Technical Report 178

DEFINING THE COLD REGIONS OF THE NORTHERN HEMISPHERE

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Roy E. Bates
and
Michael A. Bilello

JUNE 1966

U.S. ARMY MATERIEL COMMAND
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PREFACE

This study was conducted by Roy E. Bates and M. A. Bilello, Snow and Ice Group, at the request of James A. Bender, Chief of the Research Division, USA CRREL, who originally conceived the approach. Mr. Bates compiled the data used to draw the preliminary maps. Both authors conducted the re-analysis based on additional climatological data and changed the temperature criteria.

Messrs. George Gilman and L. Trembley, Construction Engineering Branch, Engineering Division, conducted the analysis of the frozen ground parameters.

The authors wish to acknowledge the interest and support from Mr. Bender, and the contribution made in drafting of the maps by Messrs. J. Gaherty and H. Larsen.
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SUMMARY

The boundaries of the cold regions of the Northern Hemisphere are located by using parameters of air temperature, snow depth, ice cover, and frozen ground. Each parameter is discussed in detail and references used to develop four Northern Hemisphere cold regions maps are given. In all mountainous areas where few reporting stations exist, specific elevations or ridge lines were used to locate the limits of certain zones. In some areas, for example Greenland and expansive bodies of water, no isopleths were drawn because the parameter was not applicable or because of insufficient information. It is concluded that nearly all of the landmass north of 40° lies within the cold regions, and that nearly half of the land mass in the Northern Hemisphere can be classified as cold regions.
DEFINING THE COLD REGIONS OF THE NORTHERN HEMISPHERE

by

Roy E. Bates and Michael A. Bilello

INTRODUCTION

In this study an attempt is made to locate the boundaries of the cold regions of the Northern Hemisphere by using various climatological parameters. The parameters selected were: (1) air temperature, (2) snow depth, (3) ice cover and (4) frozen ground. Discussion of each of these parameters in detail and the methods and references used to develop four Northern Hemisphere cold regions maps follow.

AIR TEMPERATURE

In a preliminary analysis two cold region boundaries in the Northern Hemisphere were determined by isolines of air temperatures at or below 32°F and 0°F observed 50% of the time during the coldest month of the year. Reference 1 provided such information for the Northern Hemisphere except high elevation areas and parts of Eurasia.

For those areas not covered in reference 1, long-term mean monthly temperatures (refs. 2-5) were used to locate the 50% frequency lines as follows: A plot of mean monthly temperatures for the coldest month of the year for stations in the United States showed that the 32°F isotherm for 50% frequency coincided with the mean monthly 30°F isoline. Similarly, it was found that the 0°F isotherm of 50% frequency coincided with the mean monthly 0°F isoline for the coldest month of the year. Therefore the mean temperatures of 30°F and 0°F for the coldest month of the year were used in those areas not previously covered. For mountainous areas (ref. 6) where almost no temperature data were available the 2,000 ft elevation line (based on mean lapse rate of 2.7°F/1000 ft applied to mean temperatures of nearby sea level stations) was used to locate the 32°F line.

Later, climatological data were obtained for over 200 stations in Communist China, Siberia and Mongolia (ref. 7-14). Plots of the new data revealed that the isolines for mean monthly temperatures of 30°F and 32°F for the coldest month of the year practically coincided. Since the criterion "50% frequency of the 32°F and 0°F isotherms for the coldest month of the year, " was difficult to determine for a major part of the Northern Hemisphere, it was arbitrarily decided to use the mean 32°F and 0°F values for the coldest month of the year instead. This new criterion was applied to all of the Northern Hemisphere and only minor shifts in the original line resulted. In the Himalayan Plateau region, where little or no temperature data are available, the southernmost ridge of the mountain range (approximately 2,000 ft) was used to locate the 32°F line (ref. 15).

Considerable confidence in the accuracy of the results (Fig. 1) was gained, and the authors believe that air temperature is the best single parameter to use for locating a cold region boundary. An estimate of where the mean 32°F and 0°F isotherms are located over bodies of water is also presented in Figure 1.

Recently, Landsberg, et al. (ref. 16) published some World Climatology Maps. One of the maps showing seasonal climates of the earth locates the limits of the following 5 major zones: I) Polar and Subpolar, II) Cold-Temperate Boreal, III) Cool-Temperate, IV) Warm-Temperate Subtropical,
Figure 1. Cold region boundaries as determined by air temperature.
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and V) Tropical. These major zones then, were subclassified into regions under marked continental, oceanic, mountainous or other influences.

This map showing the seasonal climates of the earth was compared with Figure 1 of this study, which was done independently. It was found that the 32°F isoline in Figure 1 closely coincides with the boundary line described by zones I, II and III, except for III$_1$ and III$_2$ which are areas under oceanic influence.

**SNOW DEPTHS**

In the analysis to define cold regions by snow cover, the maximum observed depth of snow on the ground, recorded at the end of the month, for all available years of record was used. Snow information in this form was readily available in the literature for most of the Northern Hemisphere (refs. 4, 5, 17, 18). These snow depth values (actual accumulation, not water equivalent) were plotted and isolines joining depths of 12 and 24 inches were drawn.

Later, considerably more data on maximum snow depths for Southeast Asia and parts of Eurasia (refs. 9, 10, 11, 19, 20, 21, 21a) were obtained. For certain mountainous areas, ridges or 10,000 ft elevations were used (ref. 15) as guides to locate the lines of 12 and 24 inch snow depth. Since Greenland is principally an ice sheet with depths greater than 24 inches and information on snow depths around its periphery was limited, it was decided to include the entire area within the greater than 24 inch zone.

The results of this analysis of snow depths are shown in Figure 2. Although the analysis was based on a considerable amount of information, it was necessary to approximate the location of some boundaries, and it should be noted that this parameter produced erratic patterns. Occasionally, a dotted line was used over water to provide some continuity in the isolines.

**ICE COVER**

Using data obtained from references 22, 23 and 24 a preliminary map was drawn showing the boundaries where the lakes, rivers, and harbors become, on the average, unnavigable for 100 and 180 days per year. This period can be defined, in general, as the time between the date of freeze-over of the body of water and the date when the ice begins to break up.

The additional ice cover information obtained for Southeast Asia (ref. 9) could not be directly applied because it referred to average number of days per year that ice was observed, rather than the period of unnavigability. An investigation of a relationship between the two periods revealed that 100 unnavigable days per year corresponded approximately to 150 days of observed ice and 180 unnavigable days to 200 days of observed ice. The different spread between the two periods is believed due to latitudinal variations in the persistence of cold temperatures. Occasional influx of warm temperatures at lower latitudes extends the period of navigation. These relationships then made it possible to extend the ice cover analysis to Asia.

The results are presented in Figure 3. In remote and mountainous areas where data are lacking, the isoline locations are only estimates and no attempt was made to extend these lines over major bodies of water.

**FROZEN GROUND**

The analysis in which frozen ground was used as the parameter to locate the cold regions was conducted by USA CRREL's Experimental Engineering
Figure 2. Cold region boundaries as determined by snow depths.
Figure 3. Cold region boundaries as determined by days with ice cover.
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Division. The boundary lines (or limits) for the following three criteria were determined: (a) Continuous permafrost, (b) Discontinuous permafrost, and (c) Frost penetration in the ground (approximately 1 ft) once in ten years. The third criterion was obtained by using the mean of 100 degree-days of freezing temperatures (base of 32°F) as an index.

The results are shown in Figure 4. Where actual measurements on seasonal and permanent frozen ground were available, as in Canada and the United States, the boundary lines were drawn with some degree of confidence. However, for vast areas in Asia such information was not available and air temperature data (refs. 2, 9, 11, 12) had to be used to verify or locate the lines. The procedures used to define the limits of the various frozen ground zones through the use of air temperature data are described in Appendix A.

DISCUSSION

1. As noted, in all mountainous areas where few reporting stations exist, specific elevations or ridge lines were used to locate the limits of certain zones. The accuracy of the boundaries in these areas is, therefore, debatable.

2. In some areas, for example Greenland and expansive bodies of water, no isopleths were drawn because the particular parameter was not applicable or because of insufficient information.

3. An estimate of what portion of the land mass in the Northern Hemisphere could be considered as cold regions was made. Examination of Figures 1-4 shows that the southernmost isopleths over the land masses approximately follow the 40°N latitude line. The exceptions are the lands bordering large water bodies, where the line shifts northward, and the Himalayan area, where the line shifts southward. These areas are almost equal so that we can consider that nearly all the land mass north of 40° lies within the cold regions.

Distribution of the land mass areas (in km²) in the Northern Hemisphere for increments of 5° of latitude were obtained from reference 25 and are shown in Table I. Using the following information from Table I:

48.301 x 10⁶ km² = total land mass north of 40°N lat.

100.281 x 10⁶ km² = total land mass in the Northern Hemisphere,

we obtain the following ratio:

\[
\frac{48.301 \times 10^6}{100.281 \times 10^6} = 48\%
\]

Thus, nearly half of the land mass in the Northern Hemisphere would be classified as cold regions if the southernmost isopleths in Figures 1-4 are considered the boundaries.
Figure 4. Cold region boundaries as determined by frozen ground.
DEFINING THE COLD REGIONS OF THE NORTHERN HEMISPHERE

Table I. Distribution of land mass in the Northern Hemisphere.

<table>
<thead>
<tr>
<th>Latitude (°N)</th>
<th>Northern Hemisphere Land 10^6 km^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>90-85</td>
<td>0.384</td>
</tr>
<tr>
<td>85-80</td>
<td>1.112</td>
</tr>
<tr>
<td>80-75</td>
<td>2.326</td>
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<td>75-70</td>
<td>6.116</td>
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<tr>
<td>70-65</td>
<td>7.210</td>
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<tr>
<td>65-60</td>
<td>6.613</td>
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<td>45-40</td>
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<td>7.145</td>
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<tr>
<td>10-5</td>
<td>4.737</td>
</tr>
<tr>
<td>5-0</td>
<td></td>
</tr>
<tr>
<td>90-0°</td>
<td>100.281</td>
</tr>
</tbody>
</table>

LITERATURE CITED


2. United States Weather Bureau, *World weather summaries* (monthly), Asheville, N. C.


5. United States Weather Bureau, *National weather summaries* (monthly), Asheville, N. C.


LITERATURE CITED (Cont'd)


11. United States Weather Bureau, Data tabulation by the climatic section, Asheville, N.C. Compiled by ETAC, USAF.


15. Map of Asia and adjacent areas, Compiled and drawn in the Cartographic Section of the National Geographic Society for the National Geographic Magazine, 1942.


APPENDIX A. FROZEN GROUND BOUNDARIES IN ASIA

by George Gilman

Figure 4 shows the southern boundaries of continuous permafrost, discontinuous permafrost and seasonally frozen ground for the Northern Hemisphere. These boundaries were derived from maps previously prepared by the Experimental Engineering Division*, USA CRREL. However, for Asia, particularly Communist China, the original maps were based on very limited data.

When temperature data for a large number of Chinese stations recently became available this information was used to validate or justify revision of the original boundary lines a follows:

1. The data consisted of short and long-term records (5 to 35 years) of mean monthly and annual temperatures for a number of Chinese stations. Additional data obtained from various sources listed in the references provided similar information for stations in Tibet, Mongolia, etc. These data were used as follows:

   a. Southern boundary of continuous permafrost. Since none of the stations for which new temperature data were received is located near this boundary no analysis on this criterion was made.

   b. Southern boundary of discontinuous permafrost. In 1963, J. A. Pihlainen published the paper, "An approximation of probable permafrost occurrence" (ref. 26) in which he relates observed discontinuous permafrost occurrence to mean annual temperature and a mean thawing index. The relationships he developed worked well for approximately 60 Canadian stations used in the study. For comparative purposes, the same relationships were used on 20 locations in Alaska and the results were quite satisfactory.

   It appeared, therefore, that the Chinese data could be utilized by computing thawing indexes (based on mean monthly temperature) and mean annual temperatures to predict discontinuous permafrost from the Pihlainen relationships. Obviously, such a procedure will provide only approximate results. The method, nevertheless, sufficiently validated the location of the original boundary lines, so that no changes as a result of the new data appeared warranted.

   c. Southern boundary of one foot frost penetration in the ground once in 10 years. This boundary in Eurasia is represented by a freezing index line using a mean of 100 degree days of freezing temperature as determined in an unpublished Arctic Construction and Frost Effects Laboratory (ACFEL) study on freezing indexes of the world. Such mean freezing indexes were computed using the new Chinese data and again the results did not warrant changes of the original line. However, a large seasonal frost area in Tibet and Mongolia, which had been omitted in the preliminary map, was substantiated by these additional data and included in the final map.

2. It is possible that a mean of 100 degree days of freezing temperatures is too high to define one foot penetration in the ground once in 10 years. In North America, for example, along the eastern seaboard in states such as New Jersey, Delaware, Maryland and West Virginia, this criterion omits areas which occasionally experience severe frost problems. Because of this, zones such as the area described by the lines of 0 to 100 degree days of freezing temperatures would be preferable to a boundary line.

*Then a part of the Arctic Construction and Frost Effects Laboratory, Corps of Engineers.
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Mapping--Arctic regions
Maps--Arctic regions
Air temperature
Snow cover
Frozen ground