SR 127

Special Report 127

SURFACE MEASUREMENTS OF SNOW AND ICE FOR CORRELATION WITH AIRCRAFT AND SATELLITE OBSERVATIONS

Michael A. Bilello

May 1969

DA TASK 1T061102B52A02

U.S. ARMY MATERIEL COMMAND
TERRESTRIAL SCIENCES CENTER
COLD REGIONS RESEARCH & ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

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PREFACE

This report was prepared by Mr. Michael A. Bilello, Research Meteorologist, of the Research Division, Cold Regions Research and Engineering Laboratory, U.S. Army Terrestrial Sciences Center (USA TSC). The author wishes to thank Dr. Chester C. Langway, Jr., Chief, Snow and Ice Branch, USA TSC, and Mr. Frederick J. Sanger of USA TSC for their technical review of the report.

The observations at the network of stations described in this report were made by personnel associated with the Meteorological Branch, Canadian Department of Transport; the Alaska Regional Office and Polar Operations Project, Environmental Science Services Administration; the Soil Conservation Service, Alaska Division; and the U.S. Air Force Air Weather Service. Mr. Bilello, in cooperation with the above agencies, established and maintained the continuity of record from these snow and ice observing stations for USA TSC. This report was published under DA Task 1T061102B52A02, *Research in Earth Physics – Cold Regions and Related Environments.*

USA TSC is a research activity of the Army Materiel Command.

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SURFACE MEASUREMENTS OF SNOW AND ICE FOR CORRELATION WITH AIRCRAFT AND SATELLITE OBSERVATIONS

by

Michael A. Bilello

INTRODUCTION

Examination of photographs received from aircraft and meteorological satellites has confirmed the effectiveness of such observations for surveying the snow and ice cover of the cold regions of the world.

Fritz (1963) states that, "Satellites can see white snow fields against darker backgrounds. Moreover, a snow field can be distinguished from clouds, which also appear white in satellite pictures, when pictures are taken on successive days. The cloud patterns change from day to day, but the snow fields generally remain unaltered over a period of a few days." Wark *et al.* (1962) report that from TIROS II photographs "many details of the ice can be distinguished, such as type of ice, amount, and presence of leads and cracks." They further state that although some clouds of a certain type and amount resemble ice, there is usually enough difference in appearance to allow identification by an experienced interpreter.

Snow and ice reconnaissance from satellites continues to improve since the sensors are now earth-oriented and the vehicles are in quasi-polar orbits. The equipment on board is also improving and with time will be able to take on new and more sophisticated tasks such as recording the depth and density of the snow cover and the thickness of ice on lakes, rivers, and oceans.

It would be beneficial to be able to verify the data collected from these sensors with concurrent ground measurements. An extensive observation network which could provide information on snow properties and ice thicknesses in North America is the subject of this paper.

NETWORK FOR OBSERVING SNOW AND ICE*

To provide information on the thickness of sea, lake and river ice, and the properties of the snow cover, a number of stations for observing snow and ice were established in North America starting in 1946. This network extends from the west coast of Alaska to the east coast of Canada, and from just below 83°N latitude to as far south as the Great Lakes (Fig. 1, 2). The data obtained at these widely distributed stations are valuable to commercial fishermen, loggers, aircraft pilots, government agencies, and the military. The military uses of the data are in connection with, for example, the winter movement of troops and vehicles, the landing of aircraft on ice, and the operation of icebreakers and other ships in ice. The data have also proved useful for long-range analyses of climatic and environmental regimes in the Arctic and Subarctic.

The first five stations in the network were established in the Canadian Archipelago between 1946 and 1950 as a joint venture of the Canadian Department of Transport's Meteorological Division

* Portions of this and the following section were taken from a brief report given by the author at the 15th Meeting of the U.S. Army Meteorological R&D Coordination Committee, Hanover, N.H., Nov 1966.

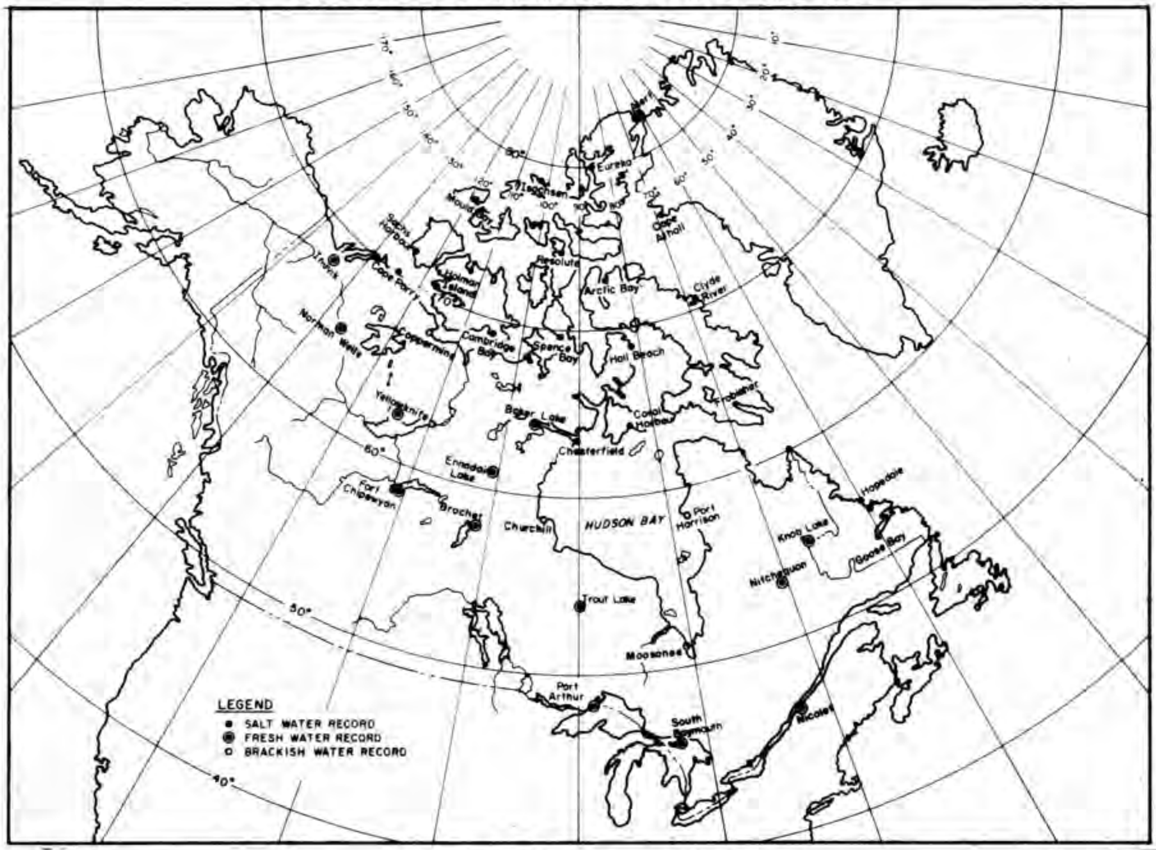

Figure 1. Canadian stations.

and the USAF Air Weather Service, and the Alaska Regional Office of the U.S. Weather Bureau. Later, personnel from the Soil Conservation Service and USARAL (U.S. Army Alaska) contributed their services and the network gradually expanded to the south and west. Most of the observations are made by military and civilian personnel associated with these agencies. Many measurements in Alaska are made by Eskimos, native Indians, school teachers, clergymen, homesteaders, and lodge-keepers.

TYPES OF OBSERVATIONS AND EQUIPMENT

Snow observations

The snow observations are made in accordance with standard procedures described in USA CRREL Instruction Manual No. 1 (USA CRREL, 1962). Each layer of snow in a vertical profile is visually delineated by structural differences, such as size and shape of the snow grains, or textural variations identifying periods of major snow accumulation. Density, temperature, hardness and crystal size are measured weekly.

The National Research Council of Canada provided the original snow-measuring equipment. CRREL later designed its own snow kit (Fig. 3). The CRREL equipment differs only slightly from that in the Canadian kit and consists of:

1. A set of snow-sampling-tubes to measure density.
2. A balance for weighing snow samples.
3. Two hardness gages, with disks, of 1 to 100,000 g/cm^2 capacity.
4. A set of thermometers to measure snow temperature in different layers.

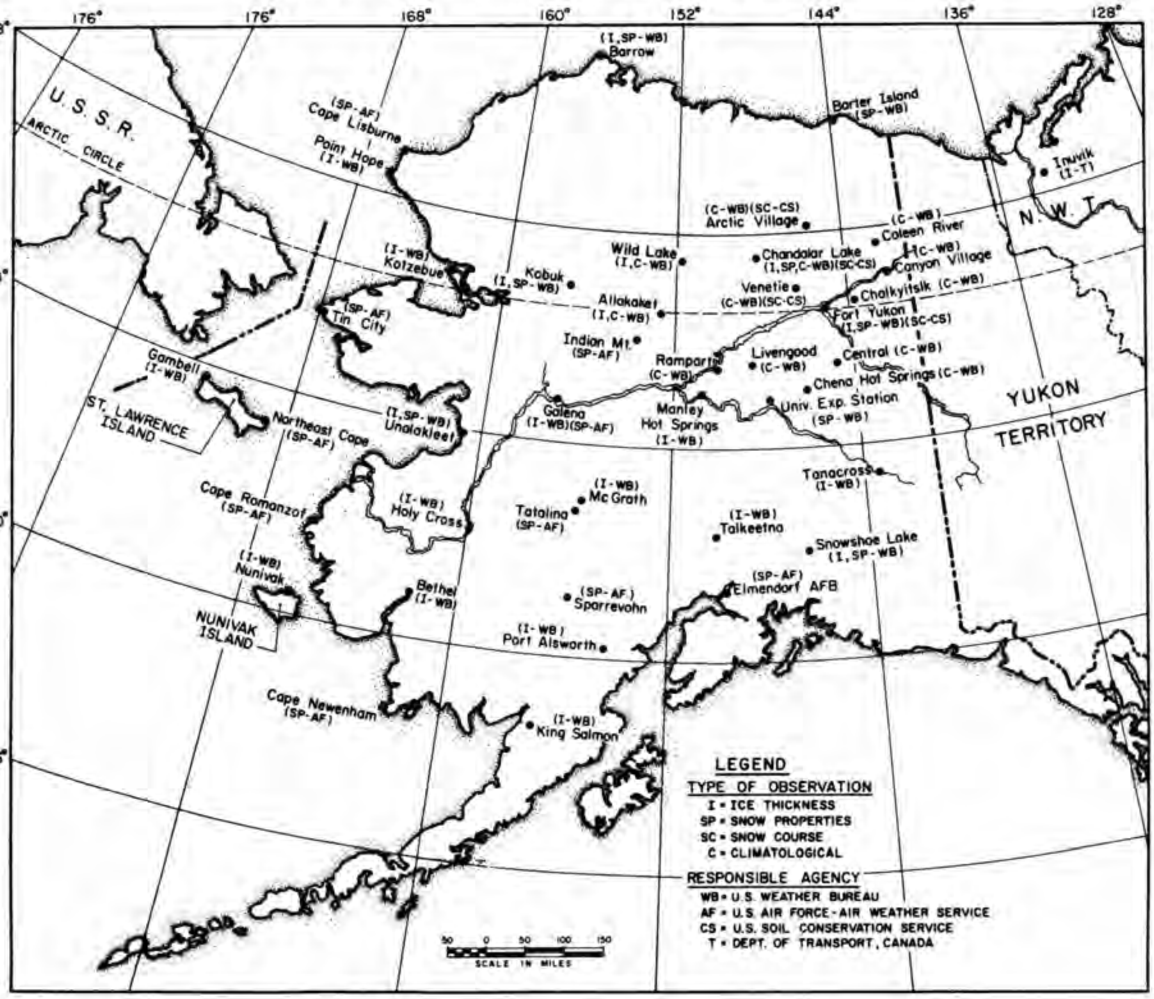

Figure 2. Alaskan stations.

5. A snow cutter and mandrel.
6. A 6-ft carpenter's rule.

Ice observations

During the first years of operation, ice thickness was measured through holes chiseled in the ice. When the ice was too thick for chiseling, the upper part was blasted with dynamite. To facilitate the ice thickness observation and to improve the accuracy of measurement, CRREL developed a hand-operated ice auger (Fig. 4) and, in April 1956, distributed one to each station. With this auger, a 1- or 1½-in.-diam hole can be bored by hand through 7 ft of ice in about 15 minutes.

To measure ice thickness, a measuring tape with a short pivotable rod attached to its end is lowered into the augered hole. When the rod is below the ice, it swings to a horizontal position. The tape is then lifted until the rod contacts the undersurface of the ice. The thickness of the ice is then recorded. A separate wire attached to the end of the rod is used to return it to the vertical position so that the rod and tape can be withdrawn from the hole.

The ice thickness observations are made once each week in bodies of water close to the station. The snow depth on the ice as well as ice surface conditions, e.g. occurrence of cracks and leads and dates of first-ice, freeze-over and break-up, are also recorded.

1. SNOW TUBES (12)
2. MANDREL
3. DIAL THERMOMETERS (6)
4. PROBE (2)
5. SCALE
6. SNOW CUTTER
7. SNOW TUBE CASE
8. SNOW HARDNESS DISK X1 (2)
9. SNOW HARDNESS DISK X10 (2)
10. SNOW HARDNESS DISK X100 (2)
11. SNOW HARDNESS DISK X1000 (2)
12. GAGE HARDNESS, RED AND BLACK
13. RULE (6 FT)
14. FIBER KIT

Figure 3. Snow observation equipment.

1. ICE CHISEL
2. MEASURING TAPE, WITH ROD
3. EXTENSION RODS
4. AUGER PROTECTIVE CAP
5. AUGER
6. BRACE
7. CANVAS COVER

Figure 4. CRREL ice thickness measuring kit.

Most observers auger only one hole at each site each week. Personnel associated with the U.S. Department of the Interior, Geological Survey, Water Resources Division periodically measure flow beneath the river ice in Alaska during the winter. The thickness of the ice is thus measured every few feet or yards across the river. These data have been published by USA CRREL (Bilello and Bates, 1966, App. A).

TYPICAL INFORMATION OBTAINED FROM THE NETWORK

Snow cover properties

An analysis of snow-cover density, temperature, and hardness data obtained from the network showed snow in the Canadian Archipelago to be colder, denser and harder than in the interior of Alaska (USA SIPRE, 1957). The range in snow-cover density for interior Alaskan stations is approximately 0.13 to 0.20 g/cm^3 in November and 0.23 to 0.27 g/cm^3 in March. The densities along the north coast of Alaska and the northern islands of Canada range from approximately 0.30 to 0.36 g/cm^3 in November, and from 0.33 to 0.39 g/cm^3 in March.

A subsequent study contained additional snow data from the network and associated regional variations in snow density with observed temperatures and wind speeds (Bilello, 1966).

Figure 5 is an average snow density map of North America in which the continent was divided into four categories (Table I).

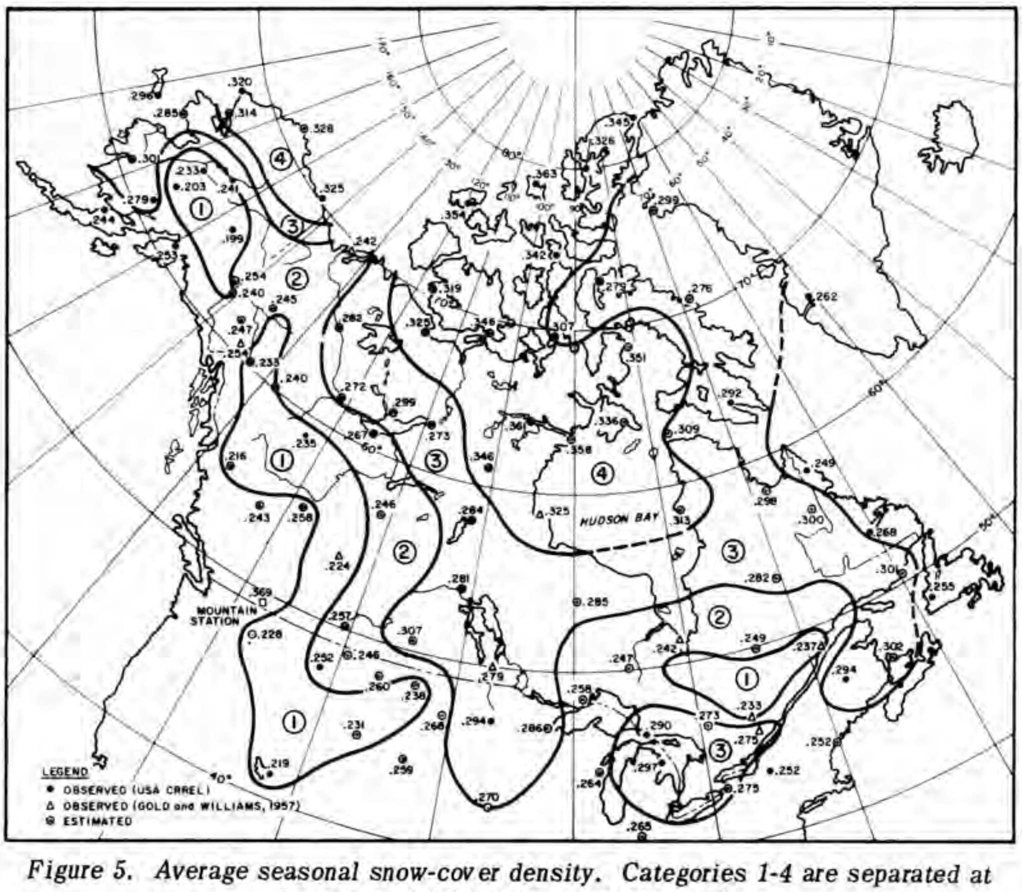

Figure 5. Average seasonal snow-cover density. Categories 1-4 are separated at densities of 0.24, 0.27 and 0.31 g/cm^3.

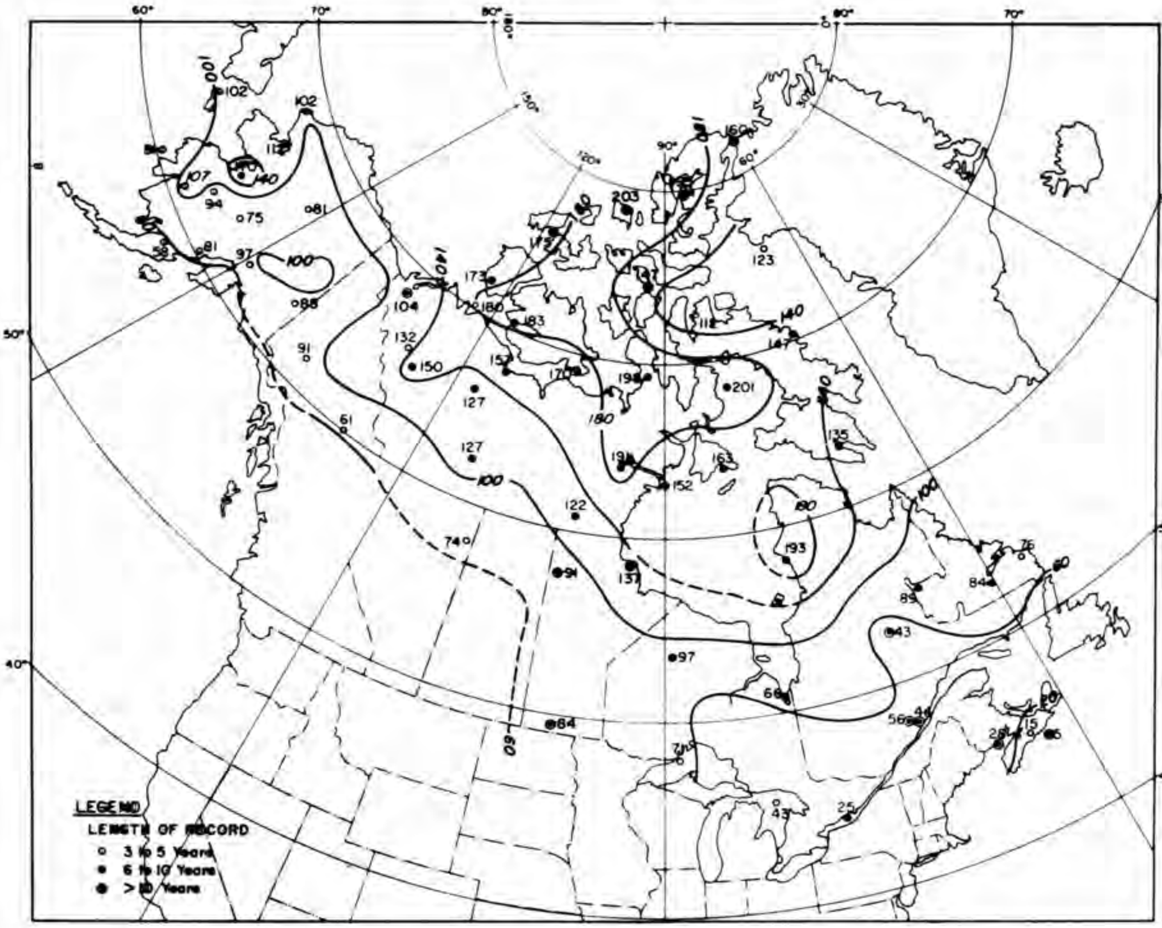

Figure 6. Least ice thickness (cm) observed at the time of maximum thickness for the years of record.

Table I. Snow-cover density categories of North America.

Category	*General region*	*Winter wind conditions*	*Average seasonal snow-cover density (g/cm^3)*
1	Inland	Light	<0.24
2	Variable	Moderate	⩾0.24 to <0.27
3	Inland and coastal	Moderate to strong	⩾0.27 to <0.31
4	Arctic and subarctic	Strong and frigid	⩾0.31

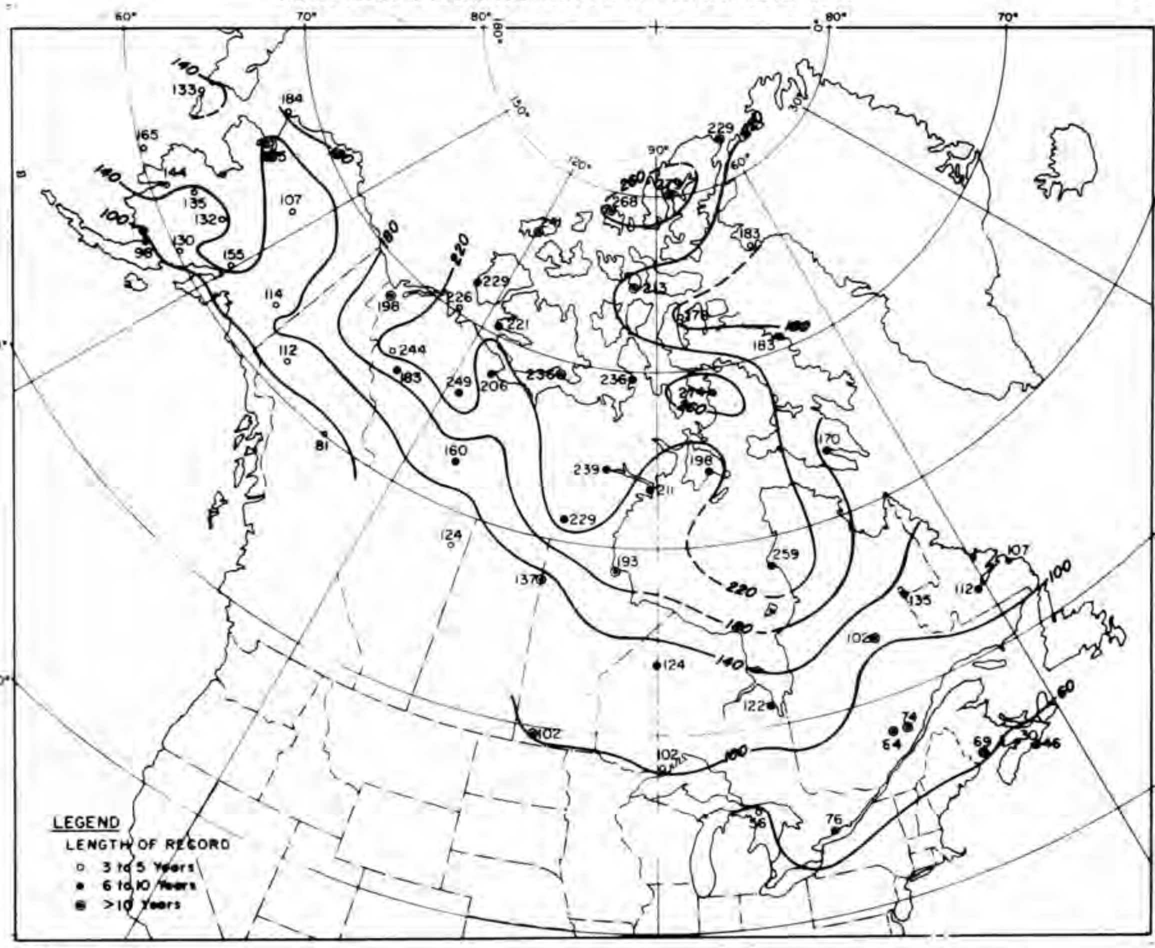

Figure 7. Greatest ice thickness (cm) observed at the time of maximum thickness for the years of record.

Naturally, the local topography and vegetation create differences in the density from point to point within a region defined by category. Deviations from the average value for each region can also be expected from month to month and year to year. Standard deviations from the average values ranged from 0.03 to 0.10 g/cm^3.

Ice thickness

The ice network provided data on the thickness and conditions of fast-ice on lakes and rivers and along the coast in North America; the data are given in USA CRREL Special Report 43 (Bilello, 1961, 1964; Bilello and Bates, 1966). To indicate the magnitude and distribution of ice thickness, isoline maps of maximum observed ice thicknesses are also presented for each year starting with the winter of 1956-57.

The ice thickness data that have been collected have made possible an analysis of: 1) the *least* ice thickness observed at the time of maximum thickness (Fig. 6), and 2) the *greatest* ice thickness observed at the time of maximum thickness (Fig. 7). Some of the information used in Figures 6 and 7 was obtained from the Department of Transport (Canada) (1959).

In Canada, the least ice thickness observed at the time of maximum thickness ranged from less than 20 cm in the vicinity of Nova Scotia to near 200 cm in the north central region (Fig. 5). In Alaska, excluding the Aleutian chain and the southeast panhandle regions, the value ranged from near 60 cm in the southern part of the state to 170 cm on the west coast. From Figure 7, we find that the greatest ice thickness observed in Canada ranged from 30 cm near Nova Scotia to over 260 cm in parts of the Arctic.

In some instances, extreme variability in ice thickness, caused by ice-rafting, is observed. Ice-rafting in oceans is caused by wind, waves, tides and currents. On lakes and rivers thawing conditions and changes in water level also cause the ice to break up and raft. Ice thickness measurements which indicate major rafting on some rivers in Alaska during November and December 1956 are presented by Bilello and Bates (1966, Appendix A).

DISCUSSION

The main purpose of this report was to present a network of stations in North America where observations on the properties of snow and the thickness of ice are being made. Results of studies using the data collected from these stations show that despite areal and yearly variations definite patterns in the magnitudes of the values emerge when they are plotted on small scale maps.

Aerial infrared and passive microwave systems are being studied for separating clouds from snow-covered terrain and for penetrating clouds to obtain snow and ice data. The Nimbus II High Resolution Infrared Radiometer pictures, taken at midnight, showed the Gulf Stream in the Atlantic Ocean by differentiating surface water temperatures (American Meteorological Society, 1966). A method of determining the temperatures of rivers by means of narrow-angle radiation-measuring devices installed in satellites has also been investigated (Dmitriev and Evnevich, 1966). Snow depths (Barnes and Bowley, 1969) and heights of snowdrifts and rafted ice can be estimated by photogrammetry.

Development of advanced equipment to measure snow depth and ice-thickness from aircraft or from space is currently under contract by several agencies, including the U.S. Army and ESSA. Remote sensors to provide information on the properties of snow and ice on earth will very likely be developed in the near future (Carter, 1967).

Another approach would be to install equipment such as snow pillows (Beaumont, 1968) and nuclear devices within remote snowpacks to measure the density. The equipment would contain a telemetering device to periodically send information to satellites which, in turn, would relay it to a central station on command. The same procedures could be used to obtain ice thickness measurements in isolated regions. However, this plan would present several problems; for example, 1) installation of the equipment, 2) care and reliability of the sensors, 3) type and longevity of the power pack and 4) telemetry operation under adverse conditions.

These are but a few of the ground/space systems for measuring surface snow and ice conditions which undoubtedly will be tested in the future. When one of the systems proves promising, observations by man on the ground could be used to verify its worth.

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DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Cold Regions Research & Engineering Laboratory U.S. Army Terrestrial Sciences Center, Hanover, New Hampshire 03755	**2a. REPORT SECURITY CLASSIFICATION** Unclassified **2b. GROUP**

3. REPORT TITLE

SURFACE MEASUREMENTS OF SNOW AND ICE FOR CORRELATION WITH AIRCRAFT AND SATELLITE OBSERVATIONS

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Special Report

5. AUTHOR(S) *(First name, middle initial, last name)*

Michael A. Bilello

6. REPORT DATE	**7a. TOTAL NO. OF PAGES**	**7b. NO. OF REFS**
May 1969	13	14

8a. CONTRACT OR GRANT NO.	**9a. ORIGINATOR'S REPORT NUMBER(S)**
b. PROJECT NO.	Special Report 127
c. DA Task 1T061102B52A02	**9b. OTHER REPORT NO(S)** *(Any other numbers that may be assigned this report)*
d.	

10. DISTRIBUTION STATEMENT

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11. SUPPLEMENTARY NOTES	**12. SPONSORING MILITARY ACTIVITY** Cold Regions Research and Engineering Laboratory, U.S. Army Terrestrial Sciences Center, Hanover, N.H. 03755

13. ABSTRACT

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 is in an early stage of development. Correlation of the remote sensing data with actual surface conditions could be accomplished through use of an existing network of snow and ice stations located throughout North America. This network, comprising over 100 stations, is maintained by U.S. Army Terrestrial Sciences Center (USA TSC) in cooperation with other government agencies and accumulates the most extensive and reliable data for such correlation studies.

14. KEY WORDS

Ice
Ice reporting
Meteorological satellites
Remote sensing
Snow
Snow cover
Snowfall
Weather intelligence
Weather observations
Weather reconnaissance aircraft
Canada -- Weather stations
Alaska -- Weather stations