This is the final report on an investigation of the feasibility of mapping selected aspects of the snow cover under Contract Da-11-190-ENG-7 with Northwestern University. It presents the results of a study undertaken for the Climatic and Environmental Research Branch, USA SIPRE under Project 22.5.9 Snow cover map feasibility study. The report was prepared by Dr. Edward B. Espenshade, Jr., Professor of Geography, Northwestern University, and Mr. S. Valter Schytt, Research Associate, Northwestern University, and Assistant Professor of Geography, University of Stockholm. The investigation is a result of a joint effort on the part of the authors but Mr. Schytt is chiefly responsible for the development of the codes and station models for the current snow maps and the evaluation of Dmitrieva's calculation of snow density from meteorological data. The authors wish to acknowledge the cooperation of USA SIPRE personnel in collecting data in the Keweenaw Peninsula and the suggestions made by Dr. R. W. Gerdel, Branch Chief at the several conferences where the plans and progress of this study were discussed.

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INTRODUCTION

Snow and ice surfaces are one of the three major types of surfaces on our earth, along with the water and land surfaces. In some parts of the world, the snow and ice surface is permanent, in others it is temporary and seasonal. These seasonal and permanent areas of snow and ice are extensive. With the increased mobility of man and expansion of his interest in polar regions, snow and the snow cover has been recognized as a unique surface, presenting problems different from those of the land and water surfaces.

Our knowledge of the extent, character, and properties of this snow cover is meager. In part, this lack reflects the difficulty of studying snow, with its extreme variability and the instability of its properties. In part, it reflects a lack of systematic observation of snow cover conditions and their publication in tabular and map form.

A conference on snow and ice maps was held in June, 1952 (SIPRE, 1952), at which individuals from interested government military agencies expressed their needs and requirements and described their current work.

An analysis of the minutes suggests the following major problems as particularly desirable to investigate:

a) the accuracy of interpretation of snow depths from small scale (1:30,000,000) average monthly maps of snow depth using isolines
b) the feasibility of plotting snow depths at larger scales (1:1,000,000)
c) the feasibility of preparing maps showing snow density, hardness and surface roughness
d) the development of current synoptic snow cover maps
e) the establishment for large and small scale maps of standardized symbols to depict snow and ice surfaces over land and water areas, for standard general topographical maps or charts.

This objective appears to be confused in the minutes of the conference with that of preparing specialized maps of snow and ice cover conditions as separate substantive compilations.

SIPRE was requested "to investigate what the problems are for obtaining the necessary data and information, to suggest how the data might be presented, and then to determine what future action may be necessary." (SIPRE, 1952, p. 16).

As a result, SIPRE in agreement with Northwestern University prepared the following brief statement which is the basis of this study.

**Brief Statement of Pilot Feasibility Study of Snow and Ice Mapping**

Military operations in areas of seasonal and permanent snow and ice cover would be improved by the availability of suitable snow and ice cover maps. Maps which delineate such snow features as depth, density, hardness and drifting would be particularly valuable.

It is proposed to make a pilot feasibility study of methods of presenting the above snow features on maps. The project will involve experimentation on both large and small scale maps for selected areas using existing and assumed data. Investigation may be made of the physical properties of snow and ice as related to surface conditions (particularly relief, vegetation, surface water) applicable to the mapping problem.

Efforts will be made in particular to develop and investigate:

a. The standardization of point symbols for surface snow characteristics as applicable to individual stations.
b. The application of quantitative linear symbols, particularly isopleths, to surface snow and ice phenomena.
c. The application of areal symbols for individual snow and ice phenomena and for major snow surface categories that may be significant.
d. The extent to which interpolation and extrapolation may be utilized in the preceding, because of the present limited number of stations.
e. The extent to which reasoned distributions, dependent upon the relationship of snow surface properties to other variables can be utilized in the preceding. This involves some investigation of the physical properties of snow and ice related to continuous and discontinuous climatic and land surface variables.
f. Snow and ice surface conditions including such features as are found on the Greenland ice cap and on inland lakes (including ice depths).
g. The validity of the above mapping procedures, i.e. probable errors and degree of accuracy.

Finally as a result of the above analysis, suggestions will be made as to additional data and research which are necessary to improve the presentation and accuracy of data concerning surface snow and ice phenomena upon maps.
In the actual investigation as carried out, the work was organized into the following five sections:

I. The Application of Isolines for Depicting Aspects of the Snow Cover
II. The Development of Other Measures, Indices, and Methods for Depicting Snow Cover Conditions
III. Snow Regions: An Approach to Mapping Snow Cover
IV. Current Snow Data Maps
V. Mapping Snow Density

These phases were a natural outgrowth as various problems were encountered during the investigation. The problem of standardized symbols for general topographic maps and charts was left for the agencies which produce such maps to examine after the features (mostly permanent or semi-permanent) desirable for depiction have been determined and data as to their distribution have been assembled.

This study has, therefore, limited itself to the substantive aspects of snow cover as a problem in specialized mapping of phenomena. Both current synoptic conditions as well as "historical" (i.e. average conditions based on past records) conditions have been considered.

Application of Isolines for Depicting Aspects of Snow Cover. Comments during the meeting on the desirability of larger scale maps (1:1,000,000), the accuracy of interpolation of isolines, and the readability of specialized maps made an investigation of these items a good point for initiating the study. Observational, sampling, and bias errors of snow depth values are explored and their possible effect upon the construction of isolines at various scales is examined. Two independently prepared maps of January snow depths are analyzed to illustrate the effect of different data periods and the use of the principle of a "reasoned distribution."

The Development of Other Measures, Indices, and Methods of Depicting Snow Cover. The inadequacy of mean values and of depth only for depicting snow cover for military purposes raises the question of other measures and types of information. Fourteen different aspects of snow depth conditions are examined and seven of them presented in map form. Since new snowfall establishes, at least temporarily, a new set of conditions, ten measures of various aspects of snowfall also are suggested. The need for the utilization of other statistical parameters in addition to the mean is pointed out and suggestions made for adoption of frequency and variability indexes. In the selected sample maps, the use of point, line, and area symbols for presentation of the various types of data and measures is illustrated.

Snow Regions. Because of the lack of data and the inherent variability of the phenomena, the application of the "regional technique" is investigated. The regional technique identifies areas within which there is some measure of homogeneity or in which conditions, although they may not be entirely homogeneous, are critically different from those in adjacent regions. The degree of homogeneity and critical limits may be arbitrarily predetermined on the basis of the data available and the requirements to be satisfied. A preliminary snow region map recognizing nine regions is presented with brief descriptions based on some of the measures investigated in the previous sections.

Current Snow Data Maps. The present lack of data concerning snow cover and the variability of conditions in time emphasize the desirability of developing (1) suitable tools and methods to collect more basic data and (2) procedures to present the assembled data in current snow maps. Characteristics and elements of the snow cover which, when measured and described, will permit an analyst to evaluate snow conditions have been selected, organized into groups, and arranged for coding for transmission. Three sets of codes have been developed and presented with station models. These codes, symbols, and station models are presented as standards for adoption by interested agencies, subject to modification after further field use.

Snow Density. Snow density is investigated, partly because of its importance, partly because of the lack of any data, and partly because it may give some insight into the feasibility of estimating a snow condition such as density from other known climatic conditions such as temperature and wind. The first part explores the validity and natural variations of density values on the basis of the fragmentary data available. In the second part snow density maps of eastern Canada (1954-55) are presented and the data are analyzed for regional differences and trends. The final part explores the possibility of estimating snow density from meteorological data.

References
CHAPTER I
APPLICATION OF ISOLINES FOR DEPICTING
ASPECTS OF THE SNOW COVER

Isolines (line symbols) are among the more widely used symbols for portraying quantitative distributions.* Their application to the depiction of individual or various combinations of snow cover conditions presents both visual and substantive problems. The visual problems are those which have a bearing on the readability of the material which is plotted. The substantive problems are those which are inherent within the measurements of the phenomena involved (i.e. reliability of data) and those related to the application of the investigator's knowledge concerning areal variations in the phenomena for which the isolines are plotted.

Visual Problems

To obtain a high degree of readability of a map, a basic principle is to eliminate all unnecessary information, to emphasize the particular, special phenomena being depicted. The plotting of a single characteristic, unless there is some special reason for plotting more than one, is always the most desirable procedure to insure facility in observing the distribution of the given phenomena. On the other hand, if some factor has an important bearing on the understanding of the phenomena being presented, it is desirable to include the second element. For example, if one is plotting sea level temperatures or pressures, highland areas would be a valuable addition to the map.

Use of a simplified base map

With these principles in mind the depiction of one parameter of snow cover, or more if necessary, should be presented upon what the cartographer would call a "simplified base map." If the data are presented on a black and white map, only a minimum number of names and lines should be utilized. The base map should only include sufficient reference lines for orientation. Since the map user is studying a specialized type of phenomena, he should not expect the map to act as a complete reference item. Furthermore, in all small scale isoline maps there is inherent in the technique of preparation a degree of generalization related to their scale. The presentation of considerable detail on the base map encourages the user to interpret the areal distribution of the phenomena with a precision which is not warranted and which is not inherent within the technique. A cartographer, preparing a contour map, does not leave all of his spot heights on his final map and neither does the cartographer leave his actual values upon the final isoline map. These deletions are partly to improve the visual presentation and partly to prevent a misinterpretation.

The utility of a particular map not only depends upon the ability of the cartographer but also upon that of the user. Recognizing the latter, the cartographer uses his judgment in determining the nature of the base map for a particular group of users. However, the inclusion of too much detail on the base map may ultimately defeat the purpose of the map by destroying its visual qualities and the readability of the phenomena which is being presented. The preliminary northern hemisphere maps showing average and median snow depths by months prepared by the Frost Effects Laboratory (1953) illustrate this problem. The wealth of base map detail, including a close latitude and longitude grid, place names, etc. greatly detract from the readability of the maps. By comparison, the final northern hemisphere maps, prepared by the same organization (Arctic Construction and Frost Effects Laboratory, 1954), provide a vivid illustration of the increased readability obtained through utilizing a simplified base. The final maps have a generalized and well defined coast; and rivers, station numbers, and place names have been omitted. Symbols have been substituted for numbers indicating years of record. These final maps have good visual qualities and would be easily read, even in black and white.

Other solutions

There are two other solutions which ameliorate these difficulties. The first is the utilization of more than one color. In this manner the base may be presented in some color which has a lesser intensity than that used to depict the phenomena plotted. This is a standard and widely used method. The second is to present the phenomena plotted upon a transparent sheet which can be overlaid on a base of the same scale when necessary. This study has limited itself to a one color presentation, but the other methods could be utilized if an increase in base map detail was considered necessary for a particular group of users.**

---

*The term isoline is used here to refer to all lines that connect points of equal value. The technical literature uses the term isorithm. Isoline and isorithm as here used include isometric and isopleth maps as defined by Wright.

**Since this study began, the final report of the Arctic Construction and Frost Effects Laboratory (1954) on snow cover has been published. The base maps in the final edition are in color with relief shown by layer tints.
The black and white base maps utilized here have had all excess details deleted, and only a minimum of reference lines commensurate with obtaining a high degree of readability of phenomena plotted have been retained (Fig. 1). Line weights of the base map have been kept light and a strong contrast achieved with the heavy weight of the isolines depicted. These principles, whereas they are relatively simple, are frequently forgotten. Failure to recognize them will lessen the visual quality of the map to the extent that its value will be greatly reduced.

Substantive Problems

The substantive problems are more serious. An understanding of them is basic in determining the feasibility of mapping a particular phenomena by line symbols. In presenting specialized information, the cartographer must recognize and know the characteristics and nature of the variable he is plotting. The recognition of errors which may be inherent in the data, as well as a knowledge of the variation of the phenomena in space and its relationship to other variables, is necessary if reasonable judgment is to be used in the plotting of isolines.

A knowledge of the nature of the errors which may be inherent in the data will help the cartographer interpret the reported data and will influence his decisions as to the placement and generalization of the isolines. Three types of errors, observational, sample, and bias, may affect the quantitative values which are available for various parameters of the snow cover. All three types may not always be present, and, if one or more are consistently present, they may be disregarded under certain circumstances, or at least discounted. But to do so without some quantitative knowledge of their size and their occurrence limits the value and the degree of reliability of any map based on the data. The status of the quantitative measurement of some of the parameters of snow cover makes it difficult to assess some of these errors at the present time. One cannot, however, disregard the probable existence of errors, and it should be realized that they may affect the validity of any map presenting one of the parameters of snow cover.

Observational errors

Observational errors are related to the method used initially for determining the quantitative values. Observational errors may be associated with the accuracy of instruments, and, if judgment of the observer is involved, with psychological limitations of the observer.

Snowfall and snow depth. Even snowfall is actually very difficult to measure, as is evidenced by the literature on the problem. The values measured by different types of snow gages may vary by a considerable percentage of the actual total, and the human factor, even when general directions are given for measurement, may result in a considerable observational error. The extensive literature on the measuring of snow depth along snow courses in western mountain areas of the United States indicates the difficulties of obtaining a representative measurement of snow depth. The following is an example of instructions for measuring snow (Canadian Department of Transport, 1951, p. 25-26):

Snow. The amount of snow should be determined by measuring and averaging the depth of new snow in several places. In so far as possible, the depth of new snow should be measured in spots where the snow has fallen undisturbed by the wind. When the snow has been drifted by the wind, the depth of new snow in the drifts and in exposed areas should be measured and the observer should then estimate the depth of snow that would have accumulated if the fall had been undisturbed by the wind, making due allowance for the relative sizes of the drifts and exposed areas.

Although no statistical studies of the probable error in snowfall and snow depth measurements are known, errors of 2 to 3 inches are not unreasonable to expect, and larger ones are possible, particularly where winds are active. Such errors are relatively unimportant when computing total precipitation but are significant when one desires a measure of the actual snow depth.

Alone, observational errors of snow depths are not too serious, as the error in the mean would probably be less than variations of the mean within a few miles of the station. For example, an estimated observational error of 1 in. in the mean for a given station is not important, if this is the reported value for an area where other means not reported may differ by 3 or 4 in.

Snow density. The degree of the observational errors in measuring snow density are more difficult to assess. A number of factors may have a bearing on the observational errors, such as the type and size of the snow sampler, the place and time and means of weighing the samples, and the care of the observer in selecting and taking the samples.

A comparison of density measurements (one for the pack, the other for individual layers using different instruments) at six different sampling locations within a hundred square miles gave the readings in Table I. The variation between the two readings at some of the sampling locations is notable and is greater than the variation between the stations. If one assumes the methods are fairly accurate and that they measure only
natural differences in density which actually existed at a given location, then one must conclude there is no measurable significant difference among the six locations. This assumption is probably false; and although there may be natural differences at a given sample location, they normally are less than differences between stations a considerable distance apart. Until a statistical study is made of these differences, and the deviations due to instrumental and natural conditions are distinguished, a synoptic map using isolines to depict snow density will have little meaning. It is very probable, however, that the observational errors in measurements by a careful observer are less than the variations in the density of the snow in a short distance within a particular layer.* Therefore, the probable sampling error in the mean density of a representative sample may be greater than any instrumental error.

TABLE I. Comparison of Density Measurements by Mount Rose Sampler and by Layer Determination

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<td>.270</td>
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<td>.247</td>
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<td>By individual layer</td>
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<td>.287</td>
<td>.270</td>
<td>.227</td>
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<td>.218</td>
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<td>Variation</td>
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<td>-.027</td>
<td>+.020</td>
<td>+.043</td>
<td>+.104</td>
<td>+.029</td>
</tr>
</tbody>
</table>

*Values are based on observations made March 12 and 13, 1952 at six stations north of Calumet in the Keweenaw Peninsula, Michigan. Each pair was taken within 5 ft. of each other.

Hardness. In measuring hardness, several instruments are now used, and in some cases it is difficult to obtain consistent values when measurements are made by several people on the same layer.

It is reasonable to assume that observational errors, although not large, do exist in the measurement of some aspects of snow cover. Until they are determined, large scale maps (more than 1:500,000) with isolines at extremely small intervals will lack the accuracy which they seem to portray.

Sampling errors

Sampling errors appear to be more important in affecting the reliability of the plotted data. In using available data for stations and in presenting average data, the final map is a representation of a larger population than is included in the plotted data themselves, and the resulting sampling error decreases the reliability of the plotted data.

These sampling errors can be a matter of sampling the "snow depth population" in space or in time. The problem of obtaining a representative sample in space is illustrated by the following. Field measurements of snow depths at five places with similar exposure along a distance of 5 miles gave minimum and maximum depths of 20 and 27 in. respectively and averaged 24 in.** Thirteen observations, made within 25 miles of Keweenaw Field Station, at Houghton, Michigan, where the snow depth was recorded officially as 26 in. gave readings ranging from 10 in. to 36 in. and averaging 22 in.*** Additional observations made in forested areas ranged from 30 to 49 in. and averaged 38 in. Thus station readings, which are the controlling values for mapping purposes, may not necessarily be representative of actual depths to be found within a distance of 15 or 20 miles.

The snow conditions are unusual in this area and the distance is considerable, but the problem of utilizing a single reading as representative of the "snow depth population" should be evident. Several procedures have been developed in snow surveys for measuring snow depth along snow courses to provide a more representative sample than that obtained from a single reading. When the snow depth value for a station is recorded and utilized in construction of isolines, there is undoubtedly a sampling error due to the variation of snow depth in the area it represents. Further investigation is needed to determine the magnitude of the unreliability. Errors of 2 to 3 in. appear probable. It is with this knowledge that the cartographer is justified in using his judgment to disregard, sometimes, the value for a particular station, when he knows it is not representative of the surrounding area.

Average values based on a period of years may also be considered a sample of the whole population which extends through time. In preparing a map of average snow depth, one may be limited to a fixed short

*Conclusion based on statements made by several members (Gerdel, Benson) of SIPRE's staff who have made numerous measurements.

**Observations were taken in March, 1954 at about 1 mile intervals along a road in the Keweenaw Peninsula, Michigan. Five or six readings were made at each station.

***These observations were made in the Keweenaw Peninsula, Michigan on March 12 and 13, 1952. They probably show greater variation than is normal because of great differences in meteorological and exposure conditions which exist on the peninsula.
period of years or one may use data based on variable periods of record for different stations. In the former case, if the period is 4 or 5 yr. there may be a considerable sampling error because of the small time span of the sample. In the latter case, the sampling error may vary greatly from one part of the map to another. An indication of the length of record will warn the user of the possible extent of these sampling errors but does not indicate their degree. A computation of the standard error in the mean of seven stations with periods of record from 7 to 19 yr. gave standard errors ranging between 1 and 5 in. in average depth values. This does not refer to the variation from year to year but to the probable departure of computed mean from the "true" mean.

Values of snow depth or other aspects of snow, therefore, may possess inherent sampling errors of these two types. For any given station the errors may compensate or supplement each other. A rough estimate calculated merely to get some assessment of the magnitude involved indicates the total standard error in snow depths may be as high as 3.5 in. in Canada. If this total standard error is distributed normally in the statistical sense, there is a probability of about 16% that a recorded value for any given station would be at least 3.5 in. too high or too low. This admittedly is a very crude estimate, but for snow density and hardness one cannot even make an estimate of sampling errors.

Bias error

Bias or persistent error may be important if methods for calculating the values differ from station to station. For example, the use of a Mount Rose snow sampler for computing snow density at a station where several inches of "depth hoar" occur may result in density readings which were too low. A second type of bias error may occur if there is a long range trend toward increasing or toward decreasing values. In such a case, an average derived from data for the last 10 yr. would have a different bias than an average based on a fixed period of 30 yr. There is some evidence that slightly warmer temperatures may be affecting snow depths in Canada, but one should not assume that the effect upon the snow depth would be the same in different regions and the same in all months. The cause of this bias in snow depth data has not been investigated sufficiently to make even a rough estimate of the error. One procedure to eliminate its effect is to base any snow depth or snowfall map on the same period of years for all stations. If, however, data are available for a common period as short as 10 yr., the resulting sampling error involved might be much greater than any bias error which may exist.

A comparison of average snow depth at the end of January for the decade of the thirties with that of the forties for some thirty stations, mostly in southern Canada, provides some insight into this bias error (see Table II). Mean snow depths in lower Ontario and the St. Lawrence valley were 20 to 300% greater in the 1940's than in the 1930's. In contrast, mean snow depths for stations in British Columbia and Alberta were 20 to 50% less in the 1940's than they were in the 1930's. Whether or not there was a difference between temperature conditions in the two regions is not known, but the comparisons suggest that the use of data for a common period of years is desirable at least when preparing an isoline map of snow depths for a major part of Canada, if regional comparisons are to be made. The comparison also indicates further the nature of the amplitude of the variations in mean snow depth values due to sampling errors from a limited record period.

Effect of reliability of data on isolines

Cartographers, in constructing isoline maps, have mostly concerned themselves with the isoline interval, the location of control points, and with utilizing their knowledge of related natural factors which influence the values of a variable. For small-scale generalized maps of limited precision, or for maps utilizing very accurate data, such considerations are sufficient. Where, however, there is a problem of reliability of the data, that reliability has a bearing on the closeness of fit and location of individual isolines or groups of them.

For example, the mean January snow depth at Fort Simpson, Northwest Territory is 19.5 in. based on 7 yr. of record. With a "standard error" of 3.1, this mean may actually be anywhere from 16.4 in. to 22.6 in. When the isoline for 20 in. on the January map of mean snow depth is redrawn for each of these two values, the average movement of the 20-in. depth isoline is about 100 miles east or west of its mean position on the January mean map.*

At the Churchill station the mean January snow depth is 19.0 in. for 10 yr. of record and the "standard error" is 4.2 in. The 20 in. average depth line could move as much as 200 miles northwest or southeast of its mean position as shown on the mean January map. However, where the gradient of the isolines during February is steeper, as near Sioux Lookout, Ontario, the movement is less. Here the 30 in. isoline would have an average movement of 50 miles to the southwest and the 20 in. depth line of about 50 miles to the northeast.

*An illustration of this same problem with respect to the position of isotherms is given in the article by Sumner (1953).
From these three examples one can gain some measure of the effect of the sampling error on the positions of given isolines. The average map user is not aware of this weakness. He tends to regard an isoline as a fixed line whose position has been established with the accuracy of an actual contour. Yet these three examples indicate that, because of inherent sampling errors alone (disregarding other errors or value judgment), selected isolines drawn at 10-in. intervals to represent average snow depths could actually be located anywhere within a zone from 100 to 400 miles wide.

In most cases, the cartographer cannot eliminate these probable sampling errors from his data, but he can minimize the possibility of misinterpretation by various means, such as selecting a relatively large interval, and omitting numerical values for stations and numerous features which the user might use for an exact determination of the position of a given isoline.

The most satisfactory method that the cartographer uses to lessen possible misinterpretation under these conditions is to draw his isolines upon a small-scale map. In fact, the use of a map scale commensurate with the reliability of the data is a basic responsibility of the cartographer. The smaller the scale, the shorter will be the map distance through which the position of an isoline with a given variability fluctuates. Thus the greater the "standard error" and the fewer the stations, the smaller should be the map scale. One cannot say exactly what the largest scale is upon which the present data, or a particular set of data on snow depth, could be plotted. However, to plot existing snow-depth data for Canada on maps with scales larger than 1:10,000,000 (about 1 in. = 160 mi.) is unwise and could lead to serious misinterpretation. Even this scale is too large considering the data available in the northern regions.

<table>
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<tr>
<th>Location</th>
<th>1930-39</th>
<th>1940-49</th>
<th>Ratio of Depth 1940's/1930's</th>
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<td>19.9</td>
<td>1.0</td>
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<td>3.9</td>
<td>2.1</td>
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<td></td>
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<td>17.7</td>
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<td>20.0</td>
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<td>0.5</td>
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<td>0.5</td>
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<td>7.7</td>
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<td>5.5</td>
<td>0.5</td>
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The relationship between the density of the network of stations and scale has not been expressed in specific values and would differ with the variability and reliability as well as the distributational nature of the phenomena. The problem for rainfall has been discussed by H. R. Mill (1908). Approximately 2000 stations were used in plotting monthly rainfall of the British Isles at the scale of 1:1,205,840. If it is assumed that most of the Canadian data is concentrated in the southern one-third of the country, the density of stations in Canada for which snow data are available is about one-tenth of that of Great Britain. A very rough measure for plotting Canadian data would be a scale of one-tenth that was used in the British study, i.e. a scale no larger than 1:12,000,000. A smaller scale than this is advisable because of the sparsity of stations in the northern two-thirds of Canada.

For example, if the values cited above for Fort Churchill are plotted at a scale of 1:1,000,000 (about 1 in. = 16 mi.), the isoline could move a maximum distance of 12.5 in. On the other hand, at the scale of 1:10,000,000, the maximum distance of possible movement on the map would be 1.25 in. and at 1:40,000,000 (about 1 in. = 640 mi.) the distance would be 0.31 in. The user could not be expected to imagine or even believe that the isoline he observes on a large-scale map is subject to a possible fluctuation of almost 12 in. A possible maximum fluctuation of only 0.3 in. on the small map, even if he does not realize it exists, lessens the degree to which he might misinterpret the map. Therefore the cartographer tries to imply the general character of his map and to prevent its misinterpretation by using a small-scale map and drawing his isolines as broad, smooth curves.

The range of scales suitable is a matter of judgment but is related to three factors: (1) the number and spacing of stations for which there are data, (2) the sampling and other errors inherent to the data, and (3) the steepness of the gradient, i.e. the spacing of the isolines at a given interval. These factors are interrelated to some degree. For example, a relatively large sampling error may not require a reduction in the scale used if the gradient is very steep, so that the spacing of the isolines at a given interval is very close on the map. In this situation, especially if the sampling error is much smaller than the interval, the true position of the isoline, if known, would shift very little. Likewise, if the gradient is very steep, so that the spacing of isolines at a given scale is close, the number of stations necessary for a certain precision in drawing the lines is less than where the gradient is slight. An exception exists if there happens to be a change in the direction of the gradient, as might occur where a mountain separated two valleys. On the other hand, if the gradient is slight, large sampling or other errors could make the position of a given isoline subject to considerable fluctuation, even with a close network of stations to fix its position.

Since each of these factors may vary individually and in their interrelationship from one part of Canada to another, any given scale will not be equally suited for mapping all of Canada. A scale selected as satisfactory for the factors as they exist in eastern Canada may be too large for western and northern Canada. If the whole of Canada is to be treated with any degree of comparability on a single map, the scale should be determined by the less reliable data, not by the most reliable.

Conclusion

An investigation of the nature and types of errors associated with each of the parameters of the snow cover is essential to form at least some idea as to the reliability of the fundamental data, which in turn will affect the cartographic presentations. The three major types of errors (observational, sampling, bias) may affect average values of various parameters of snow cover, (depth, density, etc). The possible size of errors has been discussed particularly for snow depth for which more data are available than for other parameters. The evidence suggests that there is no justification for preparing isoline maps of average snow density or hardness at the present time, since data are available for only a few scattered stations covering a period of less than 5 yr.

The data on snow depth are sufficient for the preparation of average snow depth maps, but they should be compiled at relatively small scales and with isolines at large intervals drawn as smooth curves. For general nontechnical use, a maximum scale of 1:20,000,000 (about 1 in. = 320 mi.) with an isoline interval not to exceed 10 in. of snow depth is recommended as the largest scale feasible for publication of synoptic maps of average monthly snow depth conditions. With further systematic statistical analysis of the reliability of the data, a larger scale and smaller interval might be feasible for the Great Lakes-St. Lawrence area and the southern Prairie Provinces.

The "Reasoned Distribution"

When the cartographer comes to plotting the isolines, he must not only keep in mind the probable errors that may affect his data but also apply his general distributional knowledge of the phenomena and its relationship to other phenomena that might affect its distributional picture. A map in which such factors have been considered in the plotting of isolines is called a "reasoned distribution" in contrast to one in which the isolines have been interpolated on purely a mechanical or proportional basis.
The distinction between the two types of isoline construction is not always realized. When absolute values applying to continuous phenomena, with closely spaced observations, are involved, as in drawing contours, a proportional technique is used. Even here the expert topographer exercises his knowledge of land forms and slope conditions in determining the spacing, shape, and alignment of contours. Where absolute values are scattered and sparsely distributed, or when the values are ratios, the construction of isolines becomes a more subjective process. Then placement, spacing, and alignment involve the cartographer’s knowledge of the phenomena and his judgment of the pertinent factors to a considerable degree. The result is a “reasoned distribution.” A good example of a set of principles for drawing isolines applicable to rainfall in the British Isles is quoted in Conrad and Pollak (1950).

For example, if it is known that snowfall or snow depth increases in some systematic manner on the windward slopes with increasing altitude, one would re-orient and add the additional isolines necessary to suggest the nature of the distribution of the phenomena on a reasoned basis, even though the only values are those for lowland and valley stations within the region. In such mountain regions the gradients of the snowfall or snow depth may be so steep that, at small scales, the horizontal misplacement of the isolines added by this reasoning process may be much less than any potential displacement where the gradient is less steep.

This use of a reasoned distribution in plotting isolines may be used in other connections. The knowledge of somewhat greater localized snowfall or snow depth in lower Ontario because of the presence of the Great Lakes may be used to justify distinguishing a separated area of higher snowfall, rather than tying it to other areas when data for the intervening territory is lacking (see Figs. 2 and 3). Even additional closed isolines might be justified by the descriptive literature, although observed values are lacking to indicate the higher snow depth. Where there is a paucity of stations, a projection of the known gradient may be continued into the area where data is lacking until some other related phenomena might cause a change. Thus the cartographer must have considerable knowledge of the phenomena he is plotting, and his use of this knowledge will result in a final map which portrays the distribution more realistically (even more accurately under the circumstances) than is possible by purely and completely mechanical plotting.

Effects of substantive problems

The effects of the substantive problems discussed upon the feasibility of mapping average snow depth values is well illustrated by two maps of average snow depths at the end of January (see Figs. 2 and 3).* Differences between the two maps are immediately apparent. Some of the differences are due to the inherent qualities of the values used and the extent to which the respective cartographers have recognized them. Other differences are dependent upon the degree to which the cartographers applied their knowledge concerning areal variations in the phenomena plotted.

Figure 2 is based on averages for a variable number of years, utilizing all years for which data could be obtained. Figure 3 is based on the 10 yr. from 1940-41 to 1950-51. A comparison of the individual stations used for the two maps is not possible, since the values for Figure 3 are not at hand. A sampling of stations, however, indicates that depth differences commonly are in the nature of a few inches and are reflected in slight realignment or even major shifts in the position of some isolines.

For example, compare the 40-inch closed isoline in Quebec, the more northerly position of the 20-inch line across eastern Ontario, and the southward dip of the 20-inch line over James Bay in Figure 3 with positions in Figure 2. Higher or lower values for identical stations have been used in the two constructions. Thus sampling and bias errors due to the use of two different data periods are the chief factors in these differences. Isolines are transposed in position by several hundred miles and a map distance of half an inch even at this scale.

The reasons for other specific differences are more difficult to isolate and establish, but some of them reflect varying concepts of isoline construction. For example, the bend of the 10-in. line southward, west of Lake Huron in Figure 3 is to be reasoned from the expected effect of the lake. The mechanical construction used in Figure 2 fails to take this influence into account.

Maritime Canada snow depth shows a striking contrast on the two maps. The complex pattern in Figure 3 is constructed from a reasoned distribution which recognizes the greater snow depths of the mountains and the snowlessness of the coasts. These influences are not evident in Figure 2 and were lost by holding to a simple proportional spacing of the lines. Under this procedure, a closer spaced net of stations would be required to portray correctly these local depth variations due to elevation and exposure.

The greatest contrast in the two maps is evident in the mountains and along the coast of western Canada. In Figure 2 the 10-in. line in northwestern British Columbia encloses some of the areas of the greatest snow depth in Canada. Since data available are chiefly for lowland and valley stations in this region, a

*Figure 3 has been redrafted from an unpublished map prepared by C. C. Boughner and J. G. Potter, Meteorological Division, Department of Transport, Ottawa, Canada. It is a provisional map prepared by the Climatological Section during the development of a study on snow cover in Canada and is subject to revision.
Figure 2. Redrafted on a simplified base after a map prepared by the Frost Effects Laboratory (Plate 5, 1953).
Figure 3. Reproduced with the permission of the Controller, Meteorological Division, Department of Transport, Canada.
proportional spacing leads to a serious departure of isoline alignment from actual conditions. Subjective as the reasoned distribution is considered, the results based on available data are more accurate as presented in Figure 3. The marked lesser snow depths of the coasts in Figure 3 further illustrate the difference in the two concepts of construction.

Conclusion

If control points are far apart in relation to significance, (i.e. horizontal changes in the phenomena being plotted), the interpolation of values cannot be interpreted mechanically. More than station values must be used in drawing the isolines. Figure 3 is much closer to reality than Figure 2. The difference between the two maps is eloquent testimony to the difficulty of mapping snow depths even at small scales (ca. 1:30,000,000) at an interval of 10 in. The difference does not mean that such maps are without value, but it does mean that their construction must be in the hands of individuals who possess a general distributional knowledge of the phenomena and its relationship to other phenomena that might affect the distributional picture.

The obvious solution to these problems is to record data for additional stations. With a proper selection of additional stations, critically placed, there is no doubt that the accuracy of isoline alignment could be improved and that even a larger scale could be utilized. Perhaps with as few as 250 well-placed new stations, isolines could be plotted at the scale of 1:10,000,000 (about 1 in. = 160 mi.) with no greater inherent error than on the attached maps. It should be clearly understood, however, that the precision and accuracy associated with the contour map is not attainable for snow depth, even with thousands of new stations. The inherent sampling error in average values, the wide fluctuation possible from the average in any one year, vitiate any meaningful large-scale map of snow depth at small intervals. The errors cannot be controlled statistically, but misinterpretation can be limited by using the small-scale map based on a reasoned distribution with a large isoline interval. Such a map shows, chiefly, broad regional differences and trends in snow depth. For military planning, which is dependent on snow depth conditions, it should be used with additional maps which present other measures and indexes of snow depth.

References


Canadian Department of Transport (1951) MANOBS (Manual of Standard Procedures and Practices for Weather Observing and Reporting), Meteorological Division, Toronto, Canada, 244p.


CHAPTER II
DEVELOPMENT OF OTHER MEASURES, INDICES, AND METHODS
FOR DEPICTING SNOW COVER CONDITIONS

Even if sufficient monthly or annual average values could be ascertained, the isoline map of snow depth, density, etc. would not necessarily give a completely satisfactory and comprehensive picture of probable conditions at a particular time which could be utilized for military operations and planning.

These maps can be supplemented in several different ways which may be of little value, individually, but as a group will lessen the possibility of misconceptions and suggest the range of possibilities with regard to a particular phenomena’s distribution over a period of time.

First is the cartographic presentation of other normal quantitative aspects of a given snow characteristic. For example, for snow depth the number of months with an average snow depth of more than 5 in. is a possible critical value to consider. Second is the cartographic presentation of selected statistical parameters of the quantitative values of a given element, for example the standard deviation of average snow depth for a given month. For both types, linear, point, and area symbols may be used to depict the distributional pattern.

Examples of Possible Normal Indices of Snow Cover

**Average snow depth at end of the maximum month**

The most common measure of snow depth is the average (mean) depth of the snow cover for or at a given period of time. The series of maps showing mean snow depth at the end of each month, prepared by the Arctic Construction and Frost Effects Laboratory (1954), are examples (Figure 2).* Another closely related measure is one which depicts the average depth at the end of the month which has a maximum depth of snow cover. Thus the isolines are based on averages computed at the end of different months, depending upon which month normally has the deepest cover. The resulting map of “Average Snow Depth at End of the Maximum Month” presents a very different picture than the maps of average snow depth for any given month (see Figs. 2 and 4). It synthesizes on one map the average depth of the snow cover for the period when the maximum snow depth is expected in any part of Canada. It is essentially a composite of parts of several individual monthly maps of average snow depth. The maximum average monthly snow depths occur in March and April in Labrador and in January in the southern Great Plains. Whereas this index of snow cover cannot provide an exhaustive description of snow depth, it is a possible practical index to the normal scale of maximum snow control operations during a winter. For example, if certain snow depths require particular equipment, areas of this requirement throughout an average winter can be ascertained. This index is one of the two used to determine the various snow regions described in Chapter III.

**Average Monthly snow depths, by superimposed or located line graphs**

There are a large number of other possible aspects of snow depth which can be presented. The problem is what additional aspects are more valuable in contributing to the total picture and knowledge of snow depth desired. In investigating the problem at an early stage in this feasibility study, an elementary cartographic technique was utilized. Small graphs were used as located point symbols for about one-hundred stations to prepare a map of “Average Monthly Snow Depth” for Canada (Figure 5). Each graph indicated the average monthly depth of snow during the snow period. The length of record for the statistics is shown in three categories. The map in itself presents a very useful picture of normal snow depths. Additional line graphs could be added to show averages of other characteristics of the snow pack. Thus snow depth and density can be presented together by located polygraphs. Simple line graphmaps of this sort are most readable. They are excellent for demonstrating regional differences in the depth and development of the snow cover, and the danger of misinterpretation is less than with an isoline technique.

**Time aspects**

The similarity of the graphs over large areas led to the attempt to recognize snow regions as presented in Chapter III. Also, eight aspects of snow cover were selected and plotted as a result of examining these graphs.

1. Average snow depth at end of the maximum month (Fig 4).
2. Length of snow season (by number of months).
3. Average number of months with snow depth greater than 5 in. (Fig. 6).
4. Month with greatest average snow depth at end of month (Fig. 7).

*Figure 2 was copied from Plate 5 of the preliminary edition, 1953. In the final edition considerable revision of isolines has been made.
Figure 4. This map synthesizes the average depth of the snow cover for the months when the maximum snow depth occurs.
Figure 5. Point symbolism utilized to present the average depth of snow for each month.
Figure 6. An example of presenting the length of time that a possible critical snow depth factor occurs.
MONTH WITH GREATEST AVERAGE SNOW DEPTH (AT END OF MONTH)

Figure 7. A presentation of the pattern of areas experiencing a particular snow depth condition at different times.
5. Number of months with increasing snow depth.
6. Number of months with decreasing snow depth.
7. Number of months within 5 in. of maximum depth.
8. Month with greatest increase in snow depth.

Each of these maps establishes a time aspect of some condition or change in the snow depth. Some maps show the pattern of areas experiencing a similar deviation of a particular snow depth condition. Others depict the pattern of areas experiencing similar changes at the same time. Two of these aspects of snow depth are presented here in map form (Figs. 6 and 7). An isoline technique is used for the map of “Average Number of Months with Snow Depth Greater Than Five Inches” (Fig. 6). Boundaries have been drawn to demarcate regions in the second map, “Month with Greatest Average Snow Depth” (Fig. 7). An area symbol to distinguish the regions is not necessary. An alternative technique in both cases would have been appropriate point symbols plotted for each station. The methods adopted present a picture which is grasped readily for these aspects of snow depth, but they do not appear to be equally suitable for each of the listed items.

A second group of maps which portray additional aspects of snow cover conditions have been prepared by the Meteorological Service, Canada. Although only a few of them have been published, those listed below illustrate the feasibility of presenting additional normal aspects of snow depth and cover.

1. Mean annual date of the first snow cover of an inch or more (Fig. 8) (Boughner and Potter, 1953).
2. Mean annual date of the last snow cover of an inch or more (Fig. 9) (Boughner and Potter, 1953).
3. Mean annual number of days with snow cover one inch or more (Fig. 10) (Boughner and Potter, 1953).
4. Average length of the season of snow cover (in days).*
5. Duration of snow cover expressed as a percentage of the season of snow cover.*
6. (Continuity of snow cover). Months with no breaks in snow cover 1941/42-1950/51 (Fig. 11).*

Four of them are reproduced here (Figs. 8-11). They illustrate the use of isolines to present normal or average conditions of further aspects of snow cover. The study of which these maps form a part is based on the ten winters from 1941-42 to 1950-51. About 175 of the approximately 277 first class Canadian stations provided data for the entire period, and end of the month reports from 100 climatological stations were used to supplement the data in the settled portions (chiefly southern and southeastern Canada).

These maps are based on a greater number of stations than were available for the two maps of average snow depth in the previous chapter. Nevertheless, they still have been plotted and reproduced at roughly similar small scales (somewhere between 1:20,000,000 and 1:45,000,000). Even with a closer network of stations, probably mostly in southern Canada, the data have been considered insufficient and unsatisfactory for isoline construction at larger scales (1:10,000,000 and larger). Statistical errors inherent in the average values and errors of interpretation in interpolating values continue to limit the construction to generalized isolines and to small scales.

Relatively large intervals of 20 days, which are appropriate to the type of distribution and reliability of the data, have also been selected for the maps of mean annual date of the first and last snow cover of 1 in. or more (Figs. 8 and 9). Dashed lines, inserted in three places at 10 day intervals, suggest that the cartographer found sufficient uniformity in these zones to attempt additional interpolation. On the map of mean annual number of days with a snow cover of 1 in. or more, an interval of 40 days is used.

The continuity of snow cover map is more complex cartographically (Fig. 11). Regions with a similar period of continuous snow cover are demarcated. Differences of 1 and 2 months between regions are distinguished by light and heavy boundary lines, respectively. The map is a synthesis of two isoline maps: a) the date of the beginning of the continuous snow cover, b) the date of the end of the continuous cover. The two maps with monthly intervals have been superimposed and the zones between the lines of the two maps identified as regions. This last process required some generalization. Where initial and final snow cover lines paralleled each other but the distance between them was less than the possible interpolation error, the lines have been combined. These generalizations are represented by the heavy lines which separated regions with a difference in continuous cover of 2 months.

*Photo prints of these three maps were made available by the Meteorological Division, Department of Transport, Canada. They are provisional maps, prepared by the Climatological Section during the development of a study on snow cover in Canada, and are subject to revision.

**Information supplied in a letter from J. G. Potter, Meteorological Division, Department of Transport, Canada. Daily observations of snow cover depth were established at first class stations in Canada in 1940-41. Data is from original reports, since most of it is not published in the Monthly Record of Meteorological Observations in Canada.
Figure 8. Reproduced from "Snow Cover in Canada," by C. C. Boughner and J. G. Potter (1953) with the permission of the Controller, Meteorological Division, Department of Transport, Canada.
Figure 9. Reproduced from "Snow Cover in Canada," by C. C. Boughner and J. G. Potter (1953) with the permission of the Controller, Meteorological Division, Department of Transport, Canada.
Figure 10. Reproduced from "Snow Cover in Canada," by C. C. Boughner and J. G. Potter (1953) with the permission of the Controller, Meteorological Division, Department of Transport, Canada.
Figure 11. Based with permission on a provisional map prepared in the Climatological Section, Meteorological Division, Department of Transport, Canada, during the development of a study on snow cover in Canada, and subject to revision upon completion of the project.
These maps of the Canadian Meteorological Service illustrate further the feasibility of plotting additional aspects of snow cover. They add essential information to the total picture of the nature and particularly the duration of the snow cover. Time interval isolines show the distribution of areas experiencing similar cover condition on the same date or experiencing a similar duration. Both are features which would be difficult to ascertain by study of individual monthly maps of snow depth. These maps are still subject to the weaknesses of maps depicting average or normal conditions, discussed previously, but the small scale and generalized isolines limit the degree of misinterpretation.

**Snowfall**

The nature, amount, and time and frequency of snowfall in themselves have a bearing on the over-all picture of snow in its relation to military operations. The actual direct relations of snowfall to snow depth are limited. In southern Canada, where melting may occur during the winter and along the coast of British Columbia where rain is interspersed with snow, the snow depth is independent of snowfall. On the other hand a foot of new snow at the time of a density measurement may lower density values of a shallow cover (1 to 2 ft.) by an appreciable amount.

A new snowfall establishes a new set of snow surface conditions, although only temporarily, which may have considerable effect upon operations, independent and apart from the character of the snow pack (e.g. depth, hardness, density, etc.). Therefore various aspects (amount, time, frequency) of snowfall and their various parameters should be mapped and considered along with those of the snow pack cover. Some items which should be considered are listed below. Several of these were provisionally mapped and used as a basis for expanding the description of the snow regions.

1. Average snowfall for each month.
2. Average number of days with snowfall each month.
3. Month with the most snowfall (Fig. 12).
4. Average snowfall during the maximum month (Fig. 13).
5. Maximum snowfall during the maximum month (Fig. 16).
6. Minimum snowfall during the maximum month.
7. Number of months with mean snowfall more than ten inches.
8. Average number of days of snowfall in maximum month.
9. Maximum number of days of snowfall in maximum month.
10. Number of months with more than 5 days of snowfall.

**Selected Statistical Parameters of a Particular Value**

The great disadvantage of normal or average values of any of the possible aspects of snow cover, discussed in the preceding section, is the variation from the statistical mean. This is readily apparent in an examination of January and February snow depth values for three widely spread stations in Table III.

<table>
<thead>
<tr>
<th>Station</th>
<th>Mo.</th>
<th>1940</th>
<th>1941</th>
<th>1942</th>
<th>1943</th>
<th>1944</th>
<th>1945</th>
<th>1946</th>
<th>1947</th>
<th>1948</th>
<th>1949</th>
<th>1950</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>St. John</td>
<td>Jan.</td>
<td>10.0</td>
<td>4.0</td>
<td>2.0</td>
<td>8.0</td>
<td>13.0</td>
<td>15.0</td>
<td>11.0</td>
<td>T</td>
<td>24.0</td>
<td>2.0</td>
<td>1.0</td>
<td>8.2</td>
</tr>
<tr>
<td></td>
<td>Feb.</td>
<td>10.0</td>
<td>1.0</td>
<td>2.0</td>
<td>2.6</td>
<td>12.0</td>
<td>10.0</td>
<td>14.0</td>
<td>10.0</td>
<td>7.0</td>
<td>3.0</td>
<td>4.0</td>
<td>6.8</td>
</tr>
<tr>
<td>Edmonton</td>
<td>Jan.</td>
<td>6.0</td>
<td>4.0</td>
<td>2.0</td>
<td>11.0</td>
<td>0.2</td>
<td>10.0</td>
<td>--</td>
<td>6.0</td>
<td>2.0</td>
<td>4.0</td>
<td>13.0</td>
<td>4.7</td>
</tr>
<tr>
<td></td>
<td>Feb.</td>
<td>10.0</td>
<td>6.0</td>
<td>2.0</td>
<td>--</td>
<td>8.4</td>
<td>7.0</td>
<td>11.5</td>
<td>16.0</td>
<td>12.0</td>
<td>3.0</td>
<td>12.0</td>
<td>8.8</td>
</tr>
<tr>
<td>North Bay</td>
<td>Jan.</td>
<td>17.3</td>
<td>27.0</td>
<td>21.8</td>
<td>27.0</td>
<td>5.0</td>
<td>22.5</td>
<td>23.0</td>
<td>17.0</td>
<td>20.0</td>
<td>20.0</td>
<td>1.0</td>
<td>18.3</td>
</tr>
<tr>
<td></td>
<td>Feb.</td>
<td>18.5</td>
<td>28.0</td>
<td>25.0</td>
<td>24.0</td>
<td>25.0</td>
<td>22.0</td>
<td>36.0</td>
<td>25.0</td>
<td>23.0</td>
<td>24.0</td>
<td>--</td>
<td>25.0</td>
</tr>
</tbody>
</table>

**Extreme values**

Within the 10 yr. period there is a considerable scattering of the snow depth values around the mean value. Extreme conditions, maximum and minimum values, indicate depths almost several times the mean or a small fraction of the mean. For military operations, the maximum may commonly be the more critical of these two, although both are pertinent. The size of the departures from the mean snow depth values lessens the value of the mean as a single index to probable snow depth conditions. For example, at St. John, New Brunswick a mean January depth of 8.2 in. gives no indication that this value includes two successive years with 2 ft. one year and only a trace of snow the year before. In fact, from a military stand-
Figure 12. A provisional map based on about 100 stations with variable periods of record.
Figure 13. A provisional map based on about 100 stations with variable periods of record.
point, the limiting conditions would be more valuable in planning operations than the average or mean value. The average is of course the most widely used and a most valuable parameter. If, however, departures from the average are apt to exceed critical values of the phenomena, the utility of the average is greatly reduced. For example, departures from mean rainfall in humid regions, although considerable, generally are not so great as to be critical for agriculture. On the other hand, the fact that the snow cover may be anywhere between 0 and 2 ft. in January is more important from a trafficability standpoint than a mean value of 8 in.

The importance of maximum and minimum values for snow depth is recognized in the Frost Effects Laboratory study of snow cover (1954) by the inclusion of such maps. Extreme values also are important parameters for some of the other aspects of snow cover. These examples of maximum values are included here.

1. Average (yearly) maximum depth of snow in inches (Fig. 14).
2. Average date of maximum depth of snow cover (Fig. 15).
3. Maximum snow depth recorded at end of maximum month (Fig. 16).
4. Minimum snow depth recorded at end of maximum month (Fig. 17).
5. Maximum snowfall during maximum month (Fig. 18).

In Figures 14 and 15, isolines are used to present averages for yearly maximums. In the average yearly maximum snow depth map, average extreme conditions to be found in various parts of Canada are depicted (Fig. 14). Since the variation of maximums for a period of years is less than the variation of values from which mean depths are computed, the statistic in most areas is a fair measure of the general degree of maximum conditions probable during a winter.

The average date of maximum depth of snow cover is a similar expression of extreme conditions (Fig. 15). The isolines delimit regions which experience maximum conditions during the same period. The use of a relatively large interval (1 month) increases the probability that the variation from the mean for any single year will be within the interval at a given place.

The extreme depth condition at the time of extreme conditions (Figs. 16-18) is a necessary statistic if the departures of individual maximums from the mean or average maximum are large, and if the positive departures are sufficiently large to be critical to a military operation. For example, the average yearly maximum depth along the eastern shore of Hudson Bay is 30 to 40 in., but extreme depths of more than 60 in. have been recorded (Figs. 14 and 18). If an additional 20 to 30 in. of snow depth would be critical to an operation, the maximum parameter is essential.

This map also illustrates the use of point symbols instead of isolines. The considerable variation in values within short distances makes the construction of isolines at intervals of 10 in. more difficult than on previous maps. Small islands or peaks and the complex pattern would tend to suggest a degree of detail not inherent to the data used. The point symbol technique does not portray broad regional patterns which can be readily identified, but the very complexity lessens the danger of misinterpretation.

Frequency values
Another statistical approach by which the disadvantage of using only mean values is eliminated was suggested by R. G. Stone (1940). He tabulated the number of times snow depths equalled or exceeded appropriately selected category values. The percent of frequency then was computed as a ratio of this number to the number of the years of record. The resulting frequency curves are well illustrated in the ACAFEL study (1954, Pls. 25 - 38). The advantages, utility, and limitation of these frequency curves are well stated in the following quotation from the report (p. 2).

From these curves, there can be quickly determined the percent of years of record in which equal to or better than a given number of inches of snow cover has been measured, at the end of any given month. Duration of the snow cover season, periods of the season when the maximum snow cover normally occurs, and special local characteristics of snow cover conditions can also be determined quickly from these curves by inspection.

Occasional future accumulation in excess of the maximum individual measurement recorded, if it occurs with a frequency of once in 20 or more years, will only appreciably affect the general picture given by these curves in the lower percentages of expectancy. For example, if the chart for a given station now shows that for a given date the snow cover has equaled or exceeded 12 inches in one year of a 20 year period of record, a new measurement exceeding 12 inches in the 21st year of record will change the frequency for depths in excess of 12 inches from 5% to 9.5%, but a 20 year record of 50% in excess of, let us say 1 inch, on this same date, would be changed by this new observation only to 52.5%.

The Edmonton, Alberta, graph provides a specific example of the use of the frequency graph (Fig. 19). The mean snow depth at the end of February is 8.8 inches. This mean value provides no idea of the varia-
Average Maximum Depth
of Snow in inches

Figure 14. Reproduced from "Snow Cover in Canada," by C. C. Boughner and J. G. Potter (1953) with the permission of the Controller, Meteorological Division, Department of Transport, Canada.
Figure 15. Average date of maximum depth of snow cover. Reproduced with permission from a provisional map prepared in the Climatological Section, Meteorological Division, Department of Transport, Canada, during a study on snow cover in Canada, and subject to revision.
Figure 16. A provisional map based on about 100 stations with variable periods of record.
Figure 17. A provisional map based on about 100 stations with variable periods of record.
Figure 18. Point symbolism utilized to present an extreme condition not suitable for isoline construction.
DEVELOPMENT OF OTHER MEASURES, INDICES, AND METHODS

Figure 19. Snow cover frequency curve for Edmonton, Alberta. The frequency with which certain snow depth conditions occur during a given month can be readily ascertained. From Arctic Construction and Frost Effects Laboratory, (1954, p. 29).

The frequency graph is one of the more valuable techniques for presenting the total picture of probable snow conditions at a station. The plotting of these station graphs on a large map of Canada would facilitate the recognition of area differences (see Fig. 5). At the scale of 1:3,000,000 the plotting of at least 200 graphs, 1-in. square, is feasible. Such a map, although cumbersome, is more useful and less susceptible to misconceptions than is a single isoline map of mean values. The possible range and, even the approximate probability of specific snow depth conditions in the vicinity of a station can be ascertained. The addition of a maximum value at the bottom center is advisable because the extreme conditions sometimes greatly exceed the value of the highest category.

Measures of variability

There are other possible ways to portray variability from mean snow conditions. A set of single index values from which isolines could be constructed or regions delimited is desirable. However, such single indexes of variability have distinct disadvantages. They indicate differences in variability not probable variations in absolute values. However, if they can be combined on the same map with the mean values or used in conjunction with the map of mean values, the range in absolute values may be estimated for localities. In addition, the statistical parameters which may be used as single indexes of variability are partially abstract and confusing to many potential users.

Average variability. The average of all departures from the mean (without regard to sign) provides a simple absolute index. For example, the average variability (AV) of the January snow depth at St. John, N. B. (10 years of record) is 5.8 in. (Table IV). By using the mean value (8.2 at St. John in January), the general range of snow depth (between 2.4 and 14 in.) can be computed. However, this general range must be used with caution. Actually, at St. John, only 4 of the 10 years fall within the span of values. In most cases it will permit an estimate of the snow depth to be found about one-half the time.

TABLE IV. Selected Parameters of Snow Depth

<table>
<thead>
<tr>
<th>Station</th>
<th>Period</th>
<th>Mean</th>
<th>Maximum</th>
<th>Minimum</th>
<th>Average Variability</th>
<th>Variance</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>St. John N.B.</td>
<td>Jan.</td>
<td>8.2</td>
<td>24.0</td>
<td>T</td>
<td>5.8</td>
<td>54.4</td>
<td>7.37</td>
</tr>
<tr>
<td></td>
<td>Feb.</td>
<td>6.8</td>
<td>14.0</td>
<td>T</td>
<td>4.1</td>
<td>21.9</td>
<td>4.68</td>
</tr>
<tr>
<td>Edmonton Alb.</td>
<td>Jan.</td>
<td>4.7</td>
<td>13.0</td>
<td>0.2</td>
<td>3.4</td>
<td>19.5</td>
<td>4.42</td>
</tr>
<tr>
<td></td>
<td>Feb.</td>
<td>8.8</td>
<td>16.0</td>
<td>2.0</td>
<td>3.5</td>
<td>19.1</td>
<td>4.37</td>
</tr>
<tr>
<td>North Bay Ont.</td>
<td>Jan.</td>
<td>18.3</td>
<td>27.0</td>
<td>1.0</td>
<td>6.0</td>
<td>68.8</td>
<td>8.29</td>
</tr>
<tr>
<td></td>
<td>Feb.</td>
<td>25.0</td>
<td>36.0</td>
<td>18.5</td>
<td>2.75</td>
<td>20.8</td>
<td>4.57</td>
</tr>
</tbody>
</table>
Relative variability and equivariables. For climatological studies, the distribution of places with similar reliability of a climatic phenomena is desirable. The "average variability" in absolute units is not significant without a comparison with the mean. Several statistics expressed as percentages are used for this purpose.

1) Relative variability: (Conrad and Pollack 1950)
\[ V_r = \frac{\text{Av. Variability}}{\text{Mean}} \times 100 \]

2) Coefficient of variability:
   a) \[ V_c = \frac{\text{Standard Deviation}}{\text{Mean}} \times 100 \] (Williamson and Clark, 1931)
   b) \[ V_c = \frac{\text{Inter-quartile Range}}{\text{Mean}} \times 100 \] (Hounam 1945)

Isopleths could be constructed from any one of these variability ratios. Biel's widely used map of rainfall variability uses the relative variability values from which to interpolate the equivariables.

The indexes are not satisfactory for indicating probable depths which might be expected within some frequency range. Information of this sort is more valuable for military operations than information about regional differences in variability. A possible solution is a series of maps which indicate by isolines the lower limit of the depth of snow which is to be expected for a selected percentage of the time. Figure 20 shows the minimum snow depth to be expected 20% of the time at the end of the month of maximum snow cover.* For instance, at points along the 30-in. isoline, 20% of the time (i.e. a frequency of 1 in 5 yr.) the snow depth will equal or exceed 30 in. at the end of the month. Similar maps which indicate the chances of the snow depth equaling or exceeding isoline values can be prepared for other percentage frequencies (e.g. 40%, 50%, and 80%). Figure 20 is a provisional map, using data from only fifty selected stations with records for 8 or more yr. Although data for preparation of frequency value maps is limited, they are considered more useful than a map of average snow depth.

Standard deviation. The standard deviation is considered by statisticians as the best and most exact measure of scattering of the variate (Conrad and Pollach, 1950, p. 36). Only a few examples of its use for maps of climatological phenomena have been published. Sumner (1955) used it to show variability in mean monthly temperatures.

The standard deviation provides a means for predicting, on the basis of probabilities, the range in snow depth which would occur 68% of the time (e.g. plus and minus one sigma from the mean). It is necessary, however, to assume the existence of a "normal" distribution of snow depth values, which is not always true according to the few snow depth frequencies examined in this study. Many of the distributions in southern Canada are "truncated" because the minimum cannot go below zero. Others show a skewness because of one or two very high values.

The standard deviation, alone, is a good measure of variability, but for predicting snow depth probability, it must be used with the map of mean snow depth. Time was not available and the period of record is relatively short for computing the standard deviations for sufficient Canadian stations to compile a map to show variability of snow depth. A provisional map should be made as an experiment to see if there is sufficient uniformity of trend to sigma values to isoline at intervals of 5 or 10 in. of snow depth. If this proves feasible, the sigma isolines might be superimposed on the map of mean snow depth. Different colors or area shading of one of the two distributions should solve the visual problem.

Thus on a single map it may be possible to present sufficient information about snow depths at the end of a month for many purposes. There is no reason why, with a properly worded legend, the map cannot be readily interpreted, since all isolines would be plotted in inches. The use of this parameter for other aspects of snow cover conditions also is worthy of investigation.

**Conclusion**

The inadequacy of the mean alone to depict depth of snow cover is evident. There is nothing in the mean to indicate the extremes nor the probability of values falling between the mean and the extremes. It is only a measure of central tendency. The variability of snow depths from the mean in many areas is sufficiently great to result in serious error of interpretation. The use of the mean with other parameters lessens this danger and increases the accuracy of prediction. Other aspects of snow cover related to crit-

*The application of this technique to rainfall values is discussed by Lackey (1937).*
TWENTY PER CENT FREQUENCY
MAXIMUM MONTH
DEPTH OF SNOW IN INCHES TO BE EXCEEDED
TWENTY PER CENT OF THE TIME

NORTHWESTERN UNIVERSITY SPRE CONTRACT DA-11-190-ENG-7

Figure 20. A provisional map based on only 50 stations with records of eight or more years. Data are not plotted in northern Canada.
ical values which may be determined and their duration or time of occurrence should be selected and mapped to supplement this information. The analysis of these materials should enable one to foresee snow depth conditions which would affect military operations.

References


Hounam, C. E. (1945) Climate of West Australian Wheat Belt with Special Reference to Rainfall over Marginal Areas, Melbourne: Meteorological Bureau, Commonwealth of Australia.


CHAPTER III
SNOW REGIONS: AN APPROACH TO MAPPING SNOW COVER

Snow Region Concept

The presentation of either the quantitative aspects or the purely descriptive conditions of the snow cover at both small scales (1:5,000,000 and smaller) and at medium scales (1:1,000,000 and 1:5,000,000) is limited by the data available. Even if additional data with a fairly uniform distribution over a country like Canada were available, it is questionable that quantitative and descriptive presentations of various aspects of a snow cover would have a high degree of accuracy. There are unknown and very probably large inherent observational errors, and second we do not know enough concerning the range of variability with respect to a given parameter within a limited area and over a sufficient period of time.

The widely used and accepted technique when the data and knowledge concerning an element are similar to that we have concerning snow cover is to distinguish regions within which there is some degree of homogeneity or in which conditions, although they may not be entirely homogeneous, are critically different from those in adjacent regions. This technique permits the delineation of regions which can be identified and described in terms which are commensurate with our knowledge of snow cover conditions. Furthermore, there is less danger of trying to read a precision into the map which is not justified because of the limited data.

Two studies of this type have been completed recognizing snow regions for parts of New England (Stone, 1938) and the state of Washington (Church, 1940). These studies were based on more data than are available in most sections of Canada and were limited only to snow depth conditions. An attempt has been made to apply a modification of Church's and Stone's technique to all of Canada. The following nine snow regions were identified (see Fig. 21):

1. Pacific Coast
2. Mountain Zone
3. Great Plains
4. MacKenzie-Manitoba
5. Upper Ontario
6. Northern Great Lakes-St. Lawrence
7. Labrador
8. Northern Arctic
9. Ungava-Baffinland

The snow regions have been identified essentially on the basis of the abundance of the snow cover and its duration. Actually the two parameters utilized were the maximum monthly average depth of the snow cover and the number of months with a snow depth of more than 5 in. The Russians have utilized slightly different parameters for recognizing major snow regions within the Soviet Union (Richter, 1945).*

The parameters utilized were in part dependent upon the nature of the recorded statistics. Data for each of the two parameters: a) Average snow depth at the end of the maximum month, b) Number of months with snow depths more than 5 in., were plotted for about 100 stations. These stations provided a fair network for southern Canada but are sparsely distributed in the northern regions and particularly between Hudson Bay and Great Bear Lake. In addition, the record period of years for the northern stations is frequently for a short period of time. Maximum monthly average snow depths were plotted at uniform 5-in. intervals. The number of months with a snow depth of 5 in. or more was estimated to a tenth of a month from graphs of average monthly snowfall, but plotted in full month categories. The work was limited to these particular stations because of the great amount of statistical compilation which had been done by ACAFEL (1953). Each of these maps showed large areas in which average conditions did not vary greatly. It was possible therefore to distinguish on each map regions which were fairly homogeneous or which in some cases differed radically from adjacent areas. In fact, in many places relatively sharp gradients occur along the boundary lines distinguishing the regions. This undoubtedly reflects major climatological differences related to meteorological conditions. The similarity of the pattern recognizable on the two maps made it possible to combine these two factors in distinguishing the nine major snow regions. Only in a relatively few areas were difficulties encountered in drawing the boundaries based on the two factors. In these cases greater weight was always given to the maximum monthly average snow depth.

*The Russians used a maximum ten-day average depth of snow cover and distinguished long and short abundant snow periods where the snow was more than 30 cm. deep and regions without an abundant snow period. Additional properties of the snow cover are stated to have been considered but are not specifically mentioned.
Figure 21. An example of the regional technique identifying regions with some measure of homogeneity.
One region, the mountain zone, is not commensurate with the others. Within this region conditions are highly variable with changing exposure, elevation, latitude, and distance from the coast. The complex conditions, lack of data (and data available are mostly for valley stations), and the great local variation within short distances, preclude the possibility of distinguishing any internal regional differences. But the area is distinguishable from adjacent regions by its great variability and complexity.

There is some correlation of the northern boundary of the Mackenzie Valley and the Labrador regions with the tree line boundary across Canada. Their correspondence merely emphasizes that some common climatological factor is involved. More precise data and local study might bring the two boundaries into accord. Within those regions which are forested or partly in forest and grassland, one should recognize that all of the statistics are recorded at stations in the open. Conditions in the forests may be radically different both as to depth and duration of the abundant snow period.

The similarity of conditions over these large regions, which in part reflects broad climatic similarities, suggests the possibility that generalizations may be made concerning other parameters of the snow cover in the regions. It would be especially valuable if generalizations could be made concerning such parameters as snow depth and hardness, for which we have only a few dozen observations over all of Canada at present. In another section of this report, an attempt is made to see if density can be estimated from data which are available on temperature and wind. If empirical relationships can be established with the continuous phenomena for which there are data, density and hardness values, although not precise, might be estimated for the snow regions.

In four of the nine major snow regions, subdivisions were distinguished. A northern and southern sub-region was identified within the Great Plains Region. A small area of somewhat higher snowfall in the Gaspe was recognized as a sub-region of the Northern Great Lakes-St. Lawrence Region. Subdivisions in the Mackenzie-Manitoba and Pacific Coast regions were distinguished on the basis of differences in the duration of the cover.

Descriptions of Snow Regions*

1. Pacific Coast and Coastal Valley Region

This region is a narrow coastal strip extending more than 1000 miles north from Vancouver Island, occupying a narrow strip of land between the sea and the encroaching mountains. Included in the region are lower seaward slopes of the mountains. Maritime influences are strong and the area is essentially a floured coast with offshore islands. Snow-cover conditions are highly variable due to the combined effect of the maritime conditions and elevation. Precipitation is heavy, but even in the middle of the winter much of it may fall as rain except at higher elevations. At low elevations along the coast, breaks in the cover may appear at anytime during the winter. On the other hand, snowfall of several inches up to 120 inches may occur during a month, and snow depths of a few inches up to 60 or 70 inches may occur locally. Except on the higher slopes, where it may last for two to three months, a snow depth of more than 5 in. does not last for even one month. Because of the variable conditions and the fact that available data are from valley stations, statistical averages do not give an adequate picture of snow conditions.

Snow depth. The outstanding feature of the snow-cover depth is its great variation from place to place and from month to month and year to year. The average yearly maximum depth of the snow cover ranges from less than 10 inches to a maximum of at least 40 in. Although the average depth increases slightly to the north, practically all the increase in depth is related to the increase in elevation as one goes east and inland. Average snow depth at the end of the maximum month, although less than 10 in. on the smaller islands and near the coast, reaches values generally of 25 in. and even higher locally with increases in elevation. Maximum values may be two to three times these averages.

Duration and development of snow cover. North of latitude 57° N the first snow cover of an inch or more occurs in the last two weeks of October. To the south the cover is delayed along the coast at lower elevations until after the first week in December and even as late as Christmas in the Victoria and Vancouver City area. However, at higher elevation a cover of an inch or more generally develops during November. After these dates the average depth of the snow cover increases each month slowly, along the coast and the islands and very rapidly at higher elevations, until a maximum is reached in late February, except in the vicinity of Vancouver Island and the Queen Charlotte Islands where the maximum occurs between the middle of January and February. The snow cover disappears rapidly. A cover of an inch or more is gone by 1 March along

*In preparation of these brief descriptions the series of five maps prepared by the Meteorological Service of Canada were used. (Boughner and Potter 1953, p. 155-59; 170-171). Additional manuscript maps of several other aspects of snow cover such as "Average number of days of snowfall during the maximum month" were also used.
the coast south of latitude 55°N, and as early as 10 February near Victoria. Northward along the coast and at higher elevations, throughout the region, the snow cover disappears at successively later dates, but is gone everywhere by the end of April.

These averages, however, are misleading in part. Breaks in the snow cover are apt to occur in the cover during any month in the island and coastal area south of latitude 57°N. In the remainder of the region, only January and February are free of breaks in the cover. Isolines, indicating the average duration of snow cover of an inch or more, parallel the coast and increase with increasing elevation south of latitude 55°N. It ranges from less than 20 days to as long as 120 days. In some places in the southern part, particularly along the west coast of Vancouver Island, an entire winter may pass without the formation of a snow cover. North of 55°N the duration period increases uniformly northward along the coast from 20 days to 120 days.*

Snowfall. This is a region of heavy winter precipitation, but except in the north and on the higher slopes much of it falls as rain. Mean annual snowfall south of 55°N latitude is commonly between 20 and 60 in. In the more northerly latitudes it is between 50 and 140 in. Monthly snowfall also varies considerably from year to year and place to place. Normally, January is the month of greatest fall, and the fall generally ranges between a few inches and 100 inches in a period of years. One station with an average January snowfall of 47 in. has a maximum of 167 in. Excessive snowfalls are therefore to be expected, especially in some of the deep inlets and at higher elevations. Moderately heavy snowfall (20-30 in.) may occur in January in other areas.

Locally there may be considerable variation with exposure and elevation. The difference in snowfall between the northern and southern parts reflects temperature conditions. To the north, 15 to 35% of the total precipitation is snow; to the south, between 2 and 15% is snow. Even in January, at some stations, snow may fall on only a small fraction of the days upon which precipitation is recorded. On the other hand, with a change of exposure or in elevation, snow may fall on all except 2 or 3 days upon which precipitation is recorded. As a result, snowfall may vary greatly for a given month from year to year and for places sometimes only a short distance apart.

2. The Mountain Zone

The mountain snow region is characterized by its complexity and great variation from place to place even in relatively short distances. This very complexity is what distinguishes it from adjacent regions. The region extends for more than a thousand miles from Alaska to the border of the United States and is between 200 and 400 miles wide. Since meteorological stations for which there are records are located mostly in valleys, the data on snow cover are not applicable to large parts of the region at higher elevations. This limitation of the snow cover values should be kept in mind in the following description. The maximum monthly average snow depth in areas where data are available is between 15 and 30 in. and except in a few valleys, there is a snow cover more than 5 in. deep for 4 to 5 months.

Snow depth. The outstanding feature of the snow depth is its great variability within relatively short distances because of differences in exposure, type of slope, orientation, and elevation. Locally, values as high or higher than anywhere else in Canada are described in the literature for some of the exposed windward mountain slopes. On the other hand, in sheltered places in the south, snow depths of only a few inches may occur. Since snow depth is recorded for only a few stations and these are mostly at relatively low elevations, the recorded snow depths which can be plotted on a map do not give a true picture of conditions.

The average snow depth at the end of the maximum month ranges from 15 to 35 in. for the few stations plotted in this region. These values may seem low, but much of the inland "upland" of British Columbia, with a general elevation of above 3,500 feet, is quite arid. Also some of the stations lie in sheltered valleys and are not representative of snow depths in more exposed places and at higher elevations. In these locations, i.e. in the valleys and on the inland upland, the duration of a snow cover of 5 in. or more is commonly from 4 to 5 months long. Because of the maritime influence, the duration of a heavy snow cover in this long north-south region is no greater than in southern Ontario. In a few sheltered locations, notably the Fraser Valley, the duration is less than 4 months. In the north near the Alaskan border, the period of heavy snow cover is longer, and it is much longer in the mountains at higher elevations. Both the Coast and Selkirk ranges have very heavy snowfall on the windward slopes, and permanent snow fields exist, which give rise to small glaciers.

The map of "Average Yearly Maximum Depth of Snow Cover in Inches," (Boughner and Potter, 1953, p. 170), delimits two large areas of higher snow depths which are related to major mountain areas. The Coast Ranges are correlated with an area of increased snow depths with values in excess of 40 in. for the

*The descriptions of the duration of cover of one inch or more used for each snow region are based on a map prepared in the Meteorological Service of Canada and published in Boughner and Potter, (1953, p. 159).
average yearly maximum. The second area correlates with the southern Rockies and Selkirk Mountains of Canada and average yearly maximum snow depths of more than 50 in. are indicated. Locally, depths may greatly exceed these values.

Duration and development of snow cover. The development and duration of snow cover is more variable and complex than in the other regions. Exposure, elevation, and the strength of the maritime influence disrupt the normal latitudinal effect. The first snow cover of more than 1 in. may occur any time between the middle of September and the first of the year. In the northern half of the region such a cover is established no later than the last week in October, and as early as the first week in October at higher elevations in the Mackenzie Mountains and northern Rockies. In the southern half the 1-in. snow cover develops on the inland uplands in the first half of November, but to the south and at lower elevations, such as in the Fraser valley, it may be delayed until early December.

In the northern half of the mountain region, the snow cover grows in depth rapidly at a fairly uniform rate of about 5 in. each month, until a maximum depth is attained at the end of February. In the southern half, the region on the upland plateau, the rate of growth is less at most stations and also is less uniform. The increase in the average depth of cover is at a lower rate in December and January than it is earlier in the season. In addition, the maximum average depth is reached at most stations at the end of January, a month earlier than in the North. However, on the windward sides of the Coast Range and of the Rockies, the average snow depths increase very rapidly commensurate with the greatly increased snowfall at higher elevation.

In the region as a whole, the snow depth decreases rapidly within 5 to 11 weeks after attaining maximum depth. In the southern half of the mountain region, the last cover of an inch or more disappears on the inland upland during the last 3 weeks of April, except up the Fraser Valley and along the U. S. border where it may disappear during March. In the Rockies the cover continues later, until after the end of April. In the northern half of the region, the last cover disappears at successively later dates toward the North, between the end of April and the middle of June, except in two areas. The cover lasts for a longer period along the axis of the Mackenzie Mountains and for a shorter period in the Yukon Valley.

Thus the duration of a snow cover of an inch or more increases in the northern half from 170 days to 240 days. In the south half it ranges between 120 and 170 days, except in the mountains where it is longer and in the southwest where, toward Puget Sound, it decreases very rapidly in length to less than 80 days. Depths of more than 5 in. exist at stations within the area for 120 to 150 days.

In a 10-year period, no breaks in the snow cover occurred in January and February in the southern half; and in the north no breaks occurred between December and March, and even in April in the extreme north.

Snowfall. No other snow region has such a great variation in snowfall within short distances, because of the variation in elevation and exposure. The statistics, mostly for valley stations, fail to indicate these local differences. Scattered observations suggest that a higher snowfall may occur on some mountain slopes than in any part of Canada. On the other hand, there are large upland areas where the snowfall is low or, at most, moderate in depth. The snowfall ranges between 40 and 60 in. in the north, 60 to 80 in. in the central part, and again between 40 and 60 in. on the semi-arid uplands of the south.

In the northern third of the region the maximum snowfall occurs in November and averages between 5 and 12 in. and maximum values are slightly more than twice as great. In the southern two-thirds, the maximum month of snowfall is January or December, the January date apparently more common near the coast. No particular pattern of average snowfall during the maximum month is evident from the values for the reported stations. They range from 5 to 18 in., except for one station with 44 in. Maximum snowfall, however, is from two to eight times as great with extremes tending to occur to the south. Maximum snowfall values during the maximum month are everywhere more than 20 in., at most stations more than 30 in., and at several stations over 70 in. That the range in snowfall is large is suggested by minimum recorded snowfall values from 1 to 8 in. In conclusion, it should be emphasized again that the snow depth and snowfall conditions described for the Mountain Region are based on valley stations, and even though the variation among them appears large, the local variation within 50 miles of a station may be even greater.

3. Great Plains Region

The Great Plains region is a roughly triangular area with its base extending along the U. S. border from western Montana to the Lake of the Woods and with its apex west and slightly south of Lake Athabaska. Average snow depth at the end of the maximum month is less than 15 in. Two subregions can be recognized on the basis of the duration of the cover. In the northern and larger subregion, the snow cover with a depth of more than 5 in. lasts between 90 and 120 days; in the southern subregion, the period is less than 90 days.

Snow depth. Average snow depth for the maximum month ranges between 5 and 10 in. in the southwestern and southern part of the region, and increases slightly to the north and east, to 15 in. along the
northern and eastern borders. The month with greatest snow depth at the end of the month is January in the south and February in the north. The highest snow depth ever recorded at the end of the maximum month generally ranges between 15 and 30 in., although one station has a value of more than 40 in. The lowest value of snow depth at the end of the maximum month varies from 0 to 8 in.

Duration and development of snow cover. The first snow cover of an inch or more normally occurs in the last week of October or the first week in November. The depth of the snow cover continues to increase slowly but uniformly until a maximum is reached during February in the north and January in the south. From the peak the depth decreases so that normally the snow cover of 1 in. or more disappears during April from over the entire region. Some breaks in the snow cover are apt to occur in any month in the southern and western part; in the rest of the region, breaks may occur in any month except January and February. In the northern subregion, snow depth exceeds 5 in. for as long as 4 months, whereas in the southern subregion these depths may not last for a month. The average length of the season of snow cover is between 160 and 180 days, except for a small area in the southwest of less than 160 days. In this latter area frequent thaws due to chinook winds may occur in late autumn and early spring, and the continuous snow cover may last for only 50-70% of the season of snow cover.

Snowfall. This region as a whole has less snowfall than any other in Canada, except the Arctic areas. The average annual snowfall ranges between 30 and 50 in. and there are no months with an average of more than 10 in. From November to March the average monthly snowfall remains consistently in the range of 5 to 8 in. each month and snow is apt to fall on 4 to 12 days. Even the maximum snowfall in the month of greatest fall is lower than in most parts of southern Canada. In only a few places have the maximums exceeded 25 in. in a month.

4. The Mackenzie-Manitoba Region

This large elongated region extends southeast from the mouth of the Mackenzie almost to Hudson Bay and western Ontario with a projection to the south along the Mountain Zone. Nevertheless, throughout its extent the major characteristics of its snow cover are fairly homogeneous. The average snow depth of the maximum month is between 15 and 25 in., except for slight deviation locally. Over an extensive area, for more than 5 months, the snow cover has a depth greater than 5 in., except in the far north where the period may be more than 6 months. The area extending to the southwest is designated as a subregion because of the shorter duration of the 5 in.-cover.

Snow depth. The outstanding feature of the snow cover in this region is its great uniformity in depth. For a distance of 2000 miles, average depths vary by only a few inches. Average yearly maximum depths and average depths for the maximum month range between extremes of 20 and 30 in., but in large areas remain a little below 25 in. Throughout the region in any one month there is apt to be no more than 10 in. difference in average snow depth from place to place. The maximum depth occurs normally in February but occasionally during March in the north. The maximum depths recorded during these months range from 27 to 50 in. with the 30 to 40 in. range widespread. The minimum depths have a wide variance from 1 to 19 in., but the minimums below 10 are largely restricted to the southerly subregion, reflecting the chinook winds.

Duration and development of snow cover. The first snow cover of an inch or more occurs normally over most of the region during the last 3 weeks in October. Only along the northeast and northern border is it apt to occur earlier, during the first week in October. The increase in depth until the end of January is fairly rapid and uniform averaging 4 to 5 in. each month. The increase thereafter is less rapid until the maximum depth is reached at the end of February, or March in some places. The cover melts off within 1 1/2 to 2 1/2 months. Cover of an inch or more disappears between the last week in April and the end of the first week in June. The disappearance of the snow moves progressively northeast from the northwest-southeast axis and western border of the region. Thus the snow cover may disappear at the same time along the lower middle Mackenzie River as it does in northern Manitoba, 1500 miles to the southeast.

Throughout the region the snow cover is continuous with no breaks from December to March, except along the poleward border where the period extends through April. Snow cover of an inch or more lasts between 160 and 240 days. The duration increases to the northeast across zones which extend diagonally from northwest to southeast.

Snowfall. This is a region of moderate snowfall with a mean annual snowfall between 40 and 60 in., of which about one-half occurs before January. The snowfall for November, normally the month of greatest fall, averages only about 11 in., and the maximums which have been recorded exceed this value only by two to three times. In contrast, minimum values for the same month have been between 1 and 5 in. generally. From January through April the average snowfall tends to decrease slightly each month and ranges between averages of 2 and 8 in. each month. The number of days of snowfall in any month has a pattern similar to that of the amount of snowfall. Normally snow will fall on 4 1/2 to 12 days in the maximum month of November, but at about one-half the stations, maximums of up to 20 days in the month have been recorded and minimums of 1 to 3 days.
5. Upper Ontario Region

This is a compact but somewhat irregular area, including the southern shores of Hudson and James bays and extending southward almost to the Great Lakes. The region is distinct in itself, but intermediate between adjacent regions. The cover is less deep than in the Labrador Region to the east and deeper than in the Mackenzie Region to the west. The maximum monthly average snow depth ranges between 25 and 35 in. The snow cover exceeds a depth of 5 in. for a period of 5 to 6 months.

Snow depth. The snow cover of this region is both moderate (25–35 in. average for the maximum month) and fairly uniform in depth. The average yearly maximum depth of snow cover also ranges between 25 and 35 in., except along the eastern border and in the southeast, where it increases rapidly eastward to values as high as 40 in. Late February and early March is the time of the greatest snow depth. During these months the deepest snow covers recorded have been between 30 and 60 in. and the lowest between 3 and 20 in. A snow cover of significant depth (i.e., 5 in. or more) lasts for 5 to 6 months except along the southern border where the duration decreases to slightly less than 5 months.

Duration and development of snow cover. The first snow cover of an inch or more normally occurs in the northern and western parts of the region during the last 3 weeks of October. In the southeast and east of James Bay, however, the first cover normally arrives later, during the first 2 weeks in November. The depth of the cover increases at a uniform and rapid rate of between 5 and 10 in. each month until a maximum depth is attained in most parts at the end of February or early March. The snow cover disappears even more rapidly. Over most of the area the last snow cover of an inch or more normally disappears within the first 3 weeks of May. Only in the north along the shores of Hudson Bay does it last about 2 weeks longer, and only in the southwest does it disappear earlier, during the last week in April. The average duration of the season of snow cover, 1 in. or more, increases from 160 days in the south to 240 days in the north. Throughout the greater part of the region, no break is apt to occur in the snow cover for 4 months, December to March; along the eastern Hudson Bay shore, the period is extended through April. However, in a belt about 150 miles wide along the southern border and tapering to the east, the cover may melt some years even during December and/or March and only in January and February are no breaks in the cover apt to occur.

Snowfall. A heavy snowfall characterizes this region. The mean annual snowfall is between 80 and 100 in. except along the western border where it decreases rapidly to a value of 50 in. November and December are the months of heaviest snowfall (average values of 10 in. in the west to 25 in. in the east). Maximum and minimum snowfall values have no directional gradients and thus indicate the variable nature of the snowfall from place to place in a given year and from year to year. Maximum values generally are twice average values but may be four times as great. On the other hand, minimum values recorded may be one-sixth to one-half of the average values. From January through April the average snowfall each month decreases. By April average snowfall ranges between 4 and 12 in.

Snowfall occurs more frequently in this region than in any other except the Labrador Region and locally in the Mountain Zone and Pacific Coast Region. During the months of more frequent snowfall, generally November and December, a fall may, on an average, occur anywhere from 7 to 18 days. The greater frequency is more characteristic of the eastern part of the region. At a maximum, snow has fallen anywhere from 50 to 90% of the days in a month. Rarely has it fallen on less that 20% of the days, except in the extreme south.

6. Northern Great Lakes—St. Lawrence Region

This elongated east-west region extends for 1500 miles from Lake Superior to Newfoundland but averages about 150 miles in width. There are considerable differences in snow depth within relatively short distances and from year to year as well as for the area as a whole. These variations reflect the frequency of cyclones which pass along the region from west to east, particularly in the St. Lawrence Valley. The average snow depth at the end of the maximum month ranges from 15 to 25 in. and a cover of 5 or more in. exists for about 4 months, except in the Gaspe subregion, which has average depths in the maximum month between 25 and 40 in.

Snow depth. There are two outstanding features of the snow depth pattern. First, the lines of equal snow depth run parallel with the east-west longitudinal axis of the region. Second, there is a moderately steep gradient of increasing depth across the region from south to north. Both of these reflect temperature conditions and gradients. The few irregularities in this pattern reflect locations near water bodies or higher elevations. In the northeast along the boundary with the Labrador Region very steep gradients occur, with increases in average snow depth of 30 in. within 100 miles.

Over almost the entire region the average depth of snow at the end of the maximum month grades from 15 in. along the southern boundary to 25 in. on the northern boundary. However, a small area along the St. Lawrence, the Gaspe subregion, is distinguished by average depths between 25 and 40 in. The great-
est snow depths recorded for the maximum month generally range between 30 and 45 in. except in the sub-
region where depths may reach 70 in. Minimum depths of less than 5 in. have been recorded, except in the
subregion.

Duration and development of snow cover. The first snow cover of an inch or more begins normally
during the first two weeks of November, except around the Gulf of St. Lawrence coast and in lower Ontario
where it comes about a week later. The depth increases slowly in November, but very rapidly in December
and particularly in January, when the average depth may increase from 10 to 15 in. During February, the
depth increases more slowly, and reaches its maximum. The cover melts rapidly. Except for the deep cover
of the Gaspe, the last snow of an inch or more disappears normally during the last three weeks of April or
a week earlier in most of lower Ontario. Thus the snow of 1 in. or more lasts for 120 to 160 days. The
heavier average cover of more than 5 in. has a duration of generally between 100 and 140 days.

However, breaks due to warm spells may occur during the beginning and final periods of the snow
season. February is the only month when no breaks are apt to occur anywhere in the region. No breaks are
apt to occur in January along the northern border, and for as long as 3 months (January to March) in the
Gaspe and the west of Quebec.

Snowfall. This is a region of a long period of heavy snowfall, but also one of considerable variation
from place to place. Average annual snowfall may vary by 20 to 40 in. within 100 miles. For the region as
a whole, annual averages vary from as low as 70 in. to as high as 140 in. In the western part, average val-
ues are less than 100 in. except adjacent to Lakes Superior and Huron; in the east they are higher, but also
have a very irregular distributional pattern. The average fall in October is negligible, but an occasional
heavy fall may occur. From December to February, the fall is heavy and ranges between 15 and 25 in. per
month. It drops slightly in March, but there are still 4 or 5 months when the monthly average is more than
10 in. January is the time of maximum snowfall, although it differs little from that of December and of Feb-
uary. Both maximum and minimum snowfall values recorded in January further emphasize the heavy snow-
fall. Each set of values is generally higher, particularly in the eastern section, than in other regions of
Canada, except in the mountains of the west. Snowfall is fairly frequent. From December through February
each month averages from about 6 to 16 days of snowfall, only slightly less frequent than in the Upper On-
tario and Labrador regions.

7. Labrador Region

This compact region includes most of Quebec and Labrador and extends from near the eastern shores
of Hudson and James bays to the Atlantic. Its snow cover is deeper than in any other extensive area of
Canada. The average depth at the end of the maximum month everywhere exceeds 35 in. and over the major
part exceeds 50 in. The snow cover is also of long duration. It is more than 5 in. deep for 6 to 7 months.

Snow depth. This snow depth generally decreases outward from an area a little to the south of the
true center of the region. In this area, average values for the maximum month of more than 50 in. exist.
This might be considered the snow center or pole of Canada. (Exceptions exist along and near the Atlantic
and the Gulf of St. Lawrence coasts where the depths may even exceed this value.) Greatest snow depth
occurs at the end of March in the central and northern areas, which is late in the season for these latitudes,
and during February in the remainder of the region. The maximum and minimum depth values for the maxi-
mum month are further evidence of the heavy snow cover in this region. The lowest values ever recorded
exceed a depth of 20 in., and the highest values everywhere are more than 60 in., except in the extreme
north, and reach recorded extremes of 75 in.

Duration and development of snow cover. Snow cover of an inch or more normally begins in early
October in the northwest, and extends over the whole region by the first week in November. Thereafter the
depth increases very rapidly (more rapidly than in any other part of Canada) until the maximum is reached
in February or March. Average monthly increases in depth exceed 10 in. in most areas. A cover of ..ore
than 5 in. lasts for 180 to 210 days, except along the southern margin. The snow melts rapidly in the south-
ern half and by the end of the first 3 weeks of May the last snow cover of an inch or more has disappeared
in the whole region. Considering the depth of the cover, the rate of removal is unusually rapid.

Possible thaws may clear the ground in November and December, and even during April in the extreme
south and particularly along the St. Lawrence River and Gulf, but between January and March no breaks are
apt to appear even here. The northern two-thirds of the region have no breaks in the cover from December
through April.

Snowfall. No other snow region has such widespread heavy snowfall, which here exists over several
hundred thousand square miles. Only a few small mountain or maritime areas equal or exceed the fall in
this area. Two-thirds of the region have a mean annual snowfall of more than 120 in.; only the northern
border area has as little as 80 in. An average monthly snowfall or more than 10 in. occurs during 4 to 7
months. In the month of maximum snowfall, snow may fall normally on 10 to 20 days, and over most of the region averages 20 in. or more for the month. Maximum snowfall reaches values of 60 and more in., and no fall of less than 5 in. has been recorded at any station. Particularly in the northern part, the snowfall tends to be greater in November and March and somewhat less in January and February.

8. The Northern Arctic Region

This large triangular region extends southeast from the Arctic shore of northern Alaska to the west shore of Hudson Bay north of Churchill and then north-northeast to include western and northern Baffin Island. This is a region of shallow snow cover, associated with the lower precipitation, but a cover of at least 5 in. remains for 7 months. Over much of the region, particularly in the Arctic Archipelago, elevated expanses, widely accessible to the wind, may be bare or comparatively free of snow, i.e. with a cover of about an inch in depth even in the middle of the winter. In contrast, deep compact drifts are formed around obstacles, in ravines, and in the lee of hills. Permanent snow fields may occur locally in the eastern islands.

Snow depth. The uneven nature of the depth of the snow cover, because of drifting by the wind, should be kept in mind when reading the following description. It is based on observations at stations where conditions permit some snow to accumulate. In addition, generalizations are based on only a few widely scattered stations with a record period of only a few years. From all of the few stations of record, the average snow depth at the end of the maximum month is less than 15 in. and the maximum depths in this month do not exceed 30 in. Lowest values recorded for stations, however, exceed 5 in. A weak gradient of decreasing depths to the north and from east to west is suggested by the limited data.

Duration and development of snow cover. The season of snow cover is very long. Throughout the region more than an inch of snow is to be expected for at least 240 days, and to the north and east it may last as long as 300 days. The initial snow cover of an inch or more normally begins in the first 2 weeks of September in the northern parts and by the first week in October in the south. In the first 2 months the depth increases rapidly, although the absolute gain is small. Thereafter there is little or no change in depth until March and April when it begins to increase again. The maximum is attained between the middle of April and the middle of May. For at least 7 months the snow is more than 5 in. deep. Within 2 months, by early June in the south and the end of the month in the north, the snow cover of an inch or more has disappeared. Thus for 7 months, November to May, and for another month, October, in the north, there is no break in the cover except where the surface may have been blown free by the wind.

Snowfall. This is a region of low snowfall. Average monthly snowfall values in most areas range from 1 to 5 in., except in September and October. The mean annual snowfall is less than 40 in., except in the southeast and east where it may reach a value of 50 in. The maximum fall occurs early in September and October, and the average fall, then over wide areas, appears to be less than 10 in. Maximums recorded at this period probably are rarely in excess of 20 in. The days on which snow falls during any mid-winter month is less than in other parts of Canada and ranges normally between 2 to 8 days a month. The number of days, as would be expected, is slightly greater at the beginning of the snow season in October.

9. Ungava-Baffinland Region

This irregular area in the eastern Arctic has great variation in snow cover from place to place and a heavier snow cover than the Western Arctic Region. The snow depth increases from 15 in. in the west and north to depths of 40 and 50 in. in protected coastal areas in the east and south.* The greater depth in southern Baffinland, as compared to the remainder of the region, is the result of increased snowfall due chiefly to the proximity of the track of cyclonic storms from eastern Canada and United States.** The duration of a 5 in. or more snow cover, however, for 7 to 8 months generally is as long as in the Northern Arctic Region. Exposed hills and ridges may be bare and considerable drifts may accumulate in protected areas. Permanent snow fields occur on Baffin Island.

Snow depth. As in the Northern Arctic the snow cover is uneven, with considerable area blown free and with drifts in the depressions and the lee of hills. Statistics also are limited and not too reliable. The average yearly depth of snow is between 20 and 40 in., although locally average depths at the end of the maximum month for short record periods may exceed these values.*** Considerable variation in snow

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*These high values are for protected coastal stations and for only a few years of record. Other scattered values in the literature are lower and suggest averages of 25 to 35 in. Because of drifting, a true measure of snow depth is not easy to obtain.

**The inclusion of the coastal areas of southeastern Baffinland in this region is questionable. If the few recent statistics give a more accurate portrayal than earlier records, the southeastern portion of this region should be assigned to the Labrador Region.

***At Padloping Island off the southern coast of Baffinland, in 1 of 2 years for which there were records, snow depths from January to April were more than 60 in.
depth from year to year is likely, particularly in the southeastern part of the region in view of the cyclonic origin of the precipitation. *

Duration and development of snow cover. The season of snow cover (1 in. or more) is very long, as in the Northern Arctic. All parts have a season longer than 240 days. Northward, the length of the season increases to a maximum of 280 days and exceeds this in northern Baffinland. Thereafter the increase is small and the average season perhaps does not exceed 290 days. The average date of the first snow cover of an inch or more occurs in the northeast (along the east coast of Baffinland) by the first week in September. Within a month (by October 7) all of the remaining area normally has received its first cover of an inch or more. The depth of the snow cover increases at a relatively rapid rate during the first months from September to early January. Thereafter the depth shows little change until April when it begins to increase, particularly in the southern and southeastern parts, and continues to increase until as late as 15 May. Except where blown free, a cover of 5 or more in. occurs for a period of 200 to 240 days. The decrease in snow depth in contrast to the increase is fairly rapid and lasts for only 30 to 45 days. The last snow cover of 1 in. or more normally has passed by the first week of June in the south and passed in all other areas except northeastern Baffinland by the end of June. Thus for 7 months, November to May, there is no break in the cover.

Snowfall. In contrast to the low snowfall of the Northern Arctic Region, this region has a moderate snowfall, since the effect of cyclonic storms is felt at times. Mean annual snowfall is between 50 and 90 in. The amount increases from west to east, and the higher fall is limited to the southern and eastern coastal areas of Baffinland. The snowfall is unevenly distributed during the season. The heaviest fall occurs during October and November with average monthly values between 10 and 15 in. From December to March, average monthly falls between 4 and 8 in. are characteristic, with a slight rise in April and sometimes in May. Frequency of snowfall, as expressed by the number of days upon which snow falls, shows a similar pattern to that of monthly snowfall. A frequency of 8 to 15 days in October drops to 4 to 7 days in midwinter and rises slightly in the spring.

Conclusions

The snow regions delimited on Figure 21 illustrate one way of depicting snow depth conditions. There are two outstanding advantages to this method of presentation. First, there are recognized a relatively few, comparatively large regions within which snow depth conditions are in several ways relatively homogeneous, although not identical. The particular parameters used to distinguish the regions are selected to suggest the duration of snow depth conditions which might affect military operations and the maximum conditions which may be expected. Furthermore, several of the boundaries follow the zones where sharp gradients or marked changes in conditions occur. The generalizations, resulting from the categories selected, synthesize information which would be difficult to grasp from individual maps with more detailed categories.

A second advantage is that this method eliminates some of the danger of misinterpretation which many individuals make in using more refined and detailed map presentations. The range of conditions within the category values of the snow regions encompass the greater part of the considerable place and time variations, so that actual conditions of snow cover at a given place commonly will fall within the range of the snow region involved. In this sense, the generalized snow region map may be used by the non-specialist with more accurate results than more detailed maps.

The regional presentation, as pointed out previously, is also well adapted to the limited data available on snow conditions. The possible errors involved when stations are widely spaced and records are limited to a few years may also be encompassed within the range of values delimiting a region, where statistical errors in the data might make detailed isolines subject to fluctuations of several hundred miles.

The descriptions which are given for each region describe additional snow cover conditions and indicate range from average values for the parameters utilized. They illustrate how the functional value of the snow region concept could be expanded.

References


*In the other year of record at Padloping Island, 2 months had depths of 15 and 25 in. Fragmentary records for earlier years at several places give averages that differ by as much as 20 in. These differences are more likely the result of the method and location of the observations than of climatic changes. They illustrate the inadequacy of statistics when conditions change in short distances with exposure.
Church, P. E. (1940) Type curves and duration of snow cover in Washington, Yearbook of Association of Pacific Coast Geographers, vol. 6, p. 21-25.


Rikhter, G. D. (1945) Snow cover transformation and properties, Academy of Science, USSR, Popular Science Series (Translation into English obtained through SIPRE) Moscow: Publishing House of Academy of Sciences, USSR.

CHAPTER IV
CURRENT SNOW DATA MAPS

Introduction

In other chapters the feasibility of mapping from existing limited data, the seasonal and average dis­tributional pattern of snow cover characteristics has been investigated. The variability of density values, in particular, illustrated the impracticability of using mean values and the necessity for current snow cover information, if and when needed for military operational planning. This need, in conjunction with the present lack of data, emphasizes the desirability of developing (1) suitable tools and methods to collect more basic data than now available and (2) procedures to present the assembled data in current snow maps.

The selection of those characteristics and elements of the snow cover which, when measured and described, will permit an analyst to evaluate snow conditions is the first step in the preparation of current synthetic snow cover maps. The characteristics selected here have been determined after a study of the “Minutes on the Conference on Snow and Ice Maps, 30 June 1952” (SIPRE, 1952) and after consultation with individuals who have worked with snow and traveled extensively in areas of snow.* To facilitate transmission of observations, the characteristics selected have been organized into groups and classified into categories which can be coded. The system of coding is similar to that used by the United States Weather Bureau and can be readily transmitted.

Three sets of codes have been developed. The most complete is the one suggested for the Ground Observer's Snow Report. A modification of this code, the Simplified Snow Observation Report, is designed for use where no instruments are available and/or where there were no trained observers. The Aircraft Observation Report is designed for observations that can be made from the air.

For each of these sets of snow observation codes, “station models” have been designed. These station models can be used as point symbols and recorded on base maps to portray snow cover conditions in the same manner as data are presented on the daily weather map.

Ground Observer’s Code

This code is designed to describe a snow pack using only figures, which makes it suitable for radio transmission. The original SIPRE code has been used as a framework, with new items incorporated.** Seven groups of data, each coded with five digits are used to record snow depth and cover, density, hardness, surface irregularities, qualities of snow surface and certain special conditions.

In selecting the different data to be reported, consideration has been given to the possibilities of obtaining reliable observations, the desire to get as complete information as possible, and the possibilities of getting this information coded into a reasonable number of groups with five digits each.

The following section is organized in three parts. First the code is presented. This is followed by comments on the code, defining and explaining the items involved, and discussing the reasons for the procedure. Finally, a system of symbols is presented for the preparation of station models which depict graphically all of the code data. A sample map with station models plotted is included.

Suggested code for “Ground Observer’s Snow Report”

NNNNN – lddf g - 2lsTh - 3cOop - 4rHbw - 5DDPb - 6ISSb - 7ittW

NNNNN – Station number
lddf

dd: Average depth in inches of snow cover on ground
f: Depth in units of 2 in. of snowfall during the last 24 hr. (let 9 stand for 18 in. and more)
g: Snow cover on ground

*The viewpoints and needs of specialists from various military branches are presented in these minutes. Dr. Henri Bader, Dr. A. L. Washburn, and Dr. R. W. Gerdel of SIPRE were consulted, as well as Dr. Paul Siple and others. In addition, Dr. Valter Schytt co-author on the contract has had experience with snow conditions in Antarctica, Greenland, and northern Sweden.

**The SIPRE code (typed manuscript dated August 1953) was prepared by Dr. R. W. Gerdel. The first tentative draft, prepared for this report, was discussed with the SIPRE staff during two meetings at the latter of which Dr. Paul Siple was present. The suggestions from these two sessions have been considered and contributed to the final result.
0. Snow free
1. Scattered patches (less than 15-20% snow cover)
2. Less than 50%
3. 50% to almost complete
4. Almost complete, but scattered snow free patches
5. Complete

This group is designed to portray the measurements obtained in a snow pit. One group no. 2 should be sent for each identified layer beginning from the top and going downward. The first no. 2-group should give surface conditions, e.g. surface temperature and hardness as measured vertically down onto surface — give 1 as 0 in this first group.

1: Thickness (in inches) of the snow layer being reported. If the layer is composed of pure ice and thus hardness reported as 9, give thickness in tenths of inches (e.g. 0.9' would be coded as 9).

s: Density (specific gravity)

| 0. | 0.00 - 0.10 |
| 1. | 0.10 - 0.15 |
| 2. | 0.15 - 0.20 |
| 3. | 0.20 - 0.25 |
| 4. | 0.25 - 0.30 |
| 5. | 0.30 - 0.35 |
| 6. | 0.35 - 0.40 |
| 7. | 0.40 - 0.50 |
| 8. | 0.50 - 0.60 |
| 9. | >0.60 |

T: Temperature (in C) at the middle of snow layer being reported (all temperatures are below zero).

| 0. | 0 |
| 1. | 1 |
| 2. | 2 |
| 3. | 3 - 5 |
| 4. | 5 - 10 |
| 5. | 10 - 15 |
| 6. | 15 - 20 |
| 7. | 20 - 30 |
| 8. | 30 - 40 |
| 9. | Below minus 40 |

h: Hardness as measured with the Canadian snow gage (g/cm²).

| 0. | <10 |
| 1. | 10 - 30 |
| 2. | 30 - 100 |
| 3. | 100 - 300 |
| 4. | 300 - 1000 |
| 5. | 1000 - 3000 |
| 6. | 3000 - 10000 |
| 7. | 10000 - 30000 |
| 8. | >30000 |
| 9. | pure ice |

C: Extent of surface irregularities in open country as seen from the station. Do not report here drifts associated with buildings and other man-made obstructions.

| 0. | No irregularities |
| 1. | Less than 50% of the visible area has irregularities. |
| 2. | More than 50% of the visible area has irregularities. |
| 3. | Visible area completely covered with irregularities (drift forms and sastrugi). |

O: Orientation of crests of dominating surface features.

| 0. | No pronounced orientation |
| 1. | NNE - SSW |
| 2. | NE - SW |
| 3. | ENE - WSW |
| 4. | E - W |
| 5. | ESE - WNW |
| 6. | SE - NW |
| 7. | SSE - NNE |
| 8. | N - S |

O: Orientation of crests of minor surface features. Same scale as for O above. Add "9" for no minor features.

In case of only V-shaped drifts, let O and o give the directions of the two arms of the V.

In case both V-shaped drifts and some other features have to be reported, let O and o (depending upon whether they are dominant or not) give the direction into which the V is pointing.

In case of crescentic forms, give the direction into which the convex side is pointing (i.e. the direction of the causing wind).
PROBLEMS IN MAPPING THE SNOW COVER

p: Composite pattern of predominant drift forms and sastrugi

0. No irregularities
1. Linear and parallel
2. Crisscross or multiple-oriented linear forms
3. V-shaped drifts or crescentic forms
4. Scalloped
5. Irregular pattern that cannot be included in groups defined above.

r: Type of surface features

0. Flat surface
1. Gently rounded drifts, smooth depositional forms (wave-like, tongue-like, and barchan-like drifts)
2. Sharply edged, "rough" forms (erosional)
3. Gently rounded drifts superimposed on sharply edged surface
4. Gently rounded drifts partly eroded to sharper features
5. Drifts associated with obstacles

H: Height of dominating roughness features

0. Flat surface (3 in.)
1. 3 - 5 in.
2. 5 - 8 in.
3. 8 - 12 in.
4. 12 - 18 in (1 - 1 1/2 ft)
5. 1 1/2 - 2 ft
6. 2 - 3 ft
7. 3 - 5 ft
8. 5 - 10 ft
9. >10 ft

b: Depth in units of 2 in. of observer's footprints on undisturbed snow surface in open country. (Let 9 stand for 18 inches and more.)

w: The "quality" of the surface snow.

0. Dry new snow
1. Wet new snow
2. Fine grained old snow
3. Coarse grained old snow
4. Up to 5 in. of wet, soggy snow forming the surface layer
5. 5 - 15 in. of wet, soggy snow
6. More than 15 in. of wet, soggy snow
7. Sun or rain crust
8. Wind crust
9. Surface hoar

DD: Average depth, in inches, of snow inside the forest or 'bush'

P: Mean density of the whole snow pack in a representative place inside the forest or 'bush' (Scale as for s in Group 2)

0. 0.00 - 0.10
1. 0.10 - 0.15
2. 0.15 - 0.20
3. 0.20 - 0.25
4. 0.25 - 0.30
5. 0.30 - 0.35
6. 0.35 - 0.40
7. 0.40 - 0.50
8. 0.50 - 0.60
9. >0.60

b: Depth in units of 6 in. of observer's footprints in forest or 'bush'

SS: Depth, in inches, of snow cover on ice

b: Depth, in units of 2 in. of observer's footprints when walking on the snow on the lake, river, or sea ice.
CURRENT SNOW DATA MAPS

7ittW (For shore stations only)

i: Snow cover on ice

0. Snow-free ice
1. Scattered patches of snow
2. Less than 50%
3. 50% to almost complete
4. Almost complete but scattered patches of snow free ice
5. All ice surface covered with snow

ft: Thickness in inches of lake, river, or sea ice

W: Thickness, in units of 2 in., of wet, slushy snow at the bottom of the snow cover and on top of the ice surface.

Comments

The general aim of the Ground Observer’s Report has been (1) to select those characteristics and elements of the snow cover which, when measured and described, will permit an analyst to evaluate snow conditions; (2) to portray this picture in coded form for transmission with as few digits as possible and (3) to distinguish the items measured so that the task is as easy as possible for the observer, thus increasing the reliability of the observations.

The result of such a study has to be a compromise between several interests, but it is our belief that the suggested code satisfies as many of them as is possible today.

We have studied with special interest the “Minutes of the Conference on Snow and Ice Maps, 30 June 1952” (SIPRE, 1952) where specialists from various military branches presented their needs. We have tried to pay attention to as many of these as possible, and we have also added more items, for which we can either see an immediate use, or which we believe will give a more complete understanding of the snow pack and thus will be of a great potential value. The following are specific comments on each group:

Identification Group (NNNNN). The first group identifies the station. Since the International Station numbers consist of five digits, all five digits must be so used, and the first digit cannot be used to identify the group as a whole. In all other groups (those devoted to snow information) the first digit will identify the group.

In the set of snow maps and snow statistics published by the Frost Effects Laboratory, each reporting station normally has an identification number with five digits. Sometimes, though, there was an A, B, or C attached to a number. This does not seem to be in accordance with the International Station Numbers and the station numbers may have to be changed and given five-digit numbers of their own. It should not be difficult to arrange for the identity of these stations to be expressed in terms of five digits.

Group 1ddfg. “dd” — We believe that snow depth can best be given in inches. This is rather obvious for shallow snow depth, where a few inches difference may mean very much when judging the trafficability, but it is probably also the best method for reporting great depths. We very well appreciate that the depth of a considerable snow pack is not defined with an accuracy of 1 in., but the map analyst will also know that, and we believe that the information will be more reliable the less calculation the observer has to do.

For the great majority of reporting stations, present and future, the two digits “dd” will be enough to report even the deepest snow cover. Only very few mountain stations, with exceptionally heavy snowfall, will ever have to report more than 99 inches (8 1/2 ft). If more than 99 in. is to be reported, group 1ddfg should be repeated in the form 1ddxx, where these last “dd” give the depth in excess of 99 inches. Thus, 143 in. of snow is reported as . . . - 199fg - 144xx - . . .

“f” — The third digit in the first group has an important bearing on trafficability. If a heavy snowfall has occurred during the last 24 hr, progress will probably be considerably slower than if this snow has had considerable time to settle. It might also be of operational use, since a blanket of new snow tends to wipe out all ski tracks, vehicle tracks, and other signs of our or enemy activity. Where it does not have to be disturbed, new snow will provide an excellent camouflage.

“g” — The snow cover on ground is given with one digit and is differentiated in five categories. The limits between “1” (scattered patches) and “2” (less than 50%) are of course not very well defined, and it leaves the observer some possibility for subjective judgment. But the estimation of the percentage of snow-covered ground is anyway so subjective, and reliable values for coverage around 10-20% are so difficult to

*If certain measurements or visual observations have not been made, the corresponding digit is to be coded as an “x”.
get, that we think the category "scattered patches" will prove useful. If the observer estimates the snow cover to be more than 15-20%, he should not report it as "scattered patches". This can be given as a rule in the observer's manual.

It would be interesting to have an observer or preferably several, estimate the coverage from the ground, at the same time that more accurate estimations of the same place are made from a plane or, even better, air photographs are taken for future analysis. The ground observer is probably likely to overestimate the extent of the cover in his immediate vicinity.

**Group 21sTh.** This group is designed to give a condensed report of the snow pit measurements, and the group has to be repeated once for every recognized layer, starting with the surface itself. We considered using a second digit "n" to give the number of the reported layer, thus making sure that the different layers cannot get mixed up. This system was rejected because it does not make the best use of the limited number of digits. As weather messages are always sent in 5-digit groups without any group numbers, there was a precedent for the omission of the "n"-digit and its use for a more useful piece of information.

In order to provide space for as much information as possible we have decided to use only one digit "1" for the thickness of each layer. A layer that is 10 in. or more thick has to be split up in two or more parts of 9 in. or less. This is probably not a weakness with the system, because it forces the observer to check whether the density really is the same inside a thick snow layer, which might appear homogeneous to him.

For an ice layer the inch-unit is too rough a measurement, and we have therefore chosen a unit of one-tenth inch to be used always when the hardness (the last digit in this group) is reported as 9 (i.e. pure ice). It might also be considered desirable to report hard wind crusts with this method. When enough observations have become available to SIPRE, it should be easy to find out if snow hardness values above 30,000 g/cm² indicate wind crusts. If they do, we suggest that the one-tenth inch unit be used for hardness values 8 (indicating wind crusts) as well as for 9 (ice).

The temperature for these reports is measured best at the middle of each reported layer, and the scale has been designed to be as sensitive as possible close to the melting point, where the gradient of the vapor pressure-temperature curve is steepest and the metamorphosis most intense. However, it gives a usable temperature differentiation down even to the lowest values.

Hardness values have been differentiated fairly accurately according to a logarithmic scale. The scale is very sensitive for soft snow, but probably also good enough for hard snow (values around 5000 g/cm²). If we compare this hardness scale with SIPRE's Simplified Field Classification we get:

<table>
<thead>
<tr>
<th>SIPRE Hardness</th>
<th>Hardness Code</th>
<th>Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft</td>
<td>0, 1, 2, 3</td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td>4, 5</td>
<td></td>
</tr>
<tr>
<td>Hard</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Very hard</td>
<td>7, 8, 9</td>
<td></td>
</tr>
</tbody>
</table>

**Group 3C0op** and **Group 4rBbw.** Surface features are an extremely important aspect of the snow cover, since a very rough surface can render all movement over the snow almost impossible.

These features also seem to be the most difficult to describe in code form, but we have tried to design two groups which include the more important factors.

The extent of the rough surface will tell the map user to what degree the rough areas might be bypassed; the pattern of the roughness and the orientation of the crests will tell him what directions to avoid.

*If the weather does not permit digging a pit the whole group 2 can be omitted. If the weather is really bad, the whole code may have to be limited to snow depth, snowfall in the last 24 hr., depth of observer's footprints, and the "quality" of the snow surface. The coded message would then read NNNNN - 1ddfx - 4xxbw (stop).
and prefer, and the type of roughness and its average height will indicate the degree of difficulty for surface transportation.

Since we have not differentiated our roughness features according to genetic principles, in which case the orientation would preferably have been given as the direction of the causing wind, we have chosen to give just the orientation of the crests. Thus a longitudinal, linear drift running from the NW to the SE will be reported with the same digit (6) as one that runs from the SE to the NW.

For scalloped patterns the "main axis" of the wavy line should be considered as the crest and the reported direction will thus be perpendicular to the causing wind.

If V-shaped drifts are reported as the only existing surface features, "O" and "o" of group 3 give the directions of the two arms of the V. If V-shaped drifts are reported together with some other pattern, the direction into which the V is pointing should be given as the orientation, i.e. the orientation of the bisector of the V.

In case of crescentic forms the direction of the causing wind should be given. That means a direction perpendicular to the central part of the drift or, we can say, the direction into which the convex side is pointing.

To make it easier for the observer to differentiate between different patterns and types of snow surface irregularities, we suggest that a photo-key be prepared. Roscoe's pictures from Antarctica (1953) are good, but they are too few for this purpose, and they often cover too small an area. There should be plenty of photographs both from Greenland and Antarctica to choose from, if they can be found, and, though the bulk of the pictures have to be taken from the air, ground views are also important and must not be omitted. The various patterns and types of drift forms and sastrugi to be coded as suggested in this report are based on a careful study of photographs which were available. They are descriptive rather than genetic.

In reporting height of dominating roughness features, the average value of the higher of the dominating roughness features would probably be more valuable than an over-all average.

At present there seems to be no good means of defining or measuring a bearing-capacity factor. The hardness measurements in the pit will give a general impression of the bearing capacity, but, even with these measurements, we cannot compute how deep a pedestrian or a vehicle is going to sink when traveling over the snow.

However, a measure of bearing capacity that is very easy to observe and record is given by the depth of the observer's footprints on the undisturbed snow surface. This will give the map analyst a valuable measure of trafficability, though he has to bear in mind that the depth of a footprint also depends upon the observer's weight, the size and type of his boots, and the manner in which he walks. Until more research has been done in this field, we believe that this method gives the map analyst better, more reliable and more easily interpreted information on bearing capacity than any other means that we know at present.

The last digit in group 4 gives a general characterization of the surface snow condition, especially indicating the suitability of the snow surface for movement, particularly for skiing. The categories in the scale proposed are not mutually exclusive in every case, e.g., a rain crust on coarse-grained old snow, a wind crust of fine-grained old snow, or a 10-in. deep water soaked layer of coarse-grained old snow might fall in two categories. In such cases, the latter categories, numbers 4-9 should be used to identify the surface.

Group 5DDPb. The difference between snow conditions in the forest and in the open is sufficient, we believe, to warrant separate consideration. The average snow depth over a large area is determined by precipitation and temperature, but the wind is an equally important factor for local snow conditions. The wind blows the loose snow clear across the fields and deposits it in the nearby forest or "bush" where the speed of the surface wind drops to just a fraction of its previous value. This means that the snow depth locally varies enormously between open and forested areas, and that measurements can be compared only if they are taken under very similar conditions.

Most snow depths at Canadian meteorological stations are measured at air fields and other exposed sites, and it is really astonishing to see how well the values agree even over large regions. This is, however, only illusory. A traveller in the area would find great variations; especially, he would find far greater depths in most forested areas than on the windswept open fields. (This is not always true for dense coniferous forests where a lot of the snow never reaches the ground, but stays on the branches and evaporates from there.)

Since military operations in northern areas can hardly be restricted to large open fields, we also need information about the average snow conditions out in the forest or the bush. We cannot expect to learn everything about all local variations—there will, for instance, always be a difference between the inner parts of a forest and the parts adjacent to open fields—but we can get a general idea of the main difference between the conditions inside and outside the forest.
PROBLEMS IN MAPPING THE SNOW COVER

'DD' will give the snow depth in the forest, and care should be taken to make this measurement as representative as possible. Big drifts, or at least an exceptionally thick snow cover, can be expected along the edge of the forest, where the snow blown away from the nearby field has accumulated.

Since the vegetation has broken the full force of the winds, the forest snow cover normally shows lower density and hardness values than the more wind-packed snow out in the open. It is not proposed that a pit be dug in the forest, but it would be of interest if the average density for the whole snow pack could be measured and reported.

Winter transportation in Arctic regions south of or below the tree line will take place over open fields, frozen lakes, or more or less wind-swept rivers, but, in case of military operations, some activity will be forced into the forest for concealment. Smaller troop units and motorized columns will always have to seek protection in the forests, when enemy planes are around. The greater snow depth and the low hardness values in the forest will make all such activity difficult—it may actually even be difficult to move small units out of the open into the protective vegetation. To anticipate such difficulties, we have suggested that the depth of an observer's footprints in the forest be reported. Here we suggest using units of 6 in. (½ foot), to cover those snow depths that can make movement extremely difficult.

Group 6ISSb. This and the next group are meant for shore stations only.

Lakes occupy a considerable percentage of the surface area in large parts of Canada, and are important surfaces for travel. The extent of the ice cover over adjacent waters is of utmost importance both for surface transportation and for aircraft landings and take-offs. The same is true for the snow cover on ice, both its extent and its depth (Group 7).

The coding is easy to understand. The only precaution to be emphasized is that the number 3 for extent of ice cover must always be preferred to number 2 if there is an open lead along the shore.

The bearing capacity of the snow will probably vary considerably between the open lake surface and the probably somewhat more sheltered area around the station where the ground observations are taken. A hard snow on a lake normally means very easy travelling (provided the surface is not too rough), while a soft surface with slush underneath makes progress very slow, difficult, and unpleasant. Thus we would like to use one digit for the depth of the observer's footprints on the snow out on the lake or sea.

Group 7ittW. The thickness of sea ice is already being reported to the Hydrographic Office, but for judging trafficability we consider it necessary to include that measurement in this code also, especially because of the need to report the ice thickness on inland lakes.

Under certain conditions with rain, intense melting, or heavy snowload on top of a fairly thin ice, a layer of slush will be found at the bottom of the snowpack. This slush can be a great hindrance to transportation, and it is valuable to have it reported, so that necessary measures can be taken.

Symbols for a comprehensive station model

For purposes of analysis, the ground observations assembled must be symbolized and plotted upon a map. A station model which presents, graphically, all of the snow conditions observed has been designed for mapping purposes.

A station model requires an area not to exceed 1 by 2 in. Many would require less space than this. To facilitate the plotting of the model, a thin-line grid to the right scale at every reporting station should be printed upon a special base map and in the color of the base. The grid should be ½ in. wide and 1 in. high and have both horizontal and vertical division lines at 1/10 in. intervals. The base map, by necessity, must be relatively large. The scale of the sample prepared of eastern Canada is about 1:12,500,000 (Figure 22). However, since the number of reporting stations established would be greater, a considerably larger standard base should be prepared with the special station grid. A scale of 1:3,000,000 is suggested, as a probable minimum if around 150 to 200 stations, relatively uniform in spacing, are used.

Suggested symbols for a comprehensive station model, Ground Observation Code

NNNNN - 1ddfg - 2lsTh - 3c0op - 4rHbw - 5DDPb - 6ISSb - 7ittW

Station models are designed for plotting on a special base map (ca. 1:3,000,000) upon which a thin-line grid to the right scale is printed for each station. The grid should be ½ in. wide and 1 in. high and have horizontal and vertical grid lines at each 1/10 in.

Group NNNNN. Station identification.

Group 1.

dd: The snow depth will be indicated by the height of the stratigraphy diagram (see under group 2) and the actual value may be recorded at the left of the diagram.
A POINT SYMBOLISM FOR SYNOPTIC SNOW COVER MAPS:
BASED ON GROUND OBSERVER'S SNOW COVER REPORTS

Figure 22. Requires gridded base map for plotting (data hypothetical). To interpret see symbols pages 54, and 56-60.
f: The snowfall during the last 24 hr can be shown on the ordinate of the diagram by thickening the ordinate down to proper depth using actual value (i.e. twice the code digit).

g: Snow cover on ground is indicated by a circle with differently hatched sectors plotted to the right of stratigraphy diagram.

- 0. Snow free
- 1. Scattered patches
- 2. Less than 50%
- 3. 50% to almost complete
- 4. Only scattered patches of ground visible
- 5. Complete snow cover

Group 2.

The stratigraphy diagram is plotted with the depth along the ordinate and at the scale 1:40. Density and hardness categories are plotted to the right and temperatures to the left. Reported category figures are used as measures, which means that hardness and temperature are plotted in a logarithmic scale. For especially these two the lowest values are the most critical, and thus the greatest accuracy is needed in these intervals. This is taken into account by having categories in logarithmic progression—both recorded and plotted. It is suggested that the maximum width of the diagram be 9/20 inch, i.e. each division for density, temperature, and hardness would be 1/20 inch wide.

Density is to be plotted with lines for each layer, hardness with dots at middle of the layer and temperature as a dashed line.

Group 3.

c: Indicate extent of rough surface by placing reported digit just above the diagram.

O: Orientation of crests of dominating surface features.

Draw an orientation line from the upper left hand corner of the stratigraphy diagram. Straight up for the crests running N-S, straight out to the left for E-W, etc. If "O" is reported as 0 (no pronounced orientation), draw a dashed line straight up.

o: Orientation of crests of minor surface features.

Draw a second orientation line but only half as long as the one for dominating features.

p: Composite pattern of predominant drift forms and sastrugi.

- 0. No irregularities — nothing drawn
- 1. Linear and parallel

Draw a second straight line parallel to orientation line "O" (see above)
2. Crisscross or multiple-orientated linear forms.

Draw a short line across the orientation line.

3. V-shaped drifts or crescentic forms.

Draw an "arrowhead" at the middle of orientation line.

4. Scalloped

Superimpose a wavy line on the orientation line.

5. Completely irregular pattern

Draw a cross at the middle of orientation line.

Group 4.

r: Type of surface features

0. Flat surface — nothing drawn

1. Gently rounded drifts, smooth depositional forms (wave-like, tongue-like, and barchane-like drifts)

Draw an oblong figure parallel to the orientation line and on either side of it.

2. Sharply edged, "rough" forms

Draw an elongated triangle parallel to the orientation line and on either side of it.

3. Gently rounded drifts superimposed on sharply edged surface

Superimpose an oblong figure inside an elongated triangle showing the rough surface.

4. Gently rounded drifts partly eroded to sharper features

Superimpose an elongated triangle inside the oblong figure showing the smooth forms.

5. Drifts associated with obstacles

Use same symbol as for "1" above but attach a cross at one end of the oblong figure.
H: Height of dominating roughness features

Attach one or more "feathers" to the top of the orientation line.
Let one full feather represent digit 2, two full feathers digit 4, and three full and one half feathers digit 7, etc.

0. < 3 in. 1. 3 - 5 in. 2. 5 - 8 in. 3. 8 - 12 in. 4. 1 - 1\(\frac{1}{2}\) ft 5. 1\(\frac{1}{2}\) - 2 ft 6. 2 - 3 ft 7. 3 - 5 ft 8. 5 - 10 ft. 9. > 10 ft

b: Depth of observer's footprints on undisturbed snow surface in open country (coded in units of 2 in.; 9 - 18 in. and more).

Mark the actual depth of sinkage to scale with a horizontal line out to the left from the ordinate on the stratigraphy diagram. This line should extend about 1/10 inch to the left.

w: The "Quality" of the surface snow

+ 0. Dry new snow

\(\frac{f}{f}\) 1. Wet new snow

\(\varnothing\) 2. Fine-grained old snow

\(\varnothing\) 3. Coarse-grained old snow

\(\frac{f}{f}\) 4. Up to 5 in. of water-soaked snow at the surface

\(\frac{\varnothing}{\varnothing}\) 5. 5 - 15 in. of water-soaked snow at the surface

\(\frac{\varnothing}{\varnothing}\) 6. >15 in. of water-soaked snow at the surface

\(\varnothing\) 7. Sun or rain crust

\(\varnothing\) 8. Wind crust
9. Surface hoar

The w-symbol should be placed just outside the upper right corner of the diagram.

Group 5.

DD: Average depth, in inches, of snow inside the forest or bush.

Mark with a cross on the ordinate the snow depth in the forest. If necessary, extend the ordinate below the diagram.

P: Mean density of the whole snow pack in a representative place inside the forest.

Use no symbol, plot reported value underneath the stratigraphy diagram.

b: Depth of observer’s footprints in forest or bush. (coded in units of 6 in.)

Use same procedure as for b under group 4, but draw the horizontal line 1/20 inch on each side.

Group 6.

I: Extent of ice cover on river, lake, or sea.

Plot reported figure close to the circle giving snow cover on lake or sea ice (see “I” in Group 7).

SS: Depth of snow cover on ice.

Draw a vertical line to the right of and just outside the diagram. Let the length of this line show snow depth on ice at same scale as the diagram.

b: Depth of observer’s footprints when walking over snow cover on lake or sea ice (coded in units of 2 in.).

Use same symbol as for footprints in group 4, but draw the horizontal line to the left out from snow-depth line 6SS.

Group 7.

i: Snow cover on ice.

Use same symbol method as for snow cover on ground and plot circle below “snow cover on ground” symbol.
PROBLEMS IN MAPPING THE SNOW COVER

**tt:** Thickness of lake or sea ice.

Extend the snow-depth line 6SS downward—as a double line—still using same scale as for stratigraphy diagram.

**W:** Thickness of wet, slushy snow at the bottom of the snow cover on ice.

Mark it to scale with an oblong figure superimposed on the bottom part of the snow-depth line.

Sample station model.


---

Interpretation. The snow cover is complete except for scattered patches of ground (see upper circle), and its depth is 35 in. (read only the length of the line along the left side of the graph for density). New snow which is “dry snow” (see plus sign upper right) is 8 in. deep, as indicated by the thickening of the upper part of the depth line. The upper tick extending to the left of this line shows that an observer's foot would sink 8 in.

In nearby forested areas the snow cover has a depth of 56 inches, measured by the total extent of the main axis and its density is 0.17 as written on the diagram. The short horizontal line crossing the axis shows the sinkage of an observer’s foot as 30 inches.

The density, hardness, and temperature of the snow pack can be read for each layer from the bar graph to the right of the depth line, the dotted graph to the right, and the dotted line to the left, respectively. For example, the snow surface has a density between 0.00 and 0.10, a temperature between 10° and 15° below zero, and a hardness of 10-30 g/cm². The first 8 inch layer has a density between 0.10 and 0.15, a temperature of between 10° and 15° below zero, and a hardness between 10 and 30 g/cm².

The thickness of the remaining five layers, ranging between 3 and 9 in., can be determined by the length of each vertical line to the right of the main snow depth line. The density increases with each layer (except for the last layer) as shown by the distance of each vertical line from the main axis. The temperature remains at 10-15° below zero for roughly 2 ft and then increases to 3-5° below zero, determined by the dotted line to the left. The hardness of the pack increases with each layer as shown by the dots to the right of the graph, except for the bottom layer which decreases.

The visible snow area is completely covered by surface irregularities—drift forms or sastrugi (number 3 at the top). They are gently rounded drifts (smooth depositional forms), of a linear and parallel pat-
tern, from 1-1\frac{1}{2} ft in height, and oriented NE-SW. This information is determined by the parallel lines above the graph, the two feathers extending from these, the oval above the lines, and the direction of the lines, respectively. There are no minor features.

Lake or water areas are completely or almost completely frozen over (number 2 below the lower circle). This circle indicates complete snow cover on the ice with an average depth of 11 in., shown by the upper single line part of the line at the left of the two circles. The tick on this line shows that an observer's foot would sink 6 in. The lower double line extension indicates that the thickness of the ice is 16 in. There is no slushy snow at the bottom of the snow cover.

Air Observation Code

The scattered snow observation stations in northern Canada provide a useful and necessary net of "fixed points", but there are vast expanses about which we know nothing. To extend the network to such a degree that reliable medium scale maps could be drawn will hardly be feasible in peace time, and such a net would need quite a few years before any good averages can be expected.

If, however, careful observations can be made from aircraft flying over the Arctic regions, fairly accurate traverses could be obtained in addition to the scattered spot-observations. Though only information about snow coverage and surface features can be expected, knowledge will be gained about prevailing wind conditions and to a certain degree about the amount of snowfall. The much greater extent of the area that can be covered by aircraft observation will make even a short period average very valuable. Local conditions will not play such an important role as they often do for individual ground stations.

It also can be expected that there might be in the future an urgent and immediate need for operational information about the snow conditions in a certain area. It will then be of great importance to have the observation and coding routine properly worked out and tried in practice and flying personnel trained for the purpose.

The Aircraft Snow Observation Report (SIPRE BR3 F13) has been used as a basis for our suggested report and code. It has been revised to a form suitable for coding for radio transmission and enlarged slightly to include some further desirable observations. Thus a few more surface feature characteristics have been added, especially the extent of rough areas, to enable the map user to judge to what degree the roughness is going to cause any complications.

The air observation code provides only the kind of information that can be obtained from observations made by pilots.* The code is presented on a single separate page, since it was designed to be reproduced as a standard form card for reporting observations (see Fig. 23). The report is set up so that, after having checked off all information, the observer can code into three five-digit groups (Groups 3-5) for radio transmission. Groups 1 and 2 would be used to identify the location of an observation.

Comments

The code proposed here has been designed to make observations from aircraft as easy and as meaningful as possible for the flying personnel.

To further facilitate the observations we suggest that a special photo key be worked out to fit this code. The photo key should contain a greater variety of pictures of rough areas than Roscoe's "Contributions to the Study of Antarctic Surface Features by Photogeographical Methods" (1952) and preferably photographs covering somewhat larger areas. The inclusion of some pictures showing these same irregularities as seen from the ground would increase the observer's correct understanding of what he sees.

This fairly comprehensive photo key may be too extensive for use in the plane, in which case it can be used for training purposes on the ground, and an abridged photo key, on a reduced scale, worked out for flight use.

*The reports were tested in several flights by the authors. A number of reports were also completed on flights by R. W. Gerdel of SIPRE.
PROBLEMS IN MAPPING THE SNOW COVER

Fig. 23. Aircraft Snow Observation Report

Code: ...Position...3gld - 4RrPp - 50ocw

Purpose: To collect information on the areal distribution and surface features of snow cover

Instructions: Complete one copy of this report for each area in which a major difference in snow cover distribution, snow surface feature or orientation of the feature is observed.

Unless otherwise indicated identify conditions with a check mark. Indicate orientation of drifts by drawing a full diameter line for dominating features and a radius line for minor features on the compass card below.

Transmit completed reports as soon as possible, by airmail or by any other means which will provide early delivery to SIPRE.

Date ________________________ Time ____________________ Plane Altitude ________

Latitude ______________ Longitude ______________ Bearing _______________ deg.

Enroute, from __________________ to ____________________________

Group 3.

Snow Cover, percent of visible area covered by snow.

\[
\begin{array}{ccccc}
1) & 0-25 & 2) & 25-50 & 3) & 50-75 & 4) & 75-100 & 5) & 100 \\
\end{array}
\]

g. Over land

i. Over ice

I. Ice Cover, on lakes, rivers, sea, percent

1) 0-25 , 2) 25-50 , 3) 50-75 , 4) 75-100 , 5) 100 

d. Snow Depth

1) Very thin snow, probably just a few inches.
2) Slightly deeper, but grass tussocks, fallen tree trunks, etc. well visible.
3) Deep snow, all irregularities on the ground well blanketed.

Group 4.

Snow Surface Features: check dominant feature in D-column, minor feature in M-column and indicate orientation of dominant axis and minor axis on compass card.

R.r. Roughness

1. Flat surface, no significant roughness
2. Gently rounded drifts, smooth depositional forms
3. Sharply edged, "rough" forms (erosional)
4. Drifts associated with visible obstacles

P.p. Pattern

1. Linear, parallel, well oriented
2. Crisscross, multiple oriented
3. V-shaped or crescentic
4. Scalloped
5. Indefinite

Group 5.

O.o. Orientation: Draw full diameter for dominating features and a radius for more minor features.

c. Drifted Areas as percent of visible snow covered area.

1) 0-25 , 2) 25-50 , 3) 50-75 , 4) 75-100 , 5) 100 

w. Water patches in snow cover, 1) none , 2) few , 3) many.
The observation report has been organized so that the information can be transmitted easily by radio. This should not be necessary in peace time, since the data would be primarily of statistical interest rather than of immediate value. In case of war, however, it might be of utmost importance to obtain current information as soon as possible, and, since most snow observations might be taken from planes on other missions than pure local observation flights, it is important to have a coding system for radio transmission well prepared. The introductory paragraphs of the SIPRE BR3 F13* have been left unchanged, but they must, of course, be revised slightly to fit this code, especially if the message is going to be transmitted by radio.

**Group 1 and 2.** The two first groups are used to report the geographical position of the plane. We have not suggested any coding, because we take it for granted that the Air Force has its own system of reporting positions. Two groups of five digits each should be ample, though.

**Group 3g1d.** The observations of snow cover over ground and over ice are especially valuable when taken from an aircraft, because observations can be made over larger areas and the estimates will be more accurate. The same is true for the ice cover on different waterways.

If the possibilities for surface transportation have to be considered, knowledge about the thickness of the ice is required also. There is little hope that ice thickness can be estimated from an aircraft, but it should be possible to make a fair estimate of the ice thickness if the date of the freeze-up is known as well as the general temperature conditions. The date of freeze-up should be easy to determine at least where a number of flights are taken over an area.

During flights over Canada in March of 1954, different methods for reporting snow features were tested. As a result, some information about snow depth is considered desirable for inclusion. The difference between an area completely covered with a thin layer of new snow and another area with a thick snow blanket, very important for activity on the ground, is also very noticeable from a plane. The degree to which one can observe tussocks, low shrub, fallen tree trunks, etc. is a very good indication of the thickness of the snow cover. It would take a lot of experience to estimate the actual depth and give the result in inches or even in units of 5-6 inches, and some information is better than none. The three categories proposed, although very subjective, will prove useful and can be differentiated from the air.

**Group 4RrPp.** The photographic key previously mentioned would be very valuable for the correct reporting of the different types and patterns of surface features.

We have tried to use as few categories as possible for the types of snow roughness features, and the main aim has been to force the observer to classify the drift forms either as "smooth" or "sharply edged." For all sorts of surface movement, whether motorized or on skis, the "character" of the surface can be vital. Smooth and gentle drifts will give ski troops very little trouble. A ride in a motor vehicle will perhaps be bumpy, but the speed is not slowed down too badly. If, on the other hand, the surface is rough with high sharply edged features, skiing can be very difficult and tractors and other vehicles have to be driven with the greatest care at a very slow speed.

No attempt has been made to design a scale for reporting the estimated height of the surface features, since experience indicates that it would probably be a mere guess for most observers. However, this lack of height information is considered as a rather serious weakness. If the snow surface is 100% covered with sharply edged features no higher than 2 to 3 in., the report could be very misleading, as the features would probably be interpreted as an obstacle to transportation. Because of this, the observer should be given a certain degree of freedom to exercise his own judgment and not report anything that he believes is too minor to cause any trouble. Perhaps it would be safer and slightly more objective if he is instructed not to report any features that he estimates to be lower than 3 to 4 in. Similarly, the observer must judge which of the different types of "roughness features" to report as dominant and which as minor. He must try to determine which will have most importance for surface transportation. Thus an apparently high feature should be reported as dominant even if its areal extent is less than a lower feature of less significance to movement.

"Pattern" should be fairly well provided for by the five divisions proposed. The "pattern" of the dominating roughness type should be reported as the "dominating pattern." For instance, if there are large, gently rounded drifts with a not very pronounced scalloped pattern and fairly small, sharply edged features with a very regular linear pattern, the scalloped pattern has to be reported as dominant. The very regular, linear pattern, which might be dominant as a pattern, should be reported as minor, because the features to which it belongs are the minor type of roughness.

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*SIPRE BR3 F13 is a preliminary draft of an aircraft snow observation report prepared by R. W. Gerdel, but has not been published.*
When the "roughness" has been reported with the figure "1," the corresponding "pattern" should be given the figure "0." "x" should be used only when observations have not been taken.

Group 50ocw

O and o: "Dominant orientation" always means the orientation of the dominant type of roughness.

Orientation of drift forms can be estimated rather accurately from a plane, if the observer knows the flight course. All directions should be referred to true North and not to magnetic North.

In case "crisscross or multiple oriented features" are reported as dominant or as the only features, give the most dominant direction as "O" and the second most dominant as "o."

If "crisscross or multiple oriented features" are reported as minor with another pattern as dominant, try to report the one most conspicuous orientation in the crisscross pattern as "o." If there is no dominant orientation, code "o" as an "x."

When V-shaped features are the only ones to be reported, use both "O" and "o" to give the direction of both arms. If V-shaped features are reported together with any other drift forms, give the orientation of the bisector.

Crescentic forms are partly transverse and partly longitudinal. The head, or the main body, always lies perpendicular to the causing wind, and the two tails are always flying with the wind. The direction into which the tails fly should be reported as the orientation. This is the same as the direction perpendicular to the "face" of the drift or the direction into which the convex side points.

When the pattern is scalloped, the "wave units" normally run fairly parallel, and the direction of the main axis of these waves should be reported. Since these features are transverse, the reported direction runs perpendicular to the causing wind.

c: "Drifted area" must be expressed as a percent of visible snow covered open country, without including forested area in the estimate, since it is assumed that most activity will always have to take place in open fields, on lakes, along waterways, etc.

If the plane flies over a forested region and all lakes are completely covered with roughness features, "c" shall be reported as 100% (digit 5) even though perhaps 80% of the whole field of view is forested and shows no drift forms at all.

w: If the snow, especially on lakes, is saturated with water in its lower levels, trafficability is very poor. Of course this cannot be observed from the air, but the observer should watch carefully for discolored patches in the snow indicating slush conditions.

Comments on coding for transmission. The observation report is set up so that, after having checked off all information, the observer can code the groups 3 to 5 for radio transmission in less than half a minute. He has to take only one digit at a time and write down the number of the category that has been checked. For orientation in group 5, he first takes the figure belonging to the full diameter and then the figure for the radius. If there is no orientation to report he writes a 0 (zero). He should use "x" only when he has not been able to obtain adequate observations.

Station Model for Aircraft Snow Observations

A set of symbols has been designed to make possible the plotting of the Aircraft Snow Observations in the form of a station model. This station model is, of course, much simpler and takes less space than the station model for complete ground observations. The data can be plotted within a 5/8 x 5/8 in. square.

Station models based on air observations can be mapped separately (Fig. 24) or used in conjunction with those based on ground observations.

The relative ease with which this "air observation" station model can be read and interpreted makes it also a satisfactory "simplified station model" for plotting partial data from ground observations. Air and ground observation plotted together on the same map by means of this station model can present a general picture of the extent of snow cover, its depth in rough terms, and the character of the drift surface.

Proposed symbols for station model based on air observations.

Groups: NNNNN — NNNNN — 3gild — 4RrPp — 50ocw

The first two groups are used for identification of the location of an observation. The remaining three groups can be symbolized as described below in a station model made up of two circles and one square with a few other symbols attached.
A POINT SYMBOLISM FOR SYNOPTIC SNOW COVER MAPS -
BASED ON AIR OBSERVER'S SNOW COVER REPORTS

Figure 24. Based on hypothetical data. To interpret see symbols pages 64, and 66-68.
PROBLEMS IN MAPPING THE SNOW COVER

Group 3gild

g: Snow cover on land. Plot in the upper circle.

1. 0 - 25% 

2. 25 - 50% 

3. 50 - 75% 

4. 75 - 100% 

5. 100% 

i: Snow cover over ice. Plot in the lower circle, using the same symbols as for "g" above.

1. 0 - 25% 

2. 25 - 50% 

3. 50 - 75% 

4. 75 - 100% 

5. 100% 

d: Snow depth. Draw a line about 2/10 in. long to the left of the g-circle if snow-depth is reported as #1, very thin. Draw two such lines to show snow depth #2, and three lines for #3, deep snow. Draw lines about 1/20 in. apart. For categories of depth see Fig. 23, p. 62.

Group 5Oocw. Preferably to be plotted before group 4, which follows below.

O: Orientation of dominant surface features. Draw an orientation line from the upper left hand corner of the "c"-square (see under "c" below). Draw a line straight up for N-S, straight out to the left for E-W, etc.

o: Orientation of minor surface features. Draw a second orientation line but only half as long as the one for dominant features.

c: Drifted area as percent of visible area which is covered by snow. Draw a square to the right of the snow cover circle, and apply the following scheme.
CURRENT SNOW DATA MAPS

1. 0 - 25% 

2. 25 - 50% 

3. 50 - 75% 

4. 75 - 100% 

5. 100% 

**W:** Water patches in snow cover. Plot two large dots underneath the "c"-square for "many" water patches, one large dot for "a few" water patches, and leave blank for "no" patches.

**Group 4RrPp**

**R:** Type of roughness of dominant surface features. Place the symbol at the side of the orientation line which indicates the direction of dominant surface feature.

1. Flat surface, no significant roughness

2. Gently rounded drifts, smooth depositional forms

3. Sharply edged, "rough" forms (erosional)

4. Drifts associated with obstacles

**r:** Type of roughness of minor surface features. Place a symbol at the side of the orientation line which indicates the direction of minor surface features. Use same symbols as for "R" above.

**P:** Pattern of dominant surface features. Attach another symbol to the orientation line for dominant features.

1. Linear, parallel, well oriented.
   Draw a second straight line parallel to the orientation line.

2. Crisscross, multiple oriented.
   Cross over the orientation line with one short line.

3. V-shaped or crescentic.
   Superimpose a V on the orientation line.

4. Scalloped.
   Superimpose a wavy line on the orientation line.

5. Indefinite.
   Superimpose a cross on the orientation line.
PROBLEMS IN MAPPING THE SNOW COVER

Interpretation. The three short parallel lines at the upper left hand corner, indicate a deep snow, i.e., all irregularities on the ground well blanketed.

The circle to the right of these lines indicates that the snow covers between 75 and 100% of the visible area. The square at the lower right shows that drift phenomena exist over 75 to 100% of the snow covered area.

The northeast-southeast orientation of the dominant surface features is represented by the diagonal line extending from the upper left corner of the square. The sharp triangle at the side of this line identifies the roughness features to be sharply-edged, "rough" forms (erosional). The parallel line adjacent to the orientation line means that these sharply-edged features are linear, parallel and well oriented.

A north-south oriented minor set of roughness features is portrayed by the shorter vertical line extending upward at the upper left of the square. There are gently rounded drifts, with a V-shaped or crescentic pattern, as denoted by the oval symbol to the side of the line and the inverted "V" toward the end of the line, respectively.

The lower left circle refers to the ice areas, which means that this is a shore station. The ice surface is 100% snow covered, since the inner circle is blank. Only 75 to 100% of the water area is frozen, however, as expressed by the outer circle not being complete.

Finally, the black dot below the square indicates that there are a few soaked patches in the snow cover.

A Simplified Snow Observation Report

Introduction

The Simplified Snow Observation Report has been worked out for use at stations where no trained observers and/or no instruments are available. Also, the "first class" stations which send in a complete report once or twice a week can easily increase their program with one simplified report per day, if need be. Finally, in case of military operations in the Arctic, it also can be used by any troop detachment without any extra equipment.

The simplified report is identical with the more complete Ground Observer's Snow Report, except that the groups 2, 5, and 6 have been cut out. All observations can be made without any instruments except a tape measure.* The "Comments on Ground Observer's Snow Report" apply to the remaining groups in the simplified report, and the specific comments are repeated only for the sake of making this "Simplified Snow Observation Report complete as a separate unit.

The station model designed for the Simplified Snow Observation Report may be considered also as an alternative point symbol system. For some purposes, the station models based on the elements of the simplified ground report may provide a map with sufficient information. If a current synoptic map is desired without the data on density, hardness, snow temperature, etc., the station model based on the simplified ground report is preferable, since it requires less space and is more quickly plotted. Actually the differences in the models for features which are common to both are relatively minor. The two station models were designed so that they could be used together on the same map or independently. The simplified model does not require a grid printed on the base for plotting as does the more complete model.

Proposed code and symbols for station model based on Simplified Snow Observation Report

This is a simplified and abbreviated snow observation report with symbols for a station model for ground stations. It is based on observations which can be made quickly and is suitable for use at "second class stations" in conjunction with more extended observations at "first class stations."

NNNNN - lddfg - 3cOop - 4rHbw - 7ttW

NNNNN - Station identification number

*If the ice group number seven is reported, a tool to drill or chop through the ice is necessary, also.
Group 1ddfg

dd: Average depth in inches of snow cover on ground. Draw a vertical depth line to the scale 1:40. If the depth exceeds 12 in. (equal to 3/10 in. on diagram), draw one 3/10-in. line for every 12 in. and one at scale for any value more than an even multiple of 12 in. Place the lines parallel to each other about 1/20 in. apart.

f: Depth, in units of 2 in. of snowfall during the last 24 hr. (Let 9 stand for 18 in. and more.) Draw the top part of the (left) depth line thicker down to a depth corresponding to the thickness of the last snowfall. Plot actual value.

g: Snow cover on ground. Indicate by means of a circle with differently hatched sectors. Circle to be plotted to the right of diagram.

0. Snow free
1. Scattered patches of snow
2. Less than 50%
3. 50% to almost complete
4. Scattered patches of ground visible
5. Complete snow cover

Group 3cOop

c: Extent of surface irregularities in open country as seen from the station. Do not report here drifts associated with buildings and other man-made obstructions. Give extent of rough surface as a figure (reported digit) immediately above the diagram.

0. No irregularities.
1. Less than 50% of the visible area has irregularities.
2. More than 50% of the visible area has irregularities.
3. Visible area completely covered with irregularities (drift forms and sastrugi).

O: Orientation of crests of dominant features.

0. No pronounced orientation
1. NNE - SSW
2. NE - SW
3. ENE - WSW
4. E - W
5. ESE - WNW
6. SE - NW
7. SSE - NNW
8. N - S

Draw an orientation line from the top of the (left) depth line, 2/10 to 3/10 in. long. Draw it straight up for crests running N - S, straight out to the left for E - W, etc. If O is reported as 0 (zero), no pronounced orientation, draw a dashed line straight up.

O: Orientation of crests of minor surface features. Same scale as for O above.

Symbol: Draw a second orientation line, but only half as long as the one for dominating features.
In case of only V-shaped drifts, let O and o give the directions of the two arms of the V.

In case both V-shaped drifts and some other features have to be reported, let O or o (depending upon whether they are dominant or not) give the direction into which the V is pointing.

In case of crescentic forms give the direction into which the convex side is pointing (i.e., the direction of the causing wind).

*p:* Composite pattern of predominant drift forms and sastrugi.

0. No irregularities — nothing drawn.

1. Linear and parallel.
   Draw a second straight line parallel to the orientation line “O” (see above).

2. Crisscross or multiple-oriented linear forms.
   Draw a short line across the orientation line.

3. V-shaped drifts or crescentic forms.
   Draw a “V” at the middle of orientation line.

4. Scalloped.
   Superimpose a wavy line on the orientation line.

5. Completely irregular pattern.
   Draw a cross at the middle of orientation line.

*Group 4rHbw*

*r:* Type of surface features

0. Flat surface — nothing drawn.

1. Gently rounded drifts, smooth depositional forms (wave-like, tongue-like, and barchan-like drifts).
   Draw an oblong figure parallel to the orientation line on either side of it.

2. Sharply edged, “rough” forms.
   Draw an elongated triangle parallel to the orientation line and on either side of it.

3. Gently rounded drifts superimposed on sharply edged surface.
   Superimpose an oblong figure inside an elongated triangle showing the rough surface.

4. Gently rounded drifts partly eroded to sharper features.
   Superimpose an elongated triangle inside the oblong figure showing the smooth forms.

5. Drifts associated with obstacles.
   Use same symbol as for “1” above but attach a cross at one end of the oblong figure.
H: Height of dominating roughness features
   Attach one or more "feathers" to the top of the orientation line. Let one full feather represent class 2, two full feathers, class 4, and three full and one half feather, class 7, etc.

   0. <3'  
   1. 3 - 5'  
   2. 5 - 8'  
   3. 8 - 12'  
   4. 1 - 1 1/2 ft.  
   5. 1 1/2 - 2 ft.  
   6. 2 - 3 ft.  
   7. 3 - 5 ft.  
   8. 5 - 10 ft.  
   9. >10 ft.

b: Depth in units of 2 in. of observer's footprints on undisturbed snow surface in open country. (Let 9 stand for 18 in. and more.) Mark the depth of sinkage (actual value) to scale with a horizontal line out to the left from the (left) depth line. Make this horizontal line about 1/10 in. long.

w: The quality of the snow surface
   0. Dry new snow
   1. Wet new snow
   2. Fine grained old snow
   3. Coarse grained old snow
   4. Up to 5 in. of wet, soggy snow forming the surface layer
   5. 5 -15 in. of wet soggy surface snow
   6. More than 15 inches of wet, soggy snow
   7. Sun or rain crust
   8. Wind crust
   9. Surface hoar

   The w-symbol should be placed just to the right of the g-circle.

Group ii: 
i: Snow cover on ice. Use same symbols as for "g" in group 1. Plot circle below the "g" circle.

ii: Thickness in inches of lake, river, or sea ice.
   Plot reported value immediately to the right of "i"-circle above.

w: Thickness, in units of 2 in. slushy snow at the bottom of the snow cover on the ice (on top of the ice surface).
   Plot the code-digit immediately below the "i"-circle described above.
PROBLEMS IN MAPPING THE SNOW COVER

Sample Model. The simplified snow observation report, when plotted as a station model, occupies about the same area as the air report model, but lacks the square indicating the extent of the drifted areas. Below is a sample model and its interpretation.

Sample Model

Code: NNNNN - 12245 - 32281 - 41231 - 73102
NNNNN - Station Identification

Interpretation. The snow depth is 22 in. as indicated by the one full and a second almost full line at the lower left. The thickening of the left line for three-fourths of its length indicates that there are 8 in. of new snow, and the tick extending to the left from this line shows that an observer's footprint would be 6 in. deep.

The ground is completely covered by snow (upper open circle) and between 50 and 100% of the ice surface is covered with snow (lower circle). The number "2" below this circle is read as 4 in. of slushy snow at the bottom of the pack, but on top of the ice.

Two sets of drift features exist. The dominant features are gently rounded drifts (smooth depositional forms) which are linear and parallel, 5 to 8 in. high and oriented NE - SW. These facts are indicated by the oval and two longer lines, one with a feather, extending from the snow-depth line. The N - S orientation of the minor drift features is indicated by the shorter line extending upward from the snow depth line. The digit "2" next to the drift symbols indicates that more than 50% of the visible area has irregularities on its surface.

Finally the small "f" to the right of the upper circles shows that the snow surface is of wet new snow and the number "10" to the right of the lower circle shows that the thickness of the ice is 10 in.

Conclusion

These three codes made possible the systematic recording and transmission of pertinent data concerning the snow cover. The three station models associated with the respective codes permit the recording of this data by point symbols on a map so that areal differences are apparent. At first, their use may appear difficult, but the experience of the authors as they worked with them was that they are no more complex than standard weather bureau models and codes.

Although they are designed primarily for the "snow analyst," they can be read, particularly the two shorter codes and smaller models, by anyone with a little practice.

Great care has been given to the selection of items included in each code, but some modification and changes may be necessary after their operational use in the field for a period of time.

The comprehensive ground code is designed to include all items about the snow cover which have a direct or indirect bearing on military operations. The aircraft observation code is restricted to those items which can be observed from the air, but provides a useful supplement to the ground data, particularly in areas where the latter are not available. The simplified code is limited to important snow features which can be observed quickly without instruments by an untrained observer.

The three codes and station symbols can be used together or independently. They should not be considered as separate entities. They have been integrated in their design and conception. They provide a means of systematically recording on maps a picture of the current snow cover which heretofore has not been feasible.

References


CHAPTER V
MAPPING SNOW DENSITY

Introduction

Snow density is one of the more important basic properties of the snow pack. Systematic observations of snow density with depth measurements have been carried out in some western watersheds in the United States for as long as 20 to 30 years. These surveys are used to forecast the water available for irrigation and power developments.

The density of snow is also an important physical-mechanical property of the snow cover, since all of its other properties are directly connected with it. The greater the density, the greater the area of contact between snow particles. Snow density also appears to have considerable bearing on the use of snow in transport, building, and other military operations. A thick snow cover can be a great hindrance to trafficability if density values are low, and it can, on the other hand, greatly facilitate movement through road-free country, if density values are high enough (and snow temperatures low enough).

Limitations of Data for Mapping

Available data
Statistics on snow densities in North America are meager... There is a growing mass of density data from snow surveys within important drainage basins in western United States. Similarly, there is a growing amount of data from snow surveys in lower British Columbia and southeastern Canada. The data have been collected by interested state and federal government agencies and power companies. Very little of it, however, is published, and it applies to relatively small, scattered, drainage areas, and for varying but relatively short periods of record.*

There is, therefore, a lack of systematically collected and permanently tabulated density data from a sufficient number of well-spaced stations to attempt a snow density map of Canada at even a very small scale. Where the limited data are available for a part of Canada, the period of record is too short and variable to obtain useable mean values.**

Reliability of the data
Observational, sampling and bias errors all may be involved in snow density data. The nature and size of these errors should be ascertained, since they may affect the drawing of isolines. Each of these probable sources of error was examined briefly in the chapter on isolines, chiefly as it affected snow depth values.

Integrated density values taken by the Mount Rose sampler and by individual layers at the same site varied as much as 20 to 30%. Although samples by the two methods were taken within 6 ft. of each other, one cannot be sure whether the difference is due to instrumental and other observational errors or to natural variations. In snow course observations varied sampling procedures are used. From 3 to 31 observations are made at intervals of 100 or 200 ft. (Canadian Department of Transport, 1956). Some courses are stated to be representative of the terrain and forest cover in that locality. Others do not specify conditions. Comparability of data is also lacking in the time of the observations. Although many statistics refer to the end or beginning of a month, others may be for various dates. Studies indicate that density of the snow cover, as a whole, increases on an average of 10 to 12% per month (Rikhter, 1945, p. 8). Interpolation of values to a common date could be subject to considerable error. Among other factors which may affect the reliability of the observed values are the time of day and the site (whether forested or open and protected or wind-swept).

Natural variations in density
The density of the snow cover appears to be extremely variable both in space and time. Snow density values fluctuate between 0.01 and 0.7 and ice layers in the pack attain densities of 0.9. Within the snow pack, the density may vary vertically and horizontally.

*There are a few Canadian snow surveys with records for 10-30 yr. periods. The Shawinigan Water and Power Company has made surveys for 28 years in the St. Maurice River Basin.

**The status of snow density data outside of North America is not known and no attempt was made to look for data. Systematic, permanent observations are probably lacking. There are, however, isolated observations which are part of various snow studies.
Vertical layer variations. A set of density readings picked at random suggests the nature of density variations among layers (Table V). Variations between two adjacent layers show increases and decreases in density from 2 to 27%, and the difference in density between the maximum and minimum layers is as much as 85 to 95%. These layer differences are partly the cause of different density measurements of the snow pack within a few feet. The layers may vary horizontally in thickness and thereby affect weighted mean values of the pack taken even 5 to 10 ft. apart. Density measurements, reported by Work (1948) for individual layers, show increases and decreases within a layer at 2-week intervals (Table VI).

### TABLE V. Density Values for Layers (Work, 1948, p. 532, 534)

<table>
<thead>
<tr>
<th>Layer</th>
<th>Feb. 3</th>
<th>% increase or decrease</th>
<th>March 3</th>
<th>% increase or decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>.424</td>
<td>.400</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>.390</td>
<td>-8%</td>
<td>.414</td>
<td>+ 4%</td>
</tr>
<tr>
<td>D</td>
<td>.439</td>
<td>+13%</td>
<td>.437</td>
<td>+ 6%</td>
</tr>
<tr>
<td>E</td>
<td>.372</td>
<td>-15%</td>
<td>.444</td>
<td>+ 2%</td>
</tr>
<tr>
<td>F</td>
<td>.273</td>
<td>-27%</td>
<td>.376</td>
<td>-15%</td>
</tr>
<tr>
<td>G</td>
<td>.226</td>
<td>-14%</td>
<td>.339</td>
<td>-10%</td>
</tr>
<tr>
<td>H</td>
<td></td>
<td></td>
<td>.267</td>
<td>-21%</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td></td>
<td>.240</td>
<td>-10%</td>
</tr>
<tr>
<td>Weighted Mean Density</td>
<td>.331</td>
<td></td>
<td>.439</td>
<td></td>
</tr>
</tbody>
</table>

### TABLE VI. Lateral Density of Each Snow Layer as Measured in Experiments at Crater Lake, Oregon, 1940-1941 (Work, 1948, p. 332)

| Layer | 1940 Nov. 14 Nov. 28 Dec. 9 Dec. 23 | 1941 Jan. 6 Jan. 20 Feb. 3 Feb. 17 Mar. 3 Mar. 17 Mar. 31 Apr. 15 Apr. 28 May 13 May 26 June 2 |
|-------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|
| A     | 23.7 33.4 41.8 39.4 39.8 41.2 42.4 42.2 40.0 40.6 37.6 45.2 48.9 48.3 51.6 49.8 | 22.6 32.7 37.2 41.6 44.4 48.3 48.2 51.5 52.8 56.1 |
| B     | 24.2 40.0 30.0 36.9 39.4 39.0 39.4 41.4 46.7 43.4 42.7 44.8 46.9 50.0 47.2 | 22.6 32.7 37.2 41.6 44.4 44.9 47.8 |
| D     | 32.6 37.9 42.6 43.9 44.2 43.7 46.0 48.3 48.2 51.5 52.8 56.1 | 22.6 32.7 37.2 41.6 44.4 44.9 47.8 |
| E     | 22.9 32.7 37.2 41.6 44.4 48.3 45.2 51.5 52.8 55.2 58.2 55.9 | 22.6 32.7 37.2 41.6 44.4 44.9 47.8 |
| F     | 19.3 27.3 32.8 37.6 40.6 48.0 49.7 54.1 53.3 | 19.8 26.7 37.9 43.4 41.8 |
| G     |                              | 19.8 26.7 37.9 43.4 41.8 | 24.0 | 40.6 | 40.6 |
| H     |                              | 19.8 26.7 37.9 43.4 41.8 | 24.0 | 40.6 | 40.6 |
| I     |                              | 19.8 26.7 37.9 43.4 41.8 | 24.0 | 40.6 | 40.6 |
| L     |                              | 19.8 26.7 37.9 43.4 41.8 | 24.0 | 40.6 | 40.6 |

Weighted density of A plus B

<table>
<thead>
<tr>
<th>1940</th>
<th>1941</th>
</tr>
</thead>
<tbody>
<tr>
<td>24.0</td>
<td>40.6</td>
</tr>
</tbody>
</table>

a Believed inaccurate as tube went upward into D layer when sampling east side.
b For comparison with vertical density of A plus B. (A was given weight of 8 and B weight of 1.)
PROBLEMS IN MAPPING THE SNOW COVER

Whether these differences within the same layer are due entirely to real changes in density as a result of natural processes or express, at least in part, some natural horizontal density variation within layers is not known. In either case, they are a possible source of sampling error in the mean density of the pack. Furthermore, and more important, they illustrate that the mean density of a pack is an average of layers, some of which may be high, others low. A low mean pack density may give no indication of a high density surface layer which would support a man's weight. On the other hand, a very low-density layer, which would affect mobility, may underlie a thin high-density layer.

Density variations from place to place. Information on the nature of the natural differences in the mean density of the snow pack from place to place is meager. Two sets of density observations made in the Keweenaw Peninsula, Michigan, are insufficient to make any conclusions, but indicate possible problems (Table VII).* Nine density measurements made within about 15 miles of Houghton, and all in open rolling upland country, show considerable uniformity. The mean of the nine stations is 0.367, and their standard deviation is 0.018. The range in density of 0.045 (from 0.387 to 0.342) appears to be low and indicates a relatively homogeneous mean density of the snow cover over an area of approximately 300 square miles.

TABLE VII. Snow Densities, Keweenaw Peninsula (March, 1953)\(^a\)

<table>
<thead>
<tr>
<th>Station</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southern</td>
<td></td>
</tr>
<tr>
<td>Houghton</td>
<td></td>
</tr>
<tr>
<td>Group</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>.342</td>
</tr>
<tr>
<td>2</td>
<td>.379</td>
</tr>
<tr>
<td>3</td>
<td>.387</td>
</tr>
<tr>
<td>4</td>
<td>.377</td>
</tr>
<tr>
<td>5</td>
<td>.377</td>
</tr>
<tr>
<td>6</td>
<td>.385</td>
</tr>
<tr>
<td>7</td>
<td>.346</td>
</tr>
<tr>
<td>8</td>
<td>.352</td>
</tr>
<tr>
<td>9</td>
<td>.353</td>
</tr>
<tr>
<td>Northern</td>
<td></td>
</tr>
<tr>
<td>Eagle Harbor</td>
<td></td>
</tr>
<tr>
<td>Group</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>.476</td>
</tr>
<tr>
<td>11</td>
<td>.370</td>
</tr>
<tr>
<td>12</td>
<td>.402</td>
</tr>
<tr>
<td>13</td>
<td>.379</td>
</tr>
<tr>
<td>14</td>
<td>.341</td>
</tr>
<tr>
<td>15</td>
<td>.451</td>
</tr>
<tr>
<td>16</td>
<td>.362</td>
</tr>
</tbody>
</table>

\(^a\) Densities based on observations made in March, 1953 with the assistance of SIPRE staff members. All values are readings with the Mount Rose sampler.

This range over the entire area, however, is only slightly greater than the difference between some samples taken only a few feet apart. If one were to assume, for this reason, that the density over the whole region is really uniform and that the individual readings are distributed normally about the general mean, the number of values expected to exceed the minimum and maximum could be several times the number observed.** Continuing this reasoning, one can conclude that the density is about 0.370 over the entire area, and there is no justification for drawing a sinuous density isoline to include one particular value or to exclude a neighboring one.

* Observations were made at the end of January, 1953 and in early March, 1954. Several staff members of SIPRE helped to make the measurements. The January series consisted of 16 observations, widely scattered from Houghton to the end of the peninsula, except for the northeastern section.

** This reasoning and method are used in checking upon the drawing of isotherms. See Brooks and Carruthers, 1953, p. 96.
In other words, although one could draw a series of sinuous density isolines at 0.01 intervals (for 0.350; 0.360; 0.370; 0.380) across this area, their validity and meaning is highly questionable.* The values upon which they would be based are merely a matter of chance and within the expected variation around the mean.

In contrast, the remaining seven density readings, made near the northern part of the peninsula, show a much greater variation within an area of about 30 square miles. Differences between stations, although they are more closely spaced, are equal or greater than those between the nine southern stations. Thus, if there are natural differences in density between the points of observation, the gradients are steeper in the north. However, the difference in density between stations is still not always greater than that between pairs of density readings made by different instruments at a given station. The differences in density among the seven northern observations, nevertheless, appear to represent actual natural differences in density from place to place. The differences in exposure, terrain, and vegetative cover among the seven stations make this a reasonable expectation.

The preceding partial and incomplete investigation of density differences from place to place within a relatively small area is inconclusive.** It suggests, however, that isolines drawn at intervals of 0.01 or even as large as 0.025 at large scales (1:125,000 to 1:500,000) are highly questionable. Their detailed and sinuous appearance would not express any real or actual areal differences in snow density. The feasibility of mapping snow density at large scales and at small intervals needs further investigation. Statistical analysis (more refined than that which the author was able to carry out) of systematically collected data is needed to determine observational and sampling errors and to distinguish the degree of the areal difference in snow density.***

Areal variations in snow density over extensive areas. Regional differences in the various combinations of basic conditions which affect snow density are sufficient to cause regional differences in snow density. Consequently, the snow density in northern Canada, with continuously low temperatures, would be expected to differ from the density in southern Canada with its frequent thaws and recurrent freezing weather.

Data to compute average density values for Canada are not available. Rikhter (1945, p. 8) quotes from Veinberg 'a few values for the Soviet Union (Table VIII). The stations are widely spaced, extending from northeastern and central European U.S.S.R. to the Ob-Irtysh region of eastern Asiatic U.S.S.R. For each of the four dates, there is a surprising uniformity of the average density values among the six places which are separated by as much a 700 miles in latitude and are more than 1000 miles apart east and west.

Density maps based on such average values, even with several hundred stations, would be of little or no value for military planning. The departure from year to year from the average density for a given place and a given date and variations with changing terrain and vegetative cover within a few miles of the station would be several times greater than the difference in average density between any parts of Canada. The average density value for a period of years obscures significant regional differences at a particular time.

For example, among the six Russian stations, the maximum difference in the average density on December 15th is 0.05, between Borovoe Forestry and Savatov (Table VIII). These two stations are 1000 miles apart. Observations in the Keweenaw at the end of January provided density differences as high as 0.17 within 5 miles. Two-thirds of sixteen density observations taken in the Peninsula in mid-March fell between 0.343 and 0.417. The range (0.074) among these stations, which lie within an area about 70 by 30 miles in extent, is greater than the range in average density of the widely separated Russian stations.

The use of the monthly mean or average density for mapping has all of the disadvantages of the mean when used for snow depth or rain, plus additional elements of variability which the latter do not have. The

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* Data were plotted at a scale of 1:125,000.

** The means of the northern and southern groups of stations showed no significant difference from the mean of all values by Student's "t" test. No significant difference, by the same test, was found between the means of the two groups (north and south). These tests are not conclusive proof that no difference exists. In fact, the northern group approaches the point of a possible significant difference. In addition, the selection of stations was not well planned for such a test. Further investigation is needed on this point.

*** A more detailed study of variations in snow density within an area of 4 square miles was made by SIPRE (1953). Twenty regular and eighteen special snow courses, each consisting of three to eleven observations, are analyzed. The within-course density values have a range of about 0.05 and the range among the courses was 0.18. Furthermore, no significant areal distribution of densities within the 4 square miles was found. This study, however, tends to confirm the infeasibility or impracticability of detailed isoline density maps.
apparent widespread uniformity indicated by the average density values masks the actual regional and relatively large density differences which exist at a given time.

TABLE VIII. Average Density of Russian Stations During the Winter (Rikhter, 1945, p. 8)

<table>
<thead>
<tr>
<th>Date</th>
<th>Sverdlovsk</th>
<th>Borovoe Forestry</th>
<th>Shmitlovka</th>
<th>Saratov</th>
<th>Valuiki</th>
<th>Syktyvkar</th>
<th>Aver. of six in percent. ratio to Dec. 15 density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec. 15</td>
<td>0.20</td>
<td>0.18</td>
<td>0.20</td>
<td>0.23</td>
<td>0.22</td>
<td>0.20</td>
<td>100</td>
</tr>
<tr>
<td>Jan. 15</td>
<td>0.22</td>
<td>0.20</td>
<td>0.22</td>
<td>0.25</td>
<td>0.24</td>
<td>0.22</td>
<td>112</td>
</tr>
<tr>
<td>Feb. 15</td>
<td>---</td>
<td>0.22</td>
<td>0.25</td>
<td>0.28</td>
<td>0.27</td>
<td>0.25</td>
<td>127</td>
</tr>
<tr>
<td>Mar. 15</td>
<td>0.27</td>
<td>0.25</td>
<td>0.28</td>
<td>0.30</td>
<td>0.29</td>
<td>0.26</td>
<td>138</td>
</tr>
<tr>
<td>Apr. 15</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>0.37</td>
<td>185</td>
</tr>
</tbody>
</table>

The spread of these regional density differences and variations within a locality at a given time are sufficiently wide to include several possible density categories which might be based on critical values affecting mobility. Rikhter (1945, p. 9) gives a few critical density values, although they are not necessarily important in American operations.

When snow reaches a density of 0.32 to 0.35, it will sustain a pedestrian without skis. At 0.35 to 0.38, the foot hardly leaves a mark. At over 0.4, the snow will sustain a horse, and the human foot leaves no mark whatever.

The wheels of a horse-drawn wagon no longer break through when the density is over 0.3 or 0.35, but heavy trucks require a density of not less than 0.5.

The mapping of mean density values, computed from these variable conditions, although mechanically feasible, is therefore of questionable value.

Snow Density Maps of Eastern Canada

Few, if any, maps exist depicting snow density over extensive areas at a given time in a single year, probably because of a lack of data. The preparation of such maps, however, should help to provide an insight into the regional pattern and differences in snow density.

Four snow density maps of Eastern Canada are presented here for the end of December, January, February, and March of 1955 (Figs. 25-28). These maps are based on data for 60 to 70 stations collected by power companies and provincial agencies and published by the Canadian Department of Transport (1956). The majority of the snow density values for the stations are based on snow courses. They represent means based on 10 to 30 observations at 100- or 200-foot intervals. *

Each of the four monthly maps shows a distinct pattern. Whether these patterns represent meaningful areal differences is a problem for statistical investigation.

A comparison of the four months in consecutive order shows a similarity in the patterns. Relative differences in density between large areas established in December appear to continue throughout the winter. For example, a low density area northeast of Lake Superior on December 31st (Fig. 25) persists, although slightly modified in shape and location, on the January, February, and March maps (Figs. 26, 27, and 28).

* The individual readings could not be obtained. The variability of these individual readings within a snow course in relation to the difference between snow courses should be investigated. The course means used here, unfortunately, mask the density variations within each locality.
Figure 25. The low area east of Lake Superior continues through January and February. Isolines at intervals of 0.02 are based on means for snow courses. Dashed isolines are projections only. Dotted isolines with crosses indicate individual local anomalies.
Figure 26. The high area established in the lower St. Lawrence continues through February. Isolines at intervals of 0.02 are based on means for snow courses. Dashed isolines are projections only. Dotted isolines with crosses indicate individual local anomalies.
Figure 27. The highs in the St. Lawrence valley and east of Georgian Bay have developed and expanded. Isolines at intervals of 0.02 are based on means for snow courses. Dashed isolines are projections only. Dotted isolines with crosses indicate individual local anomalies.
Figure 28. Although absolute values have changed, there is still a broad similarity of the March pattern with that of December. Isolines at intervals of 0.02 are based on means for snow courses. Dashed isolines are projections only. Dotted isolines with crosses indicate individual local anomalies.
Similarly, two areas of relatively higher density continue to exist for the four months east of Georgian Bay and the lower St. Lawrence valley.

These patterns may represent persistent relative differences between regions which exist year after year, or they may represent conditions only in a single year. As density statistics become available for additional years, maps should be made and compared. Absolute values differ considerably from year to year, but if the relative values between regions remained essentially the same from year to year, general regional descriptions could be made, and even some prediction might be possible. Index numbers based on the relative values could be plotted on a map and isolines drawn.

Statistical Investigation of Density: Eastern Canada

A preliminary statistical investigation of some aspects of density values was attempted when the monthly maps were made. These preliminary tests were made with the help and advice of William C. Krumbein, Department of Geology, Northwestern University, who has been developing statistical methods for analyzing area differences and trends in lithology and thickness of sediments.

Test for area differences

East-west differences across Eastern Canada. Plotting the density values on a map makes apparent immediately their great variability within short distances (50 to 100 miles). These values are sample means (i.e., means of individual observations made in a snow course) of the snow pack population. The question arises as to whether the variation between the sample averages is commensurate with the population variance of the snow pack. In other words, is there a greater "within sample variation" (i.e., among density values in a small area) than there is "between sample variation" (i.e., between two or more of the small areas)? An analysis of variance was made of the values for 31 January to see if there were actual regional or area differences. The January density values were divided into 20 north-south columns. The observed "F value" (4.14) was well above the 0.5% critical value (2.20) (from Dixon and Massey, 1951, p. 312). Therefore, there is a significant difference between the longitudinal north-south belts. There is greater difference between the belts than within the belts.

Density differences in a limited area. To further investigate the areal difference, the variation on 31 January within a 5-deg. grid square was examined. The 5-deg. quadrilateral (between latitudes 45° and 50° and longitudes 80° and 85°) which lies east of Lake Superior and north of Lake Huron was selected because the variability appeared greatest. An analysis of variance test, designed on the basis of values within four triangles formed by the two diagonals, did yield a significant "F value." In other words, within the area of this grid square, there is greater local variation (within samples) than there is difference between the four triangular areas. These two tests are not conclusive. They suggest, however, that at least in January, 1955 there was a significant difference in density from east to west among arbitrary north-south belts. On the other hand, locally within smaller areas the variability is greater within small areas than between the areas. Cartographically, this indicates that relatively large density intervals should be used for isolines.

Estimating regional trends in density: Orthogonal polynomials

The statistical method used to examine experimental data for significant trends by orthogonal polynomials has recently been adapted to the estimation of regional trends in field observation (Oldham and Sutherland, 1955; Krumbein, 1956). Unfortunately, the density values available for Eastern Canada in each of the months were not distributed in such a manner as to provide satisfactory rows and columns. An analysis of variance test (two factor basic with replication) was made between rows and columns of fifteen cells obtained from superimposing a grid over all the plotted values on the January map of southeastern Canada. This analysis showed no significant interaction and no significant difference north to south between the rows. The east-west difference between the columns is also questionable. The observed "F value" (1.98) was less than the 5% critical value of "F" (2.90).

The lack of an equal number of values in the fifteen cells of the grid presented a problem in computing orthogonal polynomials. Although an attempt was made to compensate for this data weakness, the result is questionable.* It appears that any east-west or north-south differences (between columns and rows) has only a very small linear gradient. The quadratic and cubic components (the "noise" in a statistical sense is much greater.

* Dr. William C. Krumbein, Department of Geology, Northwestern University, worked out the procedure used.
If this is true, the local variability is so great that no meaningful regional linear gradient exists. The sinuosity of the isolines and the local peaks and depressions in them (January 31st map) at least appear to verify this visually.

With additional data which could be used within a proper grid design, this line of statistical investigation might provide some opportunity for recognition of significant regional snow density conditions and trends which could be used for predictive purposes within useful limits.

Regional density changes during the winter

That the density of the snow generally increases during the winter is well known. The rate of increase, however, does not appear uniform. Apparently it increases rapidly at the beginning of the winter, then levels off to a slow increase and near the end of the season increases rapidly. The increase for an average of 70 stations in southeastern Canada is given in Table IX.

Density at individual stations in southeastern Canada varies more and does not always show a continued increase from month to month. Sometimes there is a decided decrease.* A comparison of the monthly density maps (Figs. 25-28) shows that, over large areas, the density generally is increasing from month to month. Only in a few places are decreases evident.

Change in snow density for Eastern Canada: analysis of variance. To test the change in density during the winter, an analysis of variance test (two factor basic with replication) was made on the basis of comparing the density in nine north-south belts (each about 100 miles wide) during the 4 months. The statistics were the same as used for the monthly maps.

A very highly significant time difference was found. The observed "F value" (18.78) exceeded the 0.5% critical "F value" (4.45) by several times. In each of the nine belts there was a strong tendency for an increase in density to occur each month. In only two instances did a decrease occur between 2 months.

The density from west to east showed only a marginally significant change (5% level). Even this is not particularly meaningful, because it refers to an abstract condition, since conditions of all 4 months are included.

Change in snow density for Eastern Canada: orthogonal polynomials. To test the gradients further the orthogonal polynomials were computed, using Krumbein's (1956) adaptation of the general method described by Oldham and Sutherland (1955). Of the total variability between the rows (i.e., the change in time), 85% was due to a linear gradient. Thus the change in density from month to month across the entire region has a pronounced linear gradient. Of the remaining irregularities (the statistical "noise"), 13% is a quadratic component and 2% is a cubic component. The quadratic component reflects the somewhat greater ratio of increase in density at the beginning and at the end of the winter. The cubic component reflects the other minor variations in density through time.

With additional investigation of data for other years and areas and with the recognition of the components in the trend of density change during the winter, estimates of density within limits may be possible.

* The statement is based on examination of snow survey data for a number of stations in southeastern Canada. Data was supplied by the Hydro-Electric Power Commission of Ontario.
Of the total variability between the columns (i.e., density trends from west to east during the four months), 65% is due to the linear component. Whereas this linear trend was not very pronounced in any one month, it appears as a stronger trend over the 4 months. On the other hand, the complexity of the directional variations is still evident. The quadratic component (2%) and cubic component (7.4%) with the linear account for only 74% of the column values. The remainder (26%) is composed of higher terms (quartic to octic).

Conclusions: statistical investigations

The natural variability of snow density in space and time raises problems in the mapping of density. The feasibility of mapping density for large or small areas, at large or small scales, with large or small isoline intervals is dependent on an understanding of this natural variability. Since density observations (individual readings or course means) are only samples from a large population, the problem is a statistical one. With the limited fragmentary data available, the limited time for this phase of the investigation, and with the statistical limitations of the authors, the scope of the statistical investigations in this study has been restricted. This phase of density, however, should be given further investigation.

Estimating Snow Density from Meteorological Data

Since density is such an important snow characteristic, it would be desirable to draw maps showing density values for a given time for those areas in which trafficability problems may occur. The meager statistics on snow density have already been pointed out. Even with considerable improvement in the collection of data, there still, in all probability, will be large areas for which data are lacking. A method by which snow density may be computed or estimated from known data of other meteorological elements would be useful.

Relation of density to wind speed and temperature

Wind speed and temperature appear to be the principal meteorological factors affecting snow density (Dmitrieva, 1950). Field observations and examination of some density measurements from Canada which have been published verify the relationship.* Stations with high average wind speeds tend to get a densely packed snow with higher hardness and density values, while in more wind-free areas the snow is deposited as a fluffy powder, which tends to preserve its loose texture all through the winter. This of course assumes that other meteorological conditions are the same.

High temperatures and rainfall have also a very pronounced effect on the density and the hardness. New snow deposited at temperatures just below freezing has a higher initial density than that deposited at lower temperatures, and, furthermore, the metamorphosis proceeds considerably faster with the higher vapor pressures existing closer to the melting point. Rain or melt water refreezing in lower and colder snow layers also contributes to higher densities.

During those months of the year when the temperature seldom or never rises above freezing, the wind is by far the most important density-increasing factor. The available reports show lower figures for stations with low wind speeds (e.g., Edmonton, Alberta) or wind breaking forest or bush (e.g., Goose Bay and Aklavik) and higher values for the windier and/or more exposed stations in the Arctic Archipelago, such as Isachsen, Resolute Bay, and Eureka.

Every writer on snow mechanics seems to agree that the wind is mainly responsible for the density increase of the fallen snow at sub-freezing temperatures, and it would therefore be of great interest to study quantitatively the relationship between the two.

A few such studies have been made and very approximate figures are reported by Seligman (1936) and Rikhter (1950) who quotes other Russian snow researchers. What has been reported is, however, not the effect of the wind on the fallen snow but on the new snow.

Dmitrieva (1950) has computed the mean density of the snow packs at different periods during the winter and for a great number of stations, using both wind and temperature measurements. He claims that the deviation of calculated density from observed values was less than 0.02 in 85% of the cases, and less than 0.03 in 97%. These calculations were made of the density for the last days of the winter, but he has also computed densities for 10-day periods. He then has to introduce special corrections for deep new snow or for fairly recent cases of heavy snowfall. His accuracy is surprisingly good even here, and the deviation between calculated and observed densities amounted to less than 0.02 in 64% of the cases, and less than 0.04 in 95%.

* Density measurements for 12 stations and for a period of 2 to 4 years are available. See Pearce and Gold (1951).
Dmitrieva's formula for computing snow pack densities reads:

\[
P = P_o + 0.0024 \tau_v + k \sqrt{\Sigma \theta_t}
\]

where \( P \) = mean density at the end of the calculation period

\( P_o \) = initial snow cover density

\( \tau_v \) = number of days with wind velocity equal to or more than 6 m/sec.

\( \Sigma \theta_t \) = sum of positive mean diurnal air temperatures at the end of the calculation period

\( k \) = empirical coefficient equal to 0.007 for densities less than 0.26, and to 0.002 for densities equal to or more than 0.26.

His formula shows the combined influence of wind and temperature, and the individual terms are derived from two diagrams included in the article.

The term "0.0024 \( \tau_v \)" is taken from the density-wind speed diagram and seems well founded. The other term, however, "\( k \sqrt{\Sigma \theta_t} \)" can hardly be correct. Let us, for instance, assume that there has been no wind and that the sum of positive air temperatures has been 100°C. If the original density is, say 0.20, the term "\( k \sqrt{\Sigma \theta_t} \)" gets the value 0.07 and the end result 0.27. According to the diagram, though, the end result should be 0.38.

A second-degree equation that portrays Dmitrieva's density-temperature diagram fairly well can be written as

\[
P = P_o + 0.0024 \tau_v + \frac{0.02}{2 \sqrt{\Sigma \theta_t}} - 0.19
\]

We get further

\[
\frac{dP}{d \Sigma \theta_t} = \frac{0.02}{2 \sqrt{\Sigma \theta_t} - 10} = \frac{2 \times 10^{-4}}{P - 0.19}
\]

and the combined equation would thus read:

\[
P = P_o + 0.0024 \tau_v + \frac{2 \times 10^{-4} \Sigma \theta_t}{P - 0.19}
\]

The coefficient \( \frac{2 \times 10^{-4}}{P - 0.19} \) varies considerably along the curve (as does also Dmitrieva's coefficient and good agreement can only be expected if the \( \Sigma \theta_t \) value is not too high. If the density has to be computed with a high sum of positive temperatures, better values will be obtained if \( P_o \) is substituted for \( P_o + \frac{P}{2} \), which means that the coefficient for the mean density is used. (It should be noted that Dmitrieva's equation "2" should read \( P_{av} = 0.15 + 0.0024 \tau_v \) instead of \( P_{av} = 0.15 + 0.024 \tau_v \)).

Application of Dmitrieva's equation

Since Dmitrieva's equations are the only ones available in which the density is expressed as a function of temperature and wind, they were applied on actual measured density values from Arctic stations.

Using the original equation, as given in the translation, the computed densities failed to show any consistent agreement with the observed densities. (Table X). Eight of the fourteen calculations departed from the observed values by more than 0.04, whereas all of Dmitrieva's computations had a smaller departure than this.

This test of Dmitrieva's equation is not sufficient to be conclusive. Further investigation with more complete data should be made of both of his equations. It is interesting to note that all of Dmitrieva's departures from observed values are less than the range in values in about one-half of the snow course readings which the authors have seen. In other words, the differences in density between two stations in a snow course may be greater than the differences Dmitrieva found between calculated and observed values. If his estimated densities were compared to observed mean course values, then his departures are of little practical consequence.

On the other hand, if his estimated densities were compared to individual density observations (instead of course means), his results are questionable. The variability among density readings, taken even a short distance apart, would be greater than his departures. At least this is true in the limited experience of the authors with density observations. His departures, as a result of his estimations, are smaller than actual natural density variations in short distances, and perhaps also smaller than potential instrumental errors.

Our own test of his equation indicates that departures of estimated from observed values are much larger (see Table X). Of course, this may be due to some error in the observed densities used or in the conversion of wind data in our calculations. The discrepancies seem greater in some cases when the sum of the positive temperatures is large.
### Table X. Observed and Estimated Densities

<table>
<thead>
<tr>
<th>Station</th>
<th>Date</th>
<th>Observed Density</th>
<th>Estimated Density</th>
<th>Discrepancy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolute Bay</td>
<td>10/24/52</td>
<td>.283</td>
<td>.368</td>
<td>+.085</td>
</tr>
<tr>
<td></td>
<td>11/27/52</td>
<td>.374</td>
<td>.331</td>
<td>-.043</td>
</tr>
<tr>
<td></td>
<td>1/27/53</td>
<td>.364</td>
<td>.398</td>
<td>-.034</td>
</tr>
<tr>
<td></td>
<td>2/27/53</td>
<td>.329</td>
<td>.390</td>
<td>+.061</td>
</tr>
<tr>
<td></td>
<td>3/28/53</td>
<td>.348</td>
<td>.348</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>4/27/53</td>
<td>.356</td>
<td>.375</td>
<td>+.019</td>
</tr>
<tr>
<td>Isachsen</td>
<td>10/26/52</td>
<td>.311</td>
<td>.399</td>
<td>+.088</td>
</tr>
<tr>
<td></td>
<td>12/30/52</td>
<td>.355</td>
<td>.337</td>
<td>-.018</td>
</tr>
<tr>
<td></td>
<td>2/27/53</td>
<td>.328</td>
<td>.366</td>
<td>+.038</td>
</tr>
<tr>
<td>Aklavik</td>
<td>2/23/48</td>
<td>.287</td>
<td>.242</td>
<td>-.045</td>
</tr>
<tr>
<td></td>
<td>2/28/49</td>
<td>.266</td>
<td>.333</td>
<td>+.067</td>
</tr>
<tr>
<td></td>
<td>2/15/50</td>
<td>.260</td>
<td>.250</td>
<td>+.010</td>
</tr>
<tr>
<td>Fort Churchill</td>
<td>2/26/48</td>
<td>.315</td>
<td>.263</td>
<td>-.066</td>
</tr>
<tr>
<td>Winnipeg</td>
<td>2/28/49</td>
<td>.262</td>
<td>.357</td>
<td>+.095</td>
</tr>
</tbody>
</table>

*a* Observed densities supplied by Lorne W. Gold, Snow and Ice Section, Division of Building Research, National Research Council, Canada.

*b* Estimates made for periods of 2 months more or less.

### Conclusion

A workable empirical formula for estimating density from known data would be a useful tool, particularly since the variability of snow density within short distances and from year to year is so great that average and widely spaced values are of limited use as indicators of actual density at a given time.

The natural variations in density need systematic investigation. Statistical analysis should be applied to grouped and one-and two-stage gridiron sampling in limited areas to establish the nature of the natural variations and the most economical method of sampling snow density. Studies of this sort should be carried out in widely separated regions, particularly areas where temperatures are continuously below freezing, as well as in those where freezing and thawing occur.

Monthly density maps offer another field for investigation. The persistence of highs and lows in the density maps over a period of 4 months in 1954-55 suggests that a comparison should be made with data for other years. Although absolute values may vary from year to year, relative values may have a distinct regional pattern.

Field investigation of density in relation to wind velocity, air temperature, and temperature gradients is desirable. Detailed observations in the open and under forest conditions, at frequent intervals, on a carefully designed sampling basis should be carried out. Schytt found large differences in density and hardness at Aklavik within 300 ft. in the open as compared to the low brush which correlated with differences in wind speeds.

Finally, it should be stressed that snow density work to the present has been directed primarily towards estimating water content for run-off prediction. For these purposes good average values are all that is needed. For military purposes, the average figure may lead to serious miscalculations.

### References


PROBLEMS IN MAPPING THE SNOW COVER


Snow Ice Permafrost Research Establishment (1953) Variations in snowpack density, Central Sierra Snow Laboratory, Corps of Engineers, U.S. Army, South Pacific Division, (February 4) Mimeographed, 13p.

CHAPTER VI

RECOMMENDATIONS

The final purpose of the study is the preparation of recommendations for assembling of additional data and for further research which are necessary to improve the presentation and accuracy of data upon maps depicting surface snow and ice phenomena. During the course of the study the authors realized that there is a great variety of data which need to be assembled and compiled into map form and of research work, both statistical and field, which should be undertaken.

1. Snow Cover Maps: Small scale Compilations of Various Aspects and Their Parameters.

No one aspect of snow cover and no single parameter of an aspect, even though mapped at monthly intervals, can provide a sufficient picture of snow cover to meet needs and requirements in planning military operations. Analysis of snow cover for military operations, in the absence of maps showing current conditions, requires maps of various aspects of the snow cover and of several statistical parameters of each. Therefore additional maps of other snow cover aspects and their parameters should be compiled to supplement those of mean, maximum, and minimum monthly snow depths which have been published by the Frost Effects Laboratory.

These maps should be compiled at small scales (1:5,000,000 - 1:10,000,000) and reduced when published. Data at the present and in the near future are not likely to be sufficient for larger scale compilations and the variability of the phenomena obviates the need and desirability of larger scales.

The number of stations used in compiling the maps should be increased over that used by the Frost Laboratory. An appreciable amount of data exists, particularly in Canada and Europe, which was not used by the Frost Effects Laboratory. Much of this data, however, will require considerable effort to extract and tabulate.* The extracting and tabulating job should be recognized as a major task and should be so designed and systematized that the various values required for the maps can be obtained with a minimum of effort.

1. Maps of the northern hemisphere

It is recommended that the following maps be compiled for the northern hemisphere: **

a. Average monthly snow depth - utilizing superimposed or located line graphs. The scale for this map needs to be larger - about 1:3,000,000 should be sufficient for graphs of known stations. (This map would be similar to Fig. 5, but would be based on a greater number of stations.)

b. Mean annual date of the first snow cover of an inch or more. Interval 20 days except where data will permit a 10-day interval. (This map is similar to Fig. 8)

c. Mean annual date of the last snow cover of an inch or more: Interval 20 days, except where data will permit a 10-day interval. (see Fig. 9)

d. Continuity of snow cover: months with no breaks in the snow cover. (See Fig. 11)

e. Mean snowfall for each month.

f. Mean number of days with snow fall each month. This may be modified to some critical value such as the mean number of days with more than 2 inches of snow each month.

g. Maximum snow fall during the maximum month.

h. Depth of snow cover for each month, utilizing frequency graphs to indicate percent of time certain depth values occur. Maximum depth should also be indicated. This map, utilizing superimposed line graphs, would require a scale of almost 1:1,000,000 where stations were closely spaced, but 1:3,000,000 would be sufficiently large if only selected stations were used in some areas.

Frequency graphs printed upon an outline map on the back of standard 1:1,000,000 sheets are considered the best single way of presenting the variable snow depth conditions which are apt to occur.

**The National Weather Records Center in Asheville is gradually expanding its punched records. Snow observations for the United States have been punched since 1948 and since 1952 water equivalent of snow on the ground. The Canadian government began punching records in 1953 and snow data for 175 of the first class Canadian stations are available from 1941 and on. On the other hand, for Siberia, China, Mongolia, and other areas, data may not exist or would be difficult to obtain not to mention the difficulty of extraction and tabulation.

**Some of these maps have been compiled for Canada on the data of 100 stations only. The new compilations should expand the number of stations used. The Canadian Meteorological Service initiated a snow cover study several years ago, There would be distinct advantages to arranging an international agreement for map compilations to be prepared by the Canadian Service for Canadian areas.
and of meeting the requirement for snow depth information expressed by some at the Conference on Snow Maps. This would be more meaningful and lead to less misunderstanding than isolines of average depth, no matter how precise.

i. Frequency maps of snow depths to be expected 20%, 40%, 60% and 80% of the time for each month. Ten-inch snow depth intervals should be used and the map can be constructed to indicate the depth of snow to be exceeded or not to be exceeded for the particular percent of the time. (See Fig. 20 for an example.)

2. Experimental compilations

It is recommended that the following maps be considered for experimental compilations. In some cases the experimentation is to test the feasibility of the technique, in others the practical contribution of the particular aspect or parameter to the overall picture of snow conditions.

a. Standard deviation of mean monthly snow depth. It is suggested that standard deviations be plotted in inches and isopleths constructed. Areas with similar departures should then be distinguished by suitable categories. Isolines of mean monthly snow depth may be superimposed on the above choropleth map of standard deviations.

This map should permit interpretation by interpolation of the frequency with which certain snow depths may be expected during a given month. The length of time required to make the necessary computations and the limited number of stations with a sufficient period of record years present difficulties. The technique is still a desirable one to try experimentally, because it could be used in other aspects of the snow cover which have extreme variability, such as snow density or snowfall.

b. Mean length of snow cover season in days. Duration of the snow cover can be defined in several ways. One way is the mean length in days of the period in which a continuous snow cover of an inch or more existed. This parameter of snow cover duration, however, may be less valuable than one which indicates the average date of the beginning and end of the period with a continuous snow cover of a particular depth.

c. Snow regions of the northern hemisphere. This technique as discussed in Chapter III should be extended and applied to a map of snow regions of the northern hemisphere (see map of Canadian Snow Regions, Fig. 21). The present lack of snow cover data, the relative homogeneity of snow cover conditions within probable critical operational values over extensive areas, and the occurrence of some zones where marked changes in the snow cover occur in short distances, all favor this technique as a method to present snow cover conditions. The range of conditions which characterize the region as a whole commonly do not exceed the range in conditions which may occur in a period of years within a particular locality.

Regional distinctions and descriptions are now limited to those aspects of the snow cover for which there are data. For the few places where they are available, the limited density and hardness data suggest that these parameters may also have distinct regional patterns. If common meteorological factors are involved, density and hardness conditions may be added to the snow region descriptions or provide a basis for establishing regional subdivisions.

II. Preparation of Synoptic Current Snow Data Maps

1. Review of proposed codes.

The codes designed for transmission, and the symbols and station models designed for plotting on synoptic snow maps, as proposed in this study, should be reviewed by interested agencies and adopted for experimental field tests. Characteristics and elements of the snow cover have been selected for three types of observational reports: ground, aircraft, and simplified ground (non-instrumental).

2. Collection of field data.

It is suggested: (a) that field data be collected by the three types of observational reports for a selected area and stations; (b) that these reports be coded, transmitted and plotted on maps.

3. Evaluation of synoptic maps.

The resulting experimental synoptic current snow data maps should be evaluated by snow analysts in relation to needs for information in military operations.

4. Application where data are limited.

Under normal conditions the preparation of such synoptic current maps at frequent intervals (e.g., weekly) over all of Canada is probably not practicable, and the need is questionable. However, observations
would be particularly valuable in those areas of Canada for which there are no data, and for mapping the
distribution and occurrence of such phenomena as drifting.

5. Utilization for military operations.

The codes, symbols, and station models, once their suitability is tested, should be particularly valuable
when and if military operations are carried out in a region of snow cover. The authors feel that they should
be considered seriously for this "standby" purpose.

III. Snow Density Research

1. Investigation of the natural variation of snow density in space.

The great variability of the snow density values based on observations within relatively small areas
(a few feet to a few miles) and the need to obtain satisfactory representative density values of the snow pack
make a systematic study of variations in snow density in space a basic line for investigation and research.

Statistical analysis of carefully planned gridded samples taken in widely separated regions should be
carried out. Such a study should determine the minimum number and spacing of samples to obtain a suitable
measure of density at a particular station. Regional and other areal differences in snow density should be
investigated by systematic sampling at greater and varying distances.

Most density measurements of snow have been made for hydrologic purposes. Thus the purpose has
been to obtain representative means which eliminate area differences or include them with a minimum of
bias. For purposes of trafficability, the object is to ascertain these area differences, at least insofar as
they may be critical to movement.

2. Snow density maps of Eastern Canada.

Maps similar to those in this study (Figs. 25-28) should be prepared for various dates for several win­
ters to ascertain whether there are any persistent regional patterns of snow density. Lacking more complete
systematic data, the plotting of the presently available density data would be valuable. Data for years prior
to 1954-55 would have to be obtained in the field from various companies and provincial agencies, since it is
not published.* There is reason to believe that data exist for between 40 and 70 stations in south-eastern
Canada, but would require collection at the source from original field notes. Data in 1955-56 similar to that
issued for 1954-55 may be published by the Canadian Meteorological Service, so the data should be mapped
and compared with the maps for 1954-55 in this report.

3. Reliability of snow density data.

The reliability of snow density observations should be investigated. Statistical analysis of systemati­
cally collected samples with the Mount Rose sampler and by the layer method should be undertaken with the
study of natural variation in snow density. The establishment of the reliability of the Mount Rose sampler
for density measurement would facilitate field observation of density. Sampling errors could be determined
at the same time as part of the investigation of natural variations in space of snow density.

4. Relation of snow density to temperature and wind.

There is considerable reason for believing that snow density can be estimated within certain limits
from temperature and wind velocity data. A workable empirical formula for estimating density from known
data would be particularly valuable because of the meager density observations available. There are several
methods of attack to this problem, some of which are suggested below. It should be realized, however, that
satisfactory results are partly dependent upon the investigation of the natural variation in snow density.

a. A field study of the relationship between snow density and wind velocity under temperatures con­tinuously below freezing. By confining the study to below freezing temperatures, the temperature
variable would be eliminated if Dmitrieva (1950) is correct. A correlation of ground wind veloci­
ties and their duration with changes in snow surface and pack density could be used to establish
an empirical coefficient.

b. Similarly an attempt should be made to establish the effect of temperature upon snow density, al­
though this may be more difficult task. Perhaps the effect of wind can be eliminated. The re­lationship of both air and internal snow temperature to changes in density should be examined
over various periods of time and used to establish an empirical coefficient. However, temperature
values finally used must be ones which can be computed from climatological records.

*Temporary use of the official field records from 1947-55 was obtained for 3 snow courses in
Ontario from the Hydro-Electric Power Commission of Ontario as this report was being completed.
RECOMMENDATIONS

c. A more extensive check of Dmitrieva's formulas is advisable. Only a few scattered density observations were available for the check made in this report. The monthly snow course density values for some of the Canadian power companies where meteorological data are available for nearby stations should provide an opportunity to check more adequately Dmitrieva's work.

IV. Investigation of Drift and Erosional Snow Surfaces

The roughness and irregularity of the snow surface can be a major factor in movement over that surface. It may be more critical than depth, density, or hardness. Present knowledge of the extent and distribution of roughness features is negligible. Several lines of work should be carried out.

1. Classification of drifts.

A system for the classification of drift and erosional snow surface forms should be developed suitable for their identification both from the air and the ground.* Minor, noncritical roughness features, even though they photograph from the air, should be disregarded.

2. Development of photographic keys.

Photographic keys which will permit accurate identification and descriptions of recognized roughness surfaces should be developed in conjunction with the classification.

3. Origin of surface roughness features.

An investigation of the origin of widespread surface roughness features should be initiated to develop our knowledge of where, when, and in what forms roughness features may occur or develop. A field study of roughness features - their physical measurements, their development, and seasonal changes should be carried out, with meteorological observations, particularly of wind conditions to establish possible relationships.

4. Experimental mapping.

As the above work progresses, a program for experimental mapping of roughness features from the air should be initiated. An area where roughness features are known to occur should be photographed at intervals to observe the extent, changes, and persistency of roughness conditions.

5. Compilation of maps showing roughness.

The compilations of maps showing the distribution of snow roughness features should be initiated as the data become available. At the present time there are few or no reported observations on roughness, and no extensive systematic air photo coverage of arctic areas which can be utilized to complete maps of roughness conditions. Even with increased interest and observations, data may still be inadequate. Therefore, maps may have to depict areas likely to be subject to drift and erosional features as relationships of roughness to known wind and exposure conditions are established.

V. Initiation of Systematic Collection and Recording of Snow Data Internationally

The single most important fact established by this study is the great lack of systematically collected and recorded data concerning the snow cover. The fragmentary nature of the data suggests that a uniform program could be initiated and developed.

This is a major task and problem requiring interservice, intergovernmental, and even international collaboration. Machinery and organizations exist for the considerations of such problems, but the problems need to be brought to the attention of the appropriate agency for their formulation and solution. Below are some suggestions for consideration.

1. International cooperation.

That Canadian, other NATO countries, and United States agencies should review their present systematic collection and publication of snow data as to type of data, frequency and time of observation, and distribution of reporting stations (various classes) to the end that a systematic program of collecting and publishing minimum data on snow cover and snow fall is initiated.

* Drift and erosional surface forms are described by their various physical parameters (orientation, shape, size, etc.) in the station models presented in this report, but there may be more convenient and simpler classifications. Furthermore there was no way to relate or identify ground conditions with their appearance on air photos. Some surface irregularities impart a "texture-like" effect to the air photo which might be correlated to specific ground conditions. Classifications based on genesis, air-photo textures, or even limited to roughness forms critical to landing of planes and vehicle movement should be considered.
2. Formulation of a minimum program.

That prior to organizing such a program: (a) a report should be prepared describing the status of present snow observations and their publication in each country involved. The report should describe types and the nature of snow cover and snow fall observations, their location, frequency and time, and the nature of reports and permanent records available. (b) The minimum snow cover and snowfall data desirable should be established and suggestions made for permanent records. The program should be modest and aimed at standardization, uniformity, and a satisfactory distribution of observing stations.

3. Adoption of a uniform program.

After conclusion of the experimentation with the selected characteristics and the code, symbols and station models proposed for current synoptic snow cover maps, the proposals should be considered for wider usage either in full or part on an international basis.

VI. Research Reports Based on Existing Literature

In reviewing the literature on snow-cover it was discovered that there is existing literature on several subjects, which needs to be read, evaluated and the data assembled in a composite form.

1. Snow cover and vegetative cover.

The relation of snow depth, duration of snow cover, drifting, and snow density to vegetative cover, particularly to forest cover of various types and density is important. Most official snow observations are taken in the open and therefore maps depict conditions which locally may not be typical in adjacent forested areas.* Analysis of the literature should permit the summarization of this data in a report which can be used for regional descriptions and to annotate maps.

2. Snow depth and altitude.

The relation of snow depth to altitude and exposure. The assembling and analysis of existing material would be helpful in applying a reasoned distribution to small or medium scale maps where data is available for chiefly valley and lowland stations. Some experimental work has been done in estimating rainfall in mountainous areas where data were deficient (see W. C. Spreen, 1957). An empirical formula for estimating approximate snowfall in relation to elevation and exposure for use in mapping snow cover is not inconceivable and might improve the validity of snow maps of medium and small scales for mountain areas.

*For example the authors found in the field that vegetation differences were a major factor in causing differences in snow cover conditions. Snow was much harder on the tundra than in the bush. Density measurements were lower within the forest than out in the open. Large lee drifts were common where lakes were surrounded by trees or bush.

References

Dmitrieva, N. G. (1950) Raschet plotnosti sneznogo pokrova po meteorologischeskim dannym, (Calculation of snow-cover density using meteorological data, SIPRE Translation 24, 1954, 4p.)