection. Within the new ice formation were belts of thicker ice, and these belts were tracked to determine the drift rate of the ice. Winds were strong and off the pack just about perpendicular to the edge. Strong winds hamper the formation and solidification of new ice by agitating the water and producing mechanically induced convection or mixing, but the air temperatures were much lower and the ice itself formed a narrow lee with relatively smooth water. This lee froze

and in turn produced another lee, which froze and formed another lee, etc. On 7 March, the strong circulation began breaking down, and by 8 March, the winds had subsided and the Bering Sea was coming under the influence of a different air mass which was not nearly as cold. During the period of the most rapid expansion (72 hours), the ice edge expanded at a rate of approximately 4.6 km per hour or 110 km per day. Rapidly changing conditions like those described above could have been dangerous for the fishing fleet or offshore drilling. The documentation of short-term changes is important to ice forecasters, providing evidence that rapid growth and expansion can take place. It is also important to other activities involved in heat budget studies, marine navigation and offshore exploration. This short-term change was not documented, although it could have and should have been.

2. During April and May of 1970, nearly 550 km of existing ice east of Greenland was not documented. As a matter of fact, existing documents provide an ice edge which is in error. One document places the ice edge nearly 550 km too far to the west. The failure to record this ice was a matter of lack of understanding of sea ice distribution, ineptness in interpreting satellite imagery, a failure to maintain a watch on the ice edge, and a failure to incorporate foreign data. Granted, the ice was partially obscured by clouds and not easily detected, but by daily evaluation the ice could have been viewed. Further, if data from Icelandic or Danish sources had been incorporated, these data would have provided other clues that more ice existed.

3. Data from aerial ice reconnaissance conducted during early October 1959 were plotted in error and accepted by ice forecasters. Within the ice message, an ice edge was provided with ice conditions north of the edge off Point Barrow, Alaska. The edge was plotted correctly, but the conditions north of the edge were plotted to the south instead of to the north, thereby indicating that the ice was hard against the coast. It may seem virtually impossible that this error could go undetected, but it did. Contributing factors to this error were a lack of "quality control" and knowledge of ice distribution, and a tendency to make assumptions when having difficulty in plotting messages. In any event, published data closed the coast to navigation about 10 days prior to the time it actually closed. These erroneous data were included in tables of closing dates and navigation dates.

In an attempt to rectify some of the errors and omissions, Sea Ice Consultants has conducted a data collection project since 1973. In the Alaskan area, for example, the actual reconnaissance messages since 1953 have been replotted, and ship and coastal station reports added. A project of this magnitude was undertaken as a result of the many mistakes encountered within existing publications when attempting to provide industry with historical ice conditions. This is not to say that other data sources do not exist and that our ice charts are completely accurate, but that they are more accurate and do provide a better insight into historical conditions than any other existing publication. In addition, but only for the Alaskan area, we have been maintaining our own record of sea ice conditions. Our charts are for periods of five days or less, depending on sea ice changes and data availability.

Conclusion

Archived sea ice data serve many purposes and various disciplines. They can be used for feasibility studies applicable to marine navigation and offshore exploration. They can also be used for studies of the global heat budget and climate, and can be used to assist in determinations pertaining to pollution control. Further, they are extremely valuable to the sea ice forecaster for "normals", drift patterns, and maximum and minimum sea ice extent.

Personnel involved in compiling historical sea ice data should understand sea ice distribution and the influencing meteorological/oceanographic parameters, use all possible data sources, and exercise quality control.

NASA Mapping Projects* (Summary)

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Firstly, it is important to realize the differences among research and development satellites (e.g., Nimbus 1-7 and Seasat-1), quasi-operational satellites (Landsat-1-D), and fully operational satellites (TIROS-N, etc.). Secondly, there are various levels of data. Table 1, from the Data Management Section of the Proposed NASA Contribution to the Climate Program, lists some satellite data sources. Table 2 classifies the data set levels. Generally, most NASA satellite data are archived at Level I and available from National Space Sciences Data Center, Goddard Space Flight Center, Greenbelt, Maryland 20771. However, the archived data vary greatly in quality, accuracy, and documentation.

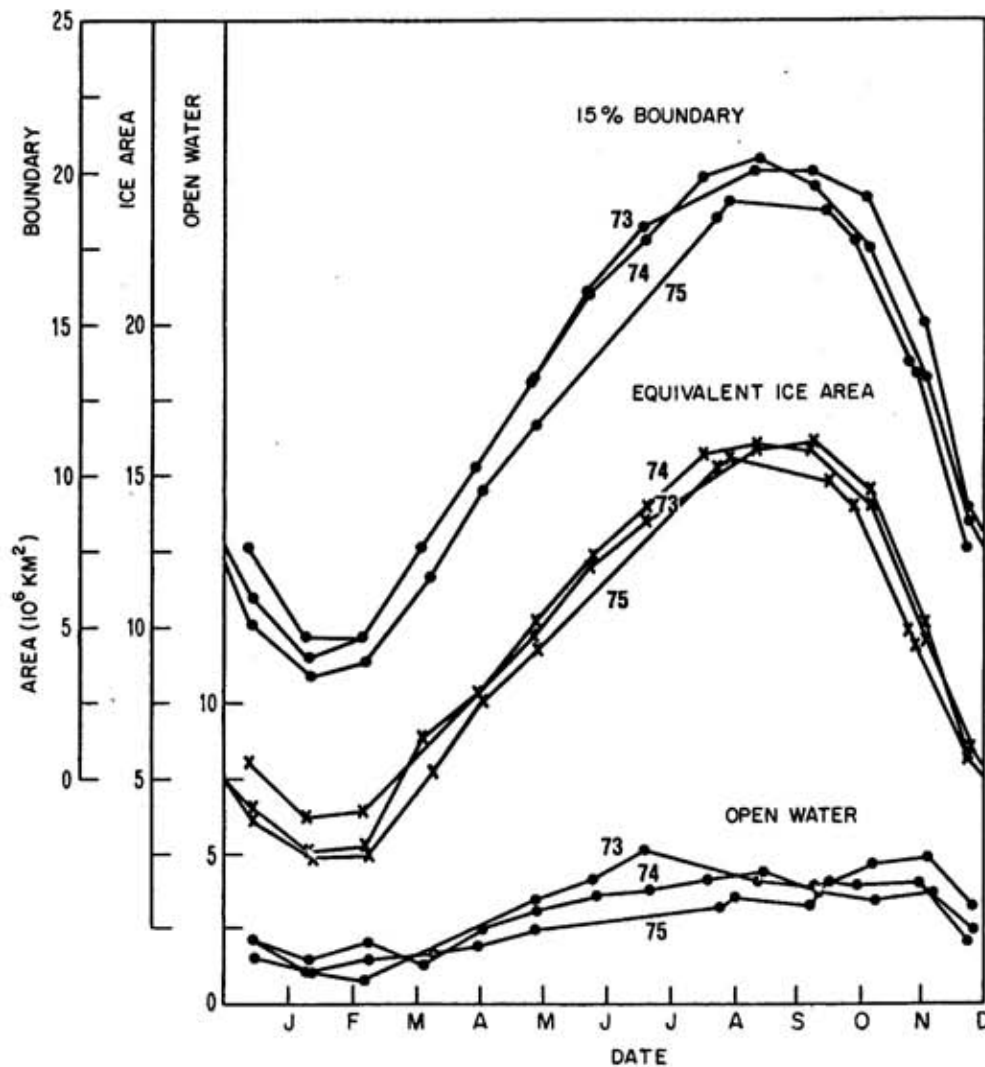


Figure 1. NIMBUS-5 - ESMR-sea ice area (Antarctic, all sectors).

Table 1. Satellite sources of climate related data.

Table 1. (Cont.)

PARAMETER	1973	1974	1975	1976	1977	1978	1979	1980 AND BEYOND	PARAMETER	1973	1974	1975	1976	1977	1978	1979	1980 AND BEYOND
SEA SURFACE TEMPERATURE	SR						AVHRR (T-N)	AVHRR/2	CO ₂ CFM N ₂ O CH ₄	REASONABLY WELL MIXED (LARGELY FROM GROUND-BASED OBSERVATIONS)					CO ₂ -LIMS N ₂ O, CH ₄ -SAMS (N-G)		LIMS/SAMS
% OPEN WATER	ESMR (N-5)		ESMR (N-6)				SMR (N-G) (S-A) SMR (N-G)	ADV. SMR	VARIABLE TROPOSPHERIC GASES (HNO ₃ , NH ₃)								
SNOW COVER	SR, VHRR						AVHRR (T-N)	AVHRR/2	POLAR ICE BOUNDARY	SR/VHRR-NOAA-SERIES					HNO ₃ LIMS (N-G) AVHRR (T-N)		AVHRR
SURFACE ALBEDO	ESMR (N-5)		ESMR (N-6)				SMR (N-G) (S-A) AVHRR (T-N)	AVHRR/2	POLAR ICE THICKNESS TOP ALTITUDE	SOME IN-SITU OBSERVATIONS					RADAR ALT. SEASAT-A		ALTIMETER
VEGETATION	SR		ERB (N-6)				ERB (N-G) AVHRR (T-N)	AVHRR/2	POLAR ICE DEFORMATION RATE	LIMITED DATA AVAILABLE FROM NAVSAT AND GROUND-BASED GEORECEIVER							ARGOS SEACONS
SOIL MOISTURE	ESMR (N-5)		ESMR (N-6)				SMR (N-G) (S-A)	LEMR	OCEAN TEMPERATURE PROFILE	NOAA-DOD EXPENDABLE BATHY THERMOGRAPH (XBT)							BUOYS
SOLAR CONSTANT			ERB (N-6)				HCMR (AEM-A) ERB (N-G) ACR (SMR)	ERB/ACR	OCEAN CURRENTS	BUOY-THERMISTOR CHAINS							BUOYS
REGIONAL RADIATION BUDGET			ERB (N-6)				ERB (N-G)	ERSS		SHIP DRIFT RECORDS-CURRENT METER RECORDS							
CLOUDS	SR		VISSR				ESMR/NEWS (N-5) ESMR/SCAMS (N-6) SMR (N-G) (S-A) SMR (N-G)	CCRBE		NOAA-DOD EXPENDABLE BATHY THERMOGRAPH (XBT)							
PRECIPITATION	ESMR (N-5)		ESMR (N-6)				SMR (N-G) (S-A) SMR (N-G)	SMR		SHIP DRIFT RECORDS-CURRENT METER RECORDS							
OZONE			BUV (N-4)				SMR (N-G) (S-A) SMR (N-G)	SMR		SHIP DRIFT RECORDS-CURRENT METER RECORDS							
STRATOSPHERIC WATER VAPOR			LRIR (N-6) LRIR (N-6)				SMR (N-G) (S-A) SMR (N-G)	SBUV		SHIP DRIFT RECORDS-CURRENT METER RECORDS							
STRATOSPHERIC AEROSOL							SMR (N-G) (S-A) SMR (N-G)	LIMS		SHIP DRIFT RECORDS-CURRENT METER RECORDS							
OPTICAL DEPTH							SMR (N-G) (S-A) SMR (N-G)	SAGE		SHIP DRIFT RECORDS-CURRENT METER RECORDS							
TROPOSPHERIC AEROSOL							SMR (N-G) (S-A) SMR (N-G)	TRACE		SHIP DRIFT RECORDS-CURRENT METER RECORDS							
OPTICAL DEPTH							SMR (N-G) (S-A) SMR (N-G)			SHIP DRIFT RECORDS-CURRENT METER RECORDS							

LEGEND

EXISTING DATA SETS

DATA SETS EXPECTED TO BE ACQUIRED FROM EXISTING INSTRUMENTS

DATA SETS EXPECTED TO BE ACQUIRED BY NEW INSTRUMENTS THAT

HAVE NOT YET BEEN LAUNCHED

N-5, -6, -G=NIMBUS 5, 6, AND G RESPECTIVELY-T-N=TIROS-N, SMM-SOLAR MAXIMUM

MISSION S-A=SEASAT-A; AEM=APPLICATIONS EXPLORER MISSION

Table 2. Classification of Data Sets

Data Set	Description	Accessibility
Raw Data	Raw telemetry data from observing instrument.	Available to parties responsible for calibrations and extraction of Level I data.
Level I (physical quantities)	Calibrated data such as brightness temperature, radiances. Extracted from raw data under rigorously controlled and documented procedures.	Available on magnetic tape to users upon request.
Level II (climate parameters)	Climate parameters at highest available spatial and temporal resolutions. Extracted from Level I data under rigorously controlled and documented procedures.	Available on magnetic tape to users upon request.
Level III (gridded climate parameters)	Spatially and temporally averaged climate parameters, including statistical information. Extracted from Level II data under rigorously controlled and documented procedures.	Available on a routine basis in hard copy form and on magnetic tape or via computer terminal.
Experimental Data Sets	Data at Levels I, II or III, but not under rigorous control. Intended for algorithm development purposes.	Available to parties responsible for development of data reduction procedures.

For several years, I have supervised a small effort to map the ESMR passive microwave data from Nimbus-5 into polar stereographic maps at 3-day intervals (Zwally and Gloersen, 1977). The data source used is the Calibrated Brightness Temperature data on orbital files in the archive (i.e., Level I data). A major problem with the earth location of the data has been corrected, but there remain calibration problems at the level of 5° to 10°K in brightness temperature. We are now converting this mapped brightness temperature data set into a set of sea ice concentration (i.e., Level II) maps. The principal product will be monthly maps of sea ice concentration in digital magnetic tape format and pseudocolor displays. We will complete the Antarctic maps for the four years, 1973 to 1976, during 1979. Figure 1 shows the preliminary analysis of the variation of Antarctic sea ice limit and open water within the pack for the years 1973, 1974, and 1975. Ice extent was less in 1975, but there also appears to have been less open water within the pack. At present, we are studying the variations in calibration over the four-year period to establish the accuracies of these curves. As we compile, analyze, validate, and publish these data, we will submit them to the World Data Center A for Glaciology (Snow and Ice).

The data processing plan for the Nimbus-7 SMMR (Scanning Multichannel Microwave Radiometer) includes the mapping of various parameters, including sea ice concentration using a multifrequency algorithm. This higher level data product will be available from the World Data Center after validation by the SMMR Experiment Team.

The processing and analysis of the radar altimeter data is not as advanced, and there is more emphasis at this time on determination of the relative and absolute accuracies. Nevertheless, a main objective of our efforts is to produce accurate data sets on ice sheet topography suitable for detection of small changes in ice sheet volume.

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Indexing Alaskan North Slope Sea Ice Conditions (1953-1977)

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Nomenclature for Mapping Sea Ice from High Resolution Satellite Imagery

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ACRONYMS

Because of the large number of acronyms present in the Workshop papers, the following list is included to assist the reader:

AES	- Atmospheric Environment Service (Canada)
AFGWC	- Air Force Global Weather Central (U.S.)
AIDJEX	- Arctic Ice Dynamics Joint Experiment
ALT	- Altimeter
ASVT	- Applications Systems Verification and Transfer
ATS	- Applications Technology Satellite
AVHRR	- Advanced Very High Resolution Radiometer
CCT	- Computer Compatible Tape
CMB	- Composite Minimum Brightness
CMT	- Composite Maximum Temperature
CRREL	- Cold Regions Research and Engineering Laboratory (U.S.)
CZCS	- Coastal Zone Color Scanner
DMI	- Danish Meteorological Institute
DMSP	- Defense Meteorological Satellite Program (U.S.)
DOC	- Department of Commerce (U.S.)
EDIS	- Environmental Data and Information Service (U.S.)
EDS	- Environmental Data Service, now EDIS
ESMR	- Electrically Scanning Microwave Radiometer
FGGE	- First GARP Global Experiment
FLEWEAFAC	- Fleet Weather Facility (U.S. Navy)
GARP	- Global Atmospheric Research Program (WMO)
GATE	- GARP Atlantic Tropical Experiment
GOES	- Geostationary Operational Environmental Satellite
GTS	- Global Telecommunications System
HRPT	- High Resolution Picture Transmission
IAHS	- International Association of Hydrological Sciences
ICSU	- International Council of Scientific Unions
IDOE	- International Decade of Ocean Exploration

IHD	- International Hydrological Decade
IHP	- International Hydrological Program
IR	- Infrared
ITOS	- Improved TIROS Operational Satellites
IUGG	- International Union of Geodesy and Geophysics
LED	- Light Emitting Diode
MPC	- Multispectral Photographic Camera
MSS	- Multispectral Scanner Subsystem
NASA	- National Aeronautics and Space Administration (U.S.)
NAWDEX	- National Data Water Exchange (U.S.)
NCC	- National Climatic Center (U.S.)
NESS	- National Environmental Satellite Service (U.S.)
NMC	- National Meteorological Center (U.S.)
NOAA	- National Oceanic and Atmospheric Administration (U.S.)
NODC	- National Oceanographic Data Center (U.S.)
NWS	- National Weather Service (U.S.)
OASSO	- Operational Application of Satellite Snowcover Observations
POLEX	- Polar Experiment (GARP Program)
RBV	- Return Beam Vidicon
RFC	- River Forecast Center
SAR	- Synthetic Aperture Radar
SASS	- Microwave Scatterometer
SCS	- Soil Conservation Service (U.S.)
SDSB	- Satellite Data Services Branch U.S.)
SEM	- Space Environmental Monitor
SLAR	- Side Looking Airborne Radar
SMS	- Synchronous Meteorological Satellites
SMMR	- Scanning Multichannel Microwave Radiometer
SNOTEL	- Snow Telemetry
SPM	- Solar Proton Monitor
SR	- Scanning Radiometer
SSEC	- Space Science and Engineering Center, University of Wisconsin
SST	- Sea Surface Temperature

UNESCO	- United Nations Educational, Scientific and Cultural Organization
USGS	- U. S. Geological Survey
VHRR	- Very High Resolution Radiometer
VIR	- Visible and Infrared Radiometer
VIS	- Visual
VISSR	- Visible and Infrared Spin Scan Radiometer
VTPR	- Vertical Temperature Profile Radiometer
WMO	- World Meteorological Organization
WWW	- World Weather Watch (WMO)
ZTS	- Zoom Transfer Scope