DATA ON ICE THICKNESS

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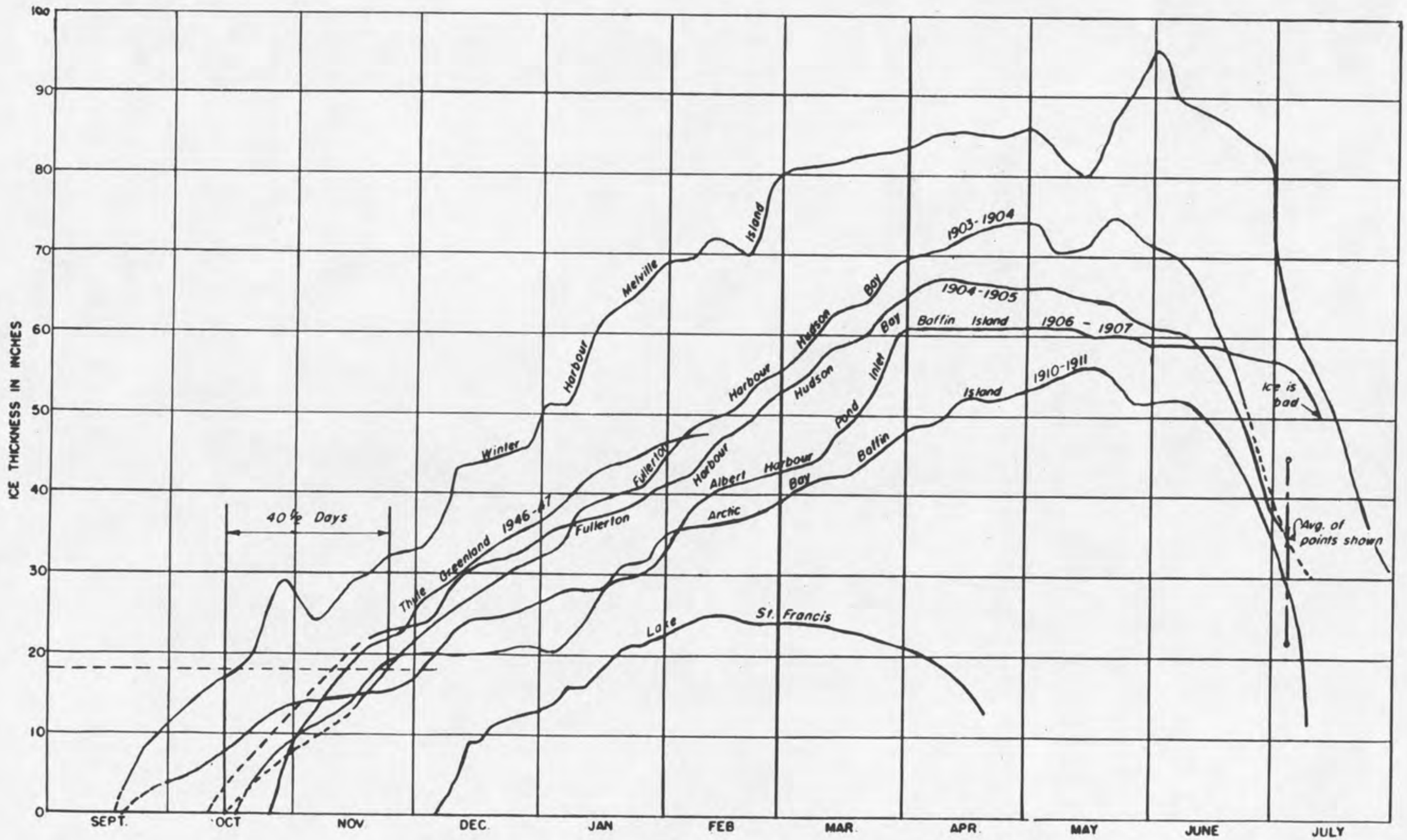
Introduction

In 1946 the Arctic Construction and Frost Effects Laboratory of the Corps of Engineers, U.S. Army, undertook a study of the occurrence, duration and quality of ice in the Northern Hemisphere. The study has not been extensive in as much as it was only one part of a continuing comprehensive investigation of the construction and maintenance of airdromes on ice, made for the Office of the Chief of Engineers. The interest of this laboratory, hereafter referred to as ACAFEL, has therefore been more as a user of the information than as a collector.

Early Studies

A limited survey of the available information was first conducted on ice thicknesses, types of ice, and rates of formation. It was found that information on freeze-up and break-up dates, and the duration of ice-cover per season, was relatively plentiful and easily collected. The Hydrographic Office of the U.S. Navy had recently completed and published the "Ice Atlas" (Reference 2) which contained a wealth of information on ice conditions and particularly the duration of ice-cover. However, even this excellent report did not provide the desired answers to the specific questions of where and for how long a period ice in the Northern Hemisphere reaches a thickness and quality sufficient to support aircraft and surface vehicles. In the rather extensive literature study conducted by ACAFEL for the overall comprehensive investigation on airdromes on ice, a few records of ice formation for specific stations in the Arctic were found.

Figure 1 shows observed rates of growth and melting of ice for various locations in the Arctic region. These data were the most complete of the records found during this first investigation. It will be noted that all the curves shown are for salt water ice except that for Lake Saint Francis. From these, and other even more limited and fragmentary data, it was concluded that for northern areas a period of approximately six weeks is required in the fall to freeze 18 inches of fresh or salt water ice. Eighteen inches was arbitrarily chosen to represent a minimum safe thickness of ice to support the common type aircraft of the 1940's. The tremendous increase in the size and weight of planes in recent years, however, has made this thickness obsolete for its original purpose, but it may still be taken as a base for the development of data. Likewise from these curves and other less complete data, it was estimated that a period of approximately three weeks might be the average time when the ice would be unusable at the end of the season before the ice went out.



NOTES

All curves for salt water Ice except Lake St. Francis.

The average period required for formation of 18" of ice from the above curves is $38\frac{1}{2}$ days (taken as 6 wks).

Typical example is the curve of Fullerton Harbour, Hudson Bay for year 1903-04 which shows $40\frac{1}{2}$ days required to form 18" of ice.

Location	Source of Data
Lake St. Francis	Ice Engineering by H.T. Barnes
Winter Harbor	Arctic, Desert, and Tropic Information Center Preliminary Report on Suitability of Ice for Aircraft Landings.
Arctic Bay, Melville Island	Report on the Dominion Government (a) Expedition to the Northern Waters and Arctic Archipelago of the D.G.S. "Arctic" in 1910
Fullerton Harbour, 1903—04	(b) Expedition to Hudson Bay and the Arctic Islands on Board the D.G.S. "Nepune" 1903—04
Fullerton Harbour, 1904-05 Albert Harbour, 1906-07	(c) Expedition to Arctic Islands and Hudson Strait on Board C.G.S. "Arctic"
Thule, Greenland	U.S. Department of Commerce, Weather Bureau, Wash., D.C.

INVESTIGATION OF AIRDROMES ON ICE

1946 — 1947

OBSERVED RATES OF GROWTH AND MELTING OF ICE

FIGURE 1

The map reproduced in Figure 2 was prepared in 1947 to show the various types of ice occurring in the Northern Hemisphere with some indication of where and for how long a time the ice might be usable for aircraft operations. It shows the areas where the three general types of sea ice occur; i.e., pack ice, drift ice and fast ice. The most extensive areas of glacier ice are also shown. For the lake and river ice areas, isopleths have been drawn, showing the estimated average number of months per season when 18 inches or more of ice would be present. The isopleths were based on charts contained in the "Ice Atlas" which gave the average number of days with ice for lakes and rivers. From the total number of days with ice there was deducted 60 days for the period when the ice was attaining a thickness of 18 inches plus the time when the ice was unusable at the end of the season. The isopleths give, of course, only an extremely general picture of ice conditions. Actual ice thicknesses and periods of usefulness would vary widely from that shown if individual locations were considered. The supposition that six weeks were required to produce 18 inches of ice, regardless of latitude, topographic locations, climate, etc., is obviously too broad an assumption, and if a more accurate map of this type is required much more information would be needed.

In the years following the publication of this first map (1947), attempts were made to collect additional data. It was soon determined that adequate data were not readily available. Furthermore, such data as were available were not assembled in a form suitable for use but were widely scattered throughout the literature.

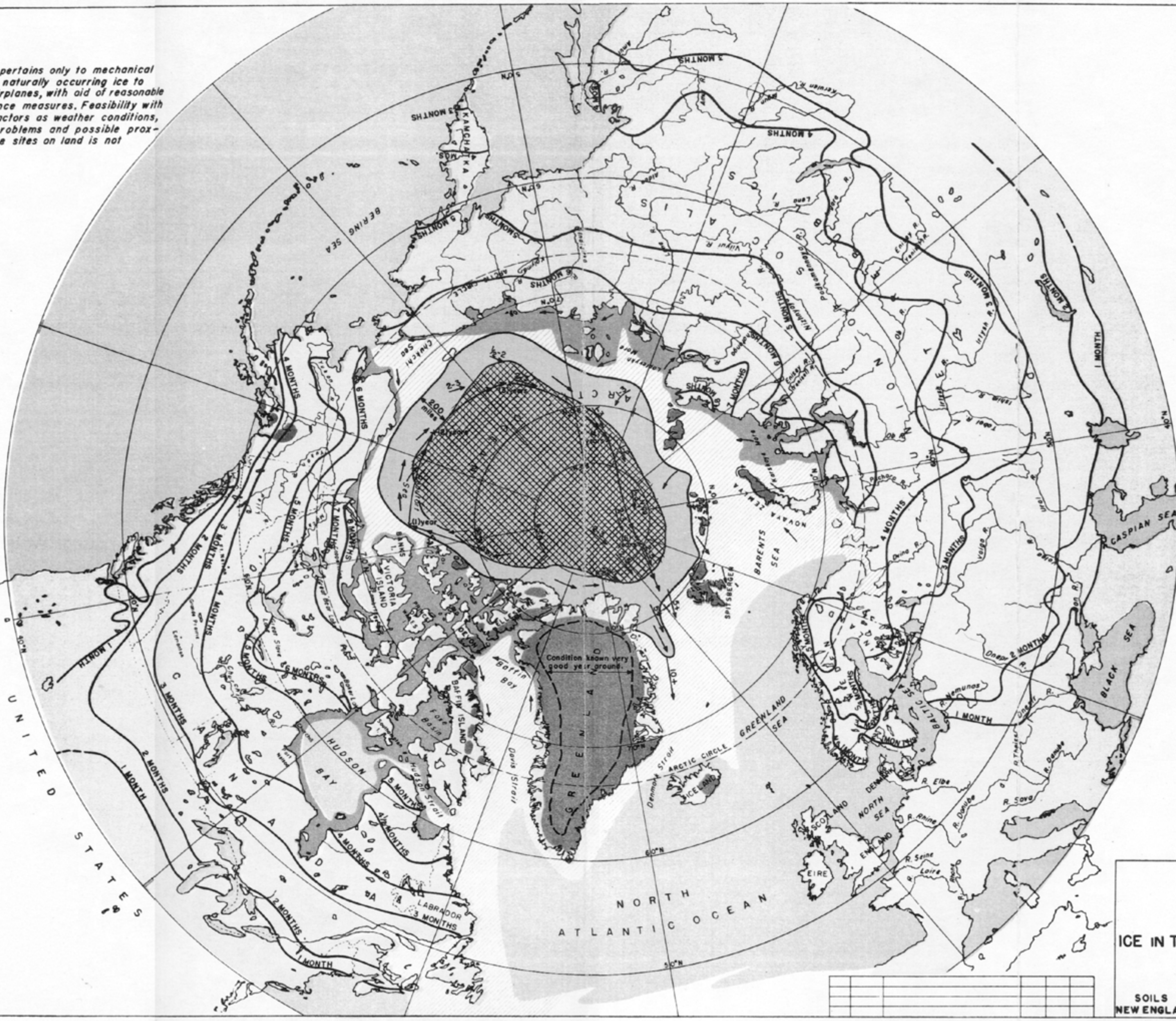
Computation of Ice Thicknesses

One solution to the problem would be to develop theoretical methods of predicting ice thicknesses on the basis of the much more plentiful meteorological data, particularly air temperatures. This possibility has not been overlooked. Some formulas were already available, such as that proposed by Barnes in his book, "Ice Engineering", (Reference 3), Chapter 3. This formula includes the factors of air temperature, time and the thermal properties of ice, and is, therefore, fundamentally an expression of the relation of ice formation to air temperature. Much work has been done on this problem since that of Barnes, and other factors influencing the rate of ice growth may be taken into account such as the effect of snow-cover, the effect of radiation, convection, etc. However, from an entirely theoretical approach, a number of factors which are known to influence the rate of ice formation are difficult to express quantitatively. Some of these factors include the effect of the turbulency of the water, the effect of subsurface temperature variations due to currents, the effect of the inorganic and organic water impurities, and the effect of wind on the surface of the water. Reliable empirical data would materially aid in the development of an adequate theoretical solution which includes all the pertinent factors.

NOTE

Data on this sheet pertains only to mechanical and structural ability of naturally occurring ice to support operations of airplanes, with aid of reasonable construction & maintenance measures. Feasibility with respect to such other factors as weather conditions, light conditions, supply problems and possible proximity to suitable airdrome sites on land is not considered.

SCALE
STATUTE MILES
NORTH AND SOUTH
0 100 200 300 400 500
EAST AND WEST
0 100 200 300 400 500



LEGEND AND NOTES

- *Major lakes and normally unfrozen seas and oceans.*
- *Areas containing lakes and rivers suitable for temporary bases as indicated by isopleths.*
- *Areas of Fast ice suitable for airdromes, 5–8 months a year.*
- *Land ice, contains areas suitable for airdromes in most cases through the full year.*
- *Areas of permanent Arctic pack not generally suitable for airdromes.*
- *Permanent Arctic pack containing areas suitable for airdromes approx. 8 months a year, (Oct. to June). Conditions for landing planes poor during remaining 4 months, but rest of establishment (radio station, etc.) can continue to function.*
- *Drifting fringe of the pack consisting of remnants of broken polar pack ice & fast ice & of local seasonal ice formations. Unsuitable for airdromes. Northerly boundary is limit of accessibility for ice breakers in occasional favorable summer seasons. Southerly limits variable with years and seasons.*
- **2 MONTHS** *Isopleths of estimated average annual number of months with 1½ ft. or more of ice on lakes and rivers.*
- **2-3** *Shows direction of ice drifts and observed average speeds over extended periods, from records of Fram, Sedov, Papanin, Jeanette, Karluk, Storkenson and other drifts. Speed in miles per day.*

Continuous line in the permanent Arctic pack indicates direction and rate of drift estimated by Stefansson for an ice camp established at A.

Estimated useful periods shown are average values and in any one year the variation from the average may amount to as much as several weeks either way. Tendency to deviate from the average will increase with decrease in latitude.

ICE IN THE NORTHERN HEMISPHERE

CORPS OF ENGINEERS
SOILS AND FROST EFFECTS LABORATORY
NEW ENGLAND DIVISION, BOSTON, MASS. MAY, 1947

FIGURE 2

American Geographical Society Contract

It was considered that the first step in obtaining the necessary data was to collect and place in convenient form all records presently available. In 1952 the Arctic Construction and Frost Effects Laboratory entered into a contract with the American Geographical Society to collect available existing data on the occurrence and thicknesses of ice in the Northern Hemisphere and place it in a form for ready reference. Funds were available for only one year's study, and it soon became evident that the task of collecting and compiling data for the entire Northern Hemisphere was too great for one year's time. The contract was modified to include only North America.

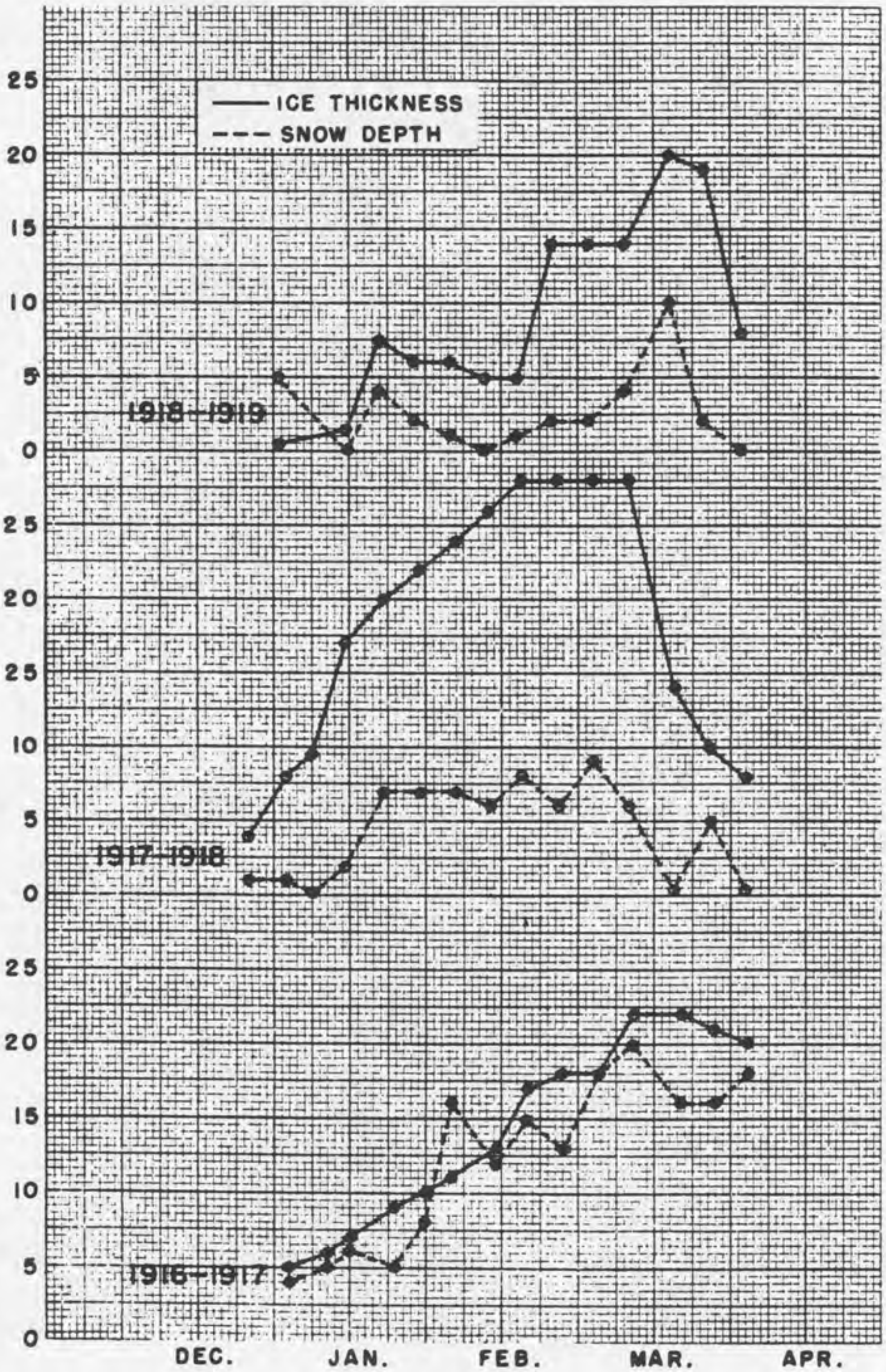
The agreement called for the tabulation of data obtained from a literature search and was to include, in addition to individual records of ice thicknesses, all available related information, such as:

1. Location of station and measuring point in relation to shore line, topography, direction of wind, etc.
2. Depth of snow on ice at time of thickness measurement.
3. Freeze-up and break-up dates.
4. Air temperatures and/or ice temperatures.
5. Depth of water at the point of thickness measurement.
6. Quality or character of the ice.

For each station where records were sufficiently complete, a summary graph was to be prepared showing the annual variation of ice thickness, time of freeze-up, time of break-up, and variation in snow-cover.

A report covering the work completed under the contract has now been prepared by the American Geographical Society. It is entitled, "Compilation and Study of Ice Thicknesses in the Northern Hemisphere", and was recently given a limited distribution by the Arctic Construction and Frost Effects Laboratory (Reference 1).

An example of one of the most complete ice thickness records in this report is reproduced in Figure 3. Ice thickness and snow-cover on the Wisconsin River at Wausau, Wisconsin, for the winters of 1916-17, 1917-18 and 1918-19 are given. To this record could be added air temperatures and possibly other meteorological measurements from other sources. Admirable as this particular set of data may be, it must be pointed out that there are still a number of shortcomings. Of principal concern is that the period of record occurred about 35 years ago and, therefore, it is unlikely that these records could be used directly in predicting present day ice conditions. On the other hand, the records have considerable value in the study of the relationships of snow-cover and air temperature to ice formation. No data are shown, or were found, on the other factors affecting the formation of ice. Furthermore, it was reported by the American Geographical Society that such information almost never appears in literature.



ICE THICKNESS CURVE: WAUSAU, WISCONSIN, ON WISCONSIN RIVER, LAT. 44° 59', LONG. 89° 85', WINTERS 1916-17, 1917-18 AND 1918-19. SOURCE: U. S. WEATHER BUREAU. SNOW AND ICE BULLETINS (WEEKLY), 1916-17-18-19.

FIGURE 3

The report prepared by the American Geographical Society contains graphs of ice thickness data for all of the stations shown on the map, Figure 4. Few are as complete as Wausau, Wisconsin, and some show only three or four points for a single year. However, the complete set of graphs present a much more comprehensive picture of ice thicknesses than has hitherto been available. It may be noted that the areas which are receiving considerable attention in recent years, such as Labrador and the Northwest territories are nearly devoid of data. Also, it should be pointed out that while ice thicknesses may frequently be recorded in the literature, they are often not of sufficient duration or taken with sufficient regularity to warrant the preparation of a graph.

Scattered data and incomplete data can sometimes be made more significant by properly combining and averaging them. Ice thicknesses have been combined and plotted together for stations in regions which are topographically and climatologically similar. One such curve was drawn for readings on seven rivers in the Province of Manitoba, Canada. This is reproduced in Figure 5. Figures 6 and 7 are similar curves for two other regions. These average curves all indicate that the time for formation of ice 18 inches thick may often be more than the six weeks estimated in 1947 and used in constructing the map in Figure 2. The Dakota regions show 7 to 8 weeks, Manitoba about 11, and New England-Eastern Canada about 12 weeks for 18 inches of ice. Data for this last curve are over 30 years old. Moreover, in this case, the area included does not actually have similar climatological characteristics throughout and, in this case, the organization of available data has been stretched somewhat beyond a reasonable or useful form.

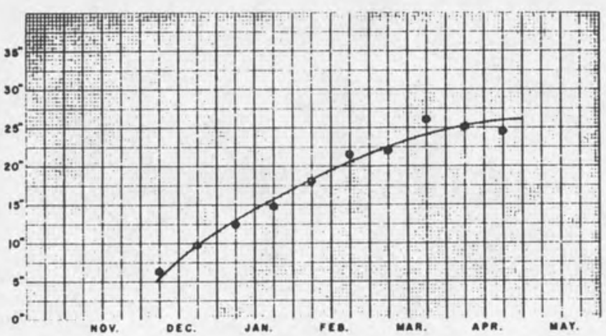
Future Work

The three curves on Figures 5, 6 and 7 illustrate one method of organizing the data. With the addition of curves showing the air temperatures and possibly the snow-cover variations, the relationship between these factors could be studied. By the comparison of measured rate of ice formation with degree-days of freeze, a correction might be applied to the older records which would convert them so as to more accurately reflect the present day ice conditions. The map on Figure 2 with isopleths of the number of months in a season when 18 inches or more of ice are present could be revised and corrected in those areas where additional data are now available, although the data are still scanty.

The present study has shown that the data coverage in North America, as a whole, is by no means satisfactory. No claim is made that all the available data have been collected and presented in the report prepared by the American Geographical Society. The report simply represents all the data that one man, Mr. Theodore Ryder, of the AGS, could collect in one year. It is considered, however, that no substantial amount of published data remains to be discovered. Therefore, if this type of information is ever to be available and adequate for use by engineers, military organizations and others, there must be commenced a a program of systematic and complete measurements covering all possible areas in the Northern Hemisphere. Even two or three years of carefully recorded and complete measurements would go far toward satisfying the immediate needs.

INDEX MAP SHOWING LOCATION OF STATIONS WHERE ICE THICKNESS DATA ARE AVAILABLE.

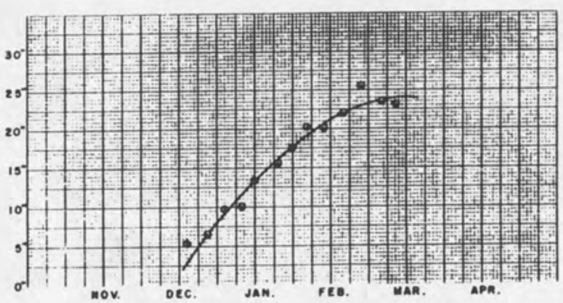
FIGURE 4



BASED ON DATA FROM SEVEN RIVERS IN THE PROVINCE OF MANITOBA FOR THE YEARS 1942–1953

AVERAGE RATES OF ICE GROWTH FOR SELECTED AREAS

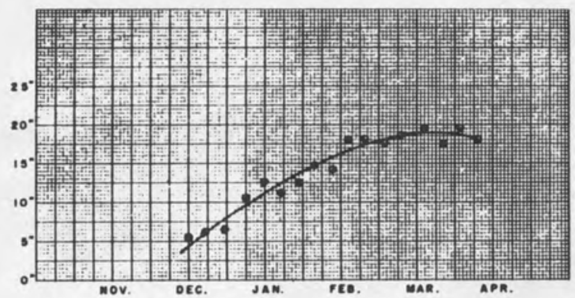
FIGURE 5



BASED ON DATA FROM TEN STATIONS ON FIVE RIVERS IN THE STATES OF NORTH AND SOUTH DAKOTA, MINNESOTA AND WISCONSIN FOR THE YEARS 1898 – 1934.

AVERAGE RATES OF ICE GROWTH FOR SELECTED AREAS

FIGURE 6



BASED ON DATA FROM EIGHT RIVERS IN THE PROVINCE OF NEW BRUNSWICK AND THE STATES OF MAINE, NEW–HAMPSHIRE, VERMONT AND NEW YORK FOR THE YEARS 1910 – 1922.

AVERAGE RATES OF ICE GROWTH FOR SELECTED AREAS

FIGURE 7

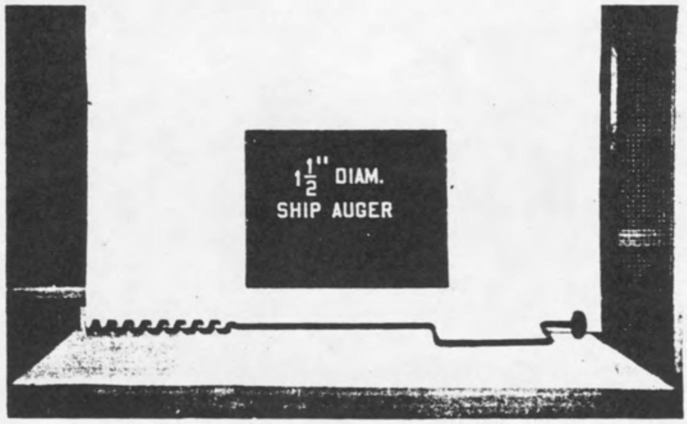


Fig. 8A
SHIP AUGER DESIGNED FOR BORING HOLES IN ICE

Fig. 8B
MOTOR DRIVEN EARTH AUGER
MODIFIED FOR DRILLING HOLES IN ICE

FIGURE 8

Measuring Ice Thickness

One deterrent to the taking of regular measurements of ice thickness is, and has been, the lack of suitable equipment for cutting holes in the ice, particularly where the ice becomes greater than one to two feet in thickness. So far as is known, there is no commercially manufactured product on the market that is entirely satisfactory. The simplest equipment is the ice chisel used in the manner of the Eskimos, with a scoop to shovel out the chips which accumulate in the bottom of the hole. With a sharp, properly shaped chisel and a well-shaped scoop on the end of a pole, a hole can be cut through six feet of ice in about an hour. In most cases, however, an auger capable of boring through perhaps three feet of ice would be most useful.

Figure 8A shows a ship auger which was used a number of years ago by one of the Boston ice companies to aid in harvesting ice from lakes and ponds. It works quite satisfactorily for ice thicknesses of about 2 to 3 feet. Unfortunately, however, this auger is no longer manufactured and if similar augers were desired, it would be necessary to have them made by special contract or to modify a wood-type ship auger to have similar characteristics. These augers have the disadvantage that they are relatively easily bent out of alinement, causing them to bine in the hole.

The most rapid and convenient means of boring a number of holes in ice with a thickness up to about six feet is a power operated auger. Figure 8B shows such an auger which has been found quite satisfactory. It is a McCulloch 5 HP Earth Drill designed for digging post holes.* To adapt the auger for drilling ice simply required replacing the standard blade with one having the necessary characteristics for cutting ice and providing a series of plates of various thicknesses which can be attached to the bottom of the auger to allow an adjustment of the depth of cut taken by the cutting blade. This adjustment is necessary to obtain the greatest efficiency in cutting ice at various temperatures. With this equipment two men can bore a six-inch diameter hole in 30 inches of ice in less than thirty seconds.

Summary

A start has been made toward the collection of presently available data on ice thicknesses in the Northern Hemisphere. Results to date indicate that the available information is inadequate to satisfy the requirements. While the collection of data on other similar factors, such as snow-cover, is progressing, it seems that the accumulation of records on the rate of ice formation and maximum thickness may have been overlooked although such information may be of nearly equal importance.

*Made by the McCulloch Motors Corporation, 6103 West Century Boulevard, Los Angeles 45, California, which has branch offices in principal cities.

REFERENCES

(1) Corps of Engineers (1954). "Compilation and Study of Ice Thicknesses in the Northern Hemisphere", Arctic Construction and Frost Effects Laboratory, Boston, Mass. Prepared by Theodore Ryder under contract with the American Geographical Society.

(2) Hydrographic Office (1946). "Ice Atlas of the Northern Hemisphere", U.S. Navy Department, Washington, D.C.

(3) Barnes, Howard T. (1928). "Ice Engineering" - Renouf Publishing Co., Montreal, Canada.