SNOW MAPS FOR THE CANADIAN HYDROLOGICAL ATLAS

By

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Introduction

The Atmospheric Environment Service, Department of the Environment, is one of several agencies cooperating in the preparation of charts for a national hydrological atlas which will commemorate the success of the International Hydrological Decade 1965-1974. The Hydrological Atlas of Canada, scheduled for publication in 1976, will be distrubuted widely to water resource agencies and educational institutions.

More than 40 pages of full-colour plates are to be included, each having an explanatory text describing the compilation and significance of the maps. The maps are drawn in scales of 1:10,000,000 and 1:20,000,000. Four major divisions are planned: meteorological; surface-water; snow, ice, and glaciers; and ground-water. The author is directly involved in the preparation of five maps and texts. These are: (a) annual precipitation; (b) annual snowfall; (c) snow cover formation and loss; (d) maximum depth and time of snow cover; (e) snow cover networks. Each is treated briefly in the following discussion.

The Precipitation Maps

The mean annual precipitation (Fig. 1) and mean annual snowfall maps (Fig. 2) have been produced separately at a scale of 1:10,000,000. The data were obtained from the meteorological archives of the Atmospheric Environment Service for its standard normal period 1941-70. Although there are over 2,700 observing stations in the national network, only a fraction of these have a sufficiently long and stable record for mapping.

Annual Precipitation

Data for stations in existence for 25 years or more during the normal period were initially plotted on a relief map with scale of 1:5,000,000. As the spacing over much of the country was too wide for useful analysis, supplementary data were added from stations having a record of observations for 10-24 years. These data were adjusted to normal record by the ratio technique, using a reliable nearby station having a similar site. The error of adjustment was random and rarely exceeded 6 mm (0.25") per month. In some instances where an adjustment could not be made, the mean values for the period available were plotted in red and used as guidance points. When drawing in the isohyets, such measures were necessary so that patterns in arctic and mountainous areas could be interpreted rationally. As a further aid, reference was made to maps prepared for earlier periods, and to field studies or papers on precipitation in areas of sparse network.

The precipitation map is a composite of total rainfall and water-equivalent of snow. Accordingly, the different measurement practices and instruments, their systematic and regional deficiencies, and the probable validity of the mean values were all kept in mind while constructing the isopleths. For instance, a snowfall-gauge undercatch can be considerable under windy conditions. Such gauges are used at principal stations but at only a few of the secondary climatological stations. Elsewhere the water-equivalent of snow is assumed to be one-tenth of the depth though this varies significantly from storm to storm and is not likely to result in a true average in areas such as the drier Canadian Northwest. On the other hand, the one-in-ten ratio may be a slight underestimate in coastal areas (Potter, 1965b). Mixed precipitation is also difficult to estimate but, fortunately, does not occur frequently.

Annual Snowfall

The chart itself was prepared by colleagues of the author, F. D. Manning and M. K. Thomas, using the records from the principal stations (^500) as the main source. The isolines are smoother than those in the Annual Precipitation chart. This is because it is

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recognized that snowfall is very difficult to measure. The usual method is to insert a ruler into the fresh snow at several points about the station and to estimate a mean fall while allowing for drifting and scouring under windy conditions. Accordingly, snowfall figures are treated cautiously by most analysts.

National Patterns of Annual Precipitation and Snowfall

The major isoline configuration of the national precipitation maps has not been greatly altered from the 1931-60 maps currently available. In the North and in some mountainous areas further details are now available. In terms of regions of apparently greater or lesser amounts, it may be noted that analysts' opinions concerning snow cover patterns vary sufficiently to preclude logical inter-decadal comparisons without recourse to actual station data, year by year.

The Snow Cover Maps

Snow cover is measured daily at principal meteorological stations and at some climatological stations. It is also measured through the winter on about 1200 snow courses established throughout the country. Because site conditions at weather stations are normally quite different from the locations where snow courses are laid out, reasonable snow depth comparisons between the two methods may be difficult. However, the quantity maps showing the seasonal and maximum depth were drawn using both sets of data, but with more emphasis on the weather station data because of the generally longer periods of record, the greater observation frequency, and superior measurement standardization and quality control. Nevertheless, snow course measurements are individually better in many ways than those from the meteorological sites. The courses are usually laid out in areas with less severe exposure, away from man-made influences, and with typical vegetation or terrain.

Snow Cover Networks

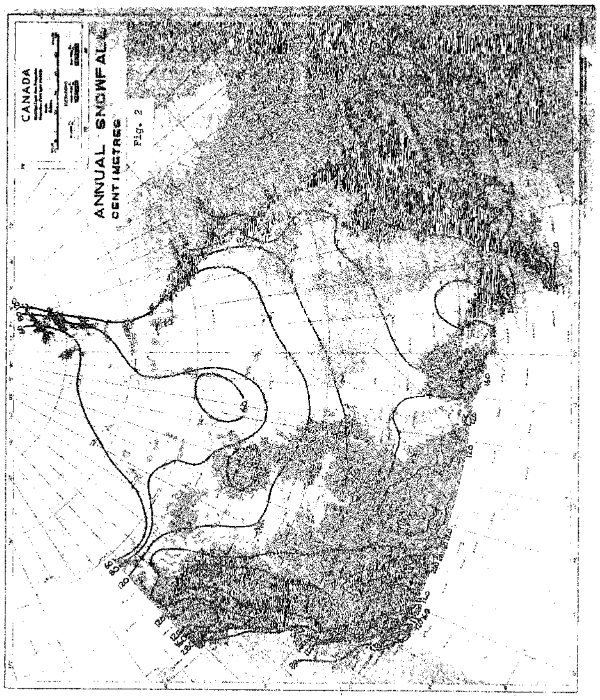
This map (Fig. 3) identifies sixteen separate agencies operating snow course networks across Canada. Excluded are the meteorological stations which measure snow depth but do not have a snow course, as these stations are shown by a Precipitation Networks map also to be included in the Atlas. Any snow course in continuous operation for five years prior to 1972-73 was included on the map.

The greater number of agencies measuring snow cover is not surprising as each province administers its own water resources, though two federal organizations, the Atmospheric Environment Service and the Inland Waters Directorate, have courses throughout the land.

All sixteen hydrological agencies use similar equipment and survey techniques, although they vary in their observation schedules and reporting procedures. For this reason researchers, who otherwise recognize the usefulness of course data to estimate regional and inter-regional snow resources, have difficulty in making time and space comparisons. There is no standard surface over which snow samples are taken, though every precipitation station measures snow depth over a short-grass, flat surface. In Western Canada, agencies do locate courses on a "standard site" which is a typical land type common within a region. In mountainous areas, this is often an alpine valley; on the Prairies, it may be a natural grassland. In Eastern Canada, and among hydrometeorological agencies in general, the "representative site" is chosen. This is an area typical of the terrain and the vegetation over several square kilometres. While it is natural that each agency must satisfy its unique needs first, some standardization in reporting procedures would enable machine archiving and a wider use of course data (Goodison 1975). New remote sensing procedures should eventually improve course locations and sampling.

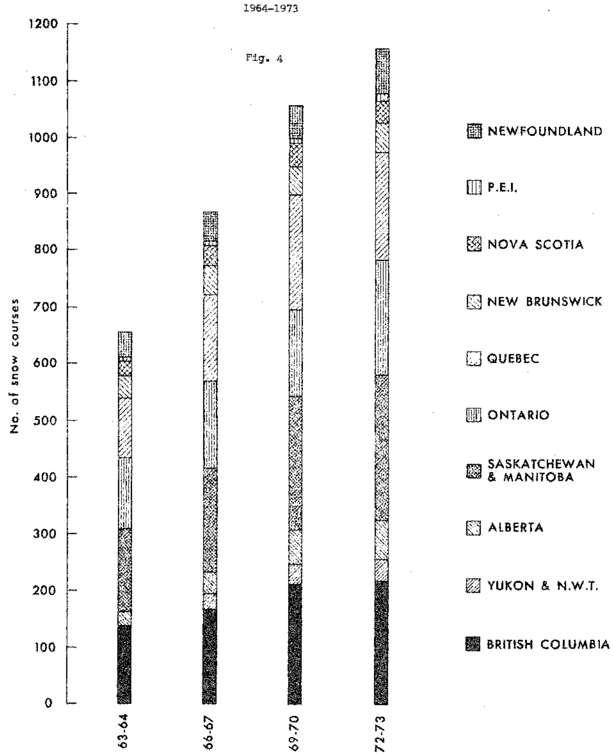
The recent growth of the network has been very vigorous as Fig. 4 testifies. The fact that the number of courses have doubled in ten years as well as the rapid expansion of the program in the North where water resources require inventory, points to the success of the International Hydrological Decade.

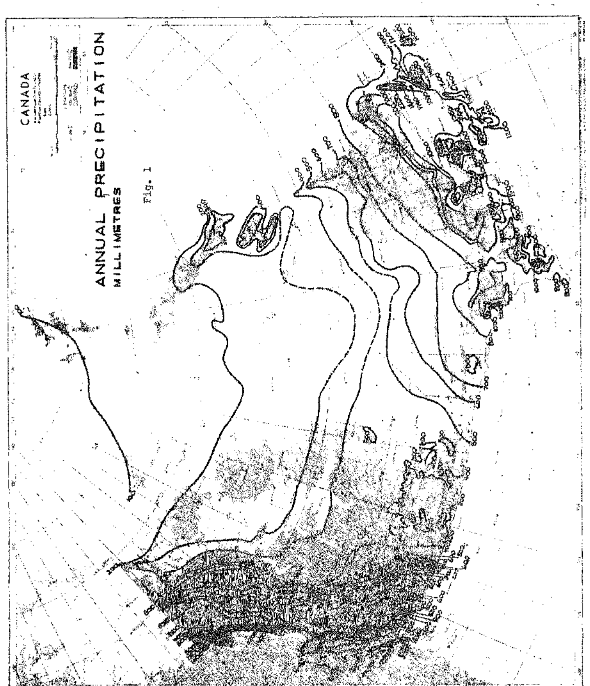
Snow courses have been operated in Canada since the early days of this century when a few power companies wisely followed the counsel of J. E. Church to improve spring-run-off forecasts by snow surveying. Further direction came from the National Research Council in



Regional Growth of Canadian Snow Cover Networks

1964–1973





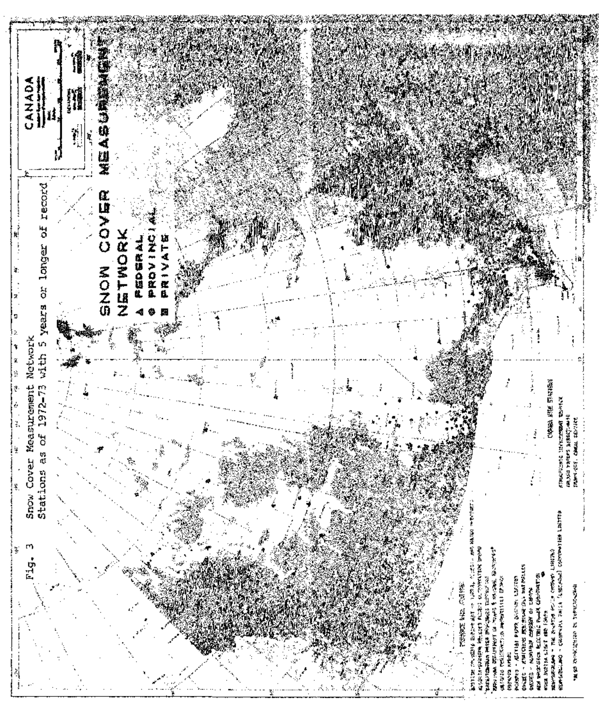


Fig. 3 Snow Cover Measurement Network
Stations as of 1972-73 with 5 years or longer of record

Ottawa. That agency, as a result of experiments conducted in the mid-thirties on the effect of snow properties on aircraft-ski performance, decided to establish regional facilities to measure the physical characteristics of snow cover.

However, twenty years earlier the Dominion Water Power Branch had been actively involved in projects such as the annual Bow River (Alberta) survey.

Formation and Loss of Snow Cover

The length of the snow cover season from year to year is related to atmospheric circulation patterns and can be quite variable in certain regions (Figs. 5, 6, 7). On the Prairies, McKay and Thompson (1968) found that the definition by Potter (1965a) to the effect that the first and last one-inch or more (2.5 cm) snow cover marking the beginning and ending of the season, respectively, tends to be difficult to work with because of the occurrence of early- and late-season storms which leave ephemeral snowpacks. These authors chose to modify the season definition by specifying that the cover of one-inch (or more) should remain for 7 days or more during the formation period and the season would end when a 7-day period of one-inch or less cover occurred in spring.

This definition was adopted and a tabulation covering 538 principal stations for the period 1955-72 was generated, being limited only by the restricted availability of data on magnetic tape. The program printout also gave annual maximum depths and month-end data as well as the means and standard deviations.

It follows that the change in defining the snow season has the effect of shortening its length in most areas. An exception is the Arctic Archipelago where, because of rapid increases in spring solar radiation, the season evolves quickly thus allowing Potter's simpler definition to suffice. Elsewhere, the formation dates are delayed a week on the Arctic mainland, by two weeks south of 60^{o}N.Lat., and for longer periods in the Maritimes and Southern Ontario where winters are quite variable. For over 80 per cent of the years on the islands of coastal British Columbia, such as the Queen Charlottes', no continuous snow cover is established. On the coastal mainland the chance of continuous cover increases rapidly inland, though in the dry southern interior valleys winter snow is again sporadic. Other areas of unreliable snow cover include the dry western Arctic Archipelago, the southeast coast of Baffin Island, and Sable Island-180 km offshore from Nova Scotia.

The standard deviations of the formation and loss dates are mapped to illustrate seasonal variability. In fall, high standard deviations are characteristic of some coastal regions, while low values occur in snowbelt areas, on windward mountain slopes, in the lee of large lakes, and, in general, over higher terrain in Eastern Canada. In spring low values are common in the northern Rockies, the northern Prairies, and the Foxe Basin-Baffin Island area.

Spatial contrasts in standard deviation are generally higher for formation dates than for the loss period. It is suggested that this is because the onset of winter is related particularly to storm tracks more than to the reduction in solar radiation; but in spring the atmosphere is, in general, more stable and progressively increasing sun angles systematically promote a poleward retreat of snow cover.

McKay and Thompson (1968) have demonstrated that when mean formation/loss dates plot as a straight line on normal probability paper, specific return periods may be estimated after the standard deviation is computed.

$$\hat{x} = \bar{x} + K\ (S.D.) \quad (1)$$

where

$\hat{x}$ is the return period value to be estimated

$\bar{x}$ is the sample mean

K is the frequency factor

S.D. is the sample standard deviation

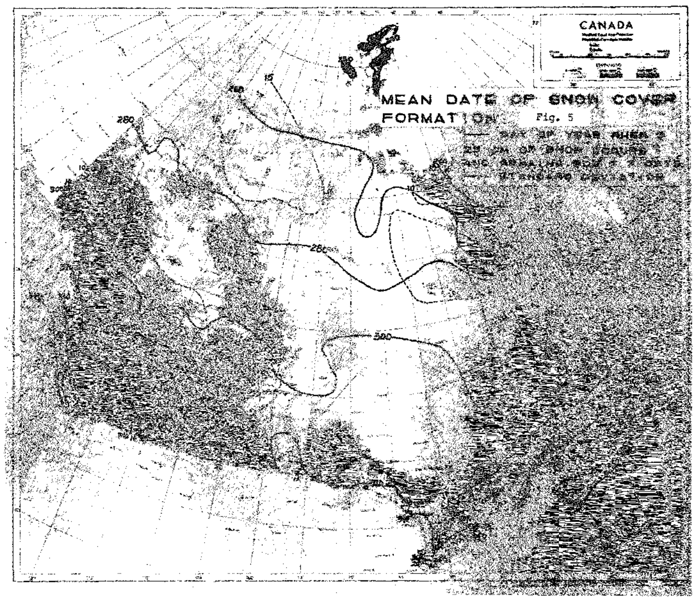


Fig. 5

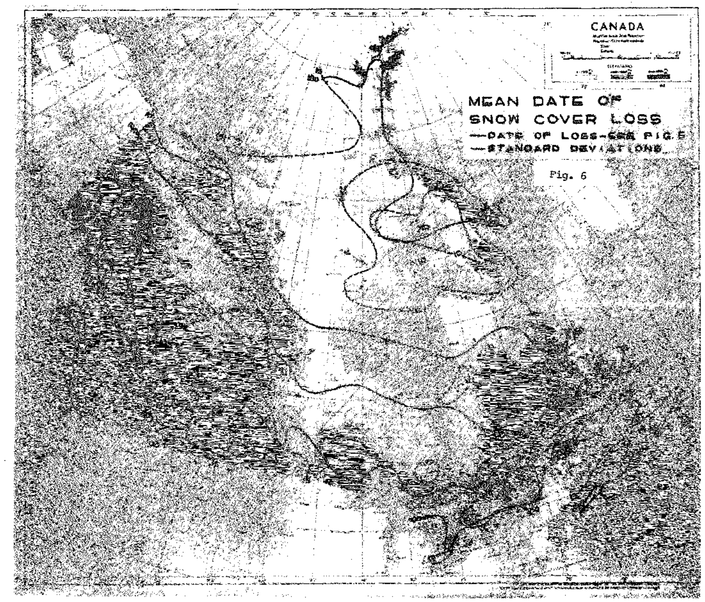


Fig. 6

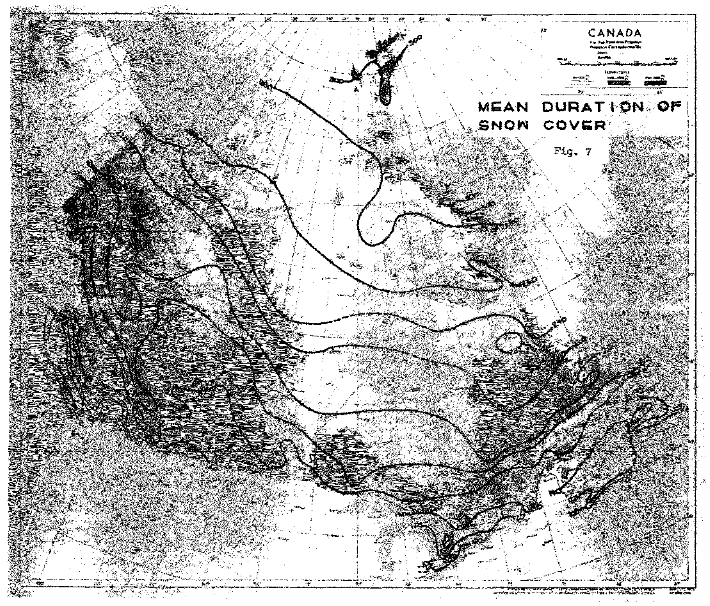


Fig. 7

With a 17-year sample the K factors for a normal distribution may be tabulated.

Return Period (yrs.)	5	10	15	20	25	50	100
Frequency factor (K)	1.2	1.5	1.6	1.7	1.8	2.2	2.3

In view of subjective errors in cartographic analysis, computed return periods from these data should be used only for broad-scale generalizations.

In the Atlas a composite map will portray both fall and spring conditions.

Maximum Depth and Time Occurrence

Data from meteorological stations were combined with a snow course tabulation prepared for a previous paper (McKay and Findlay 1971 see Fig. 8a). As previously noted each set of data has limitations but since the meteorological network is nationally standardized, has longer records and more frequent observations, its data were given precedence.

This means that higher point-values were normally chosen during isopleth interpolation, for fresh snow increments from storms are often recorded at meteorological stations before wind compaction and redistribution. At the snow courses which are visited less frequently, such events are usually missed. However, by emphasizing data from the meteorological stations direct comparison can be made with the 1941-60 tabulations (Potter 1965a). Isoline locations were judged in the light of the combined time series. Standard deviations of the 1955-72 depth averages were mapped as well. In general the values of these dispersion indices were about one-third of the means, though on the West Coast, over the Prairie grasslands, and on Baffin Island they approach one-half. As these variations are rather large, it is not considered prudent to estimate extreme values. Nevertheless, the mean values as portrayed by the isopleths are much better than 17-year averages because complementary data are incorporated in the isoline interpolation.

The 1955-72 station averages for maximum depth were directly checked against those in Potter's report (1965a). In a very general sense small increases (2-4 cm) may be noticed throughout the country. North-Central Manitoba seems to experience an increase of approximately 12 cm, although Churchill, on Hudson Bay, has a similar decrease. The situation is confusing in the eastern provinces with adjacent areas showing positive and negative anomalies of 10 cm or more. These may be real regional changes or noise resulting from individual station peculiarities. Further investigation is warranted.

The time of maximum accumulation (Fig. 8b) varies over about a four-month period. The 30th day occurs at low elevations near the British Columbia coast, through the southern Interior, and continuing along the southern fringe of the Prairies and Ontario, whereas the 90th day is characteristic of much of the Arctic Archipelago. Interesting anomalies seem to occur in the Archipelago adjacent to the straits between the Islands and the Mainland where the peak season is a month earlier. This is perhaps a result of open water areas persisting late in the year. The 60th day otherwise refers to the northern areas of most of the provinces the exceptions being Quebec, where the isochrone passes through the Laurentian District, and the Maritimes both having a somewhat earlier mean maximum date.

Conclusion

With each passing decade, the effects of network growth and thus availability of longer periods of statistical material allow for greater accuracy in the mapping of hydrometeorological data. An additional benefit has arrived from a nation-wide bank of statistical material from snow courses established at the beginning of the sixties and earlier.

At the same time quality control of observations has been streamlined through network planning, frequent station inspections, use of standard instruction manuals, computer verification, etc. There is no question that the annual precipitation and snowfall maps are based on the best material available to date.

However, the data format on which to construct snow cover maps is less than ideal. While snow depths have been measured daily at principal meteorological stations since 1941 - Potter (1965a) has made a summary through 1960 - the computer file does not antedate 1955. Even though a program was available to generate many of the statistical expressions needed

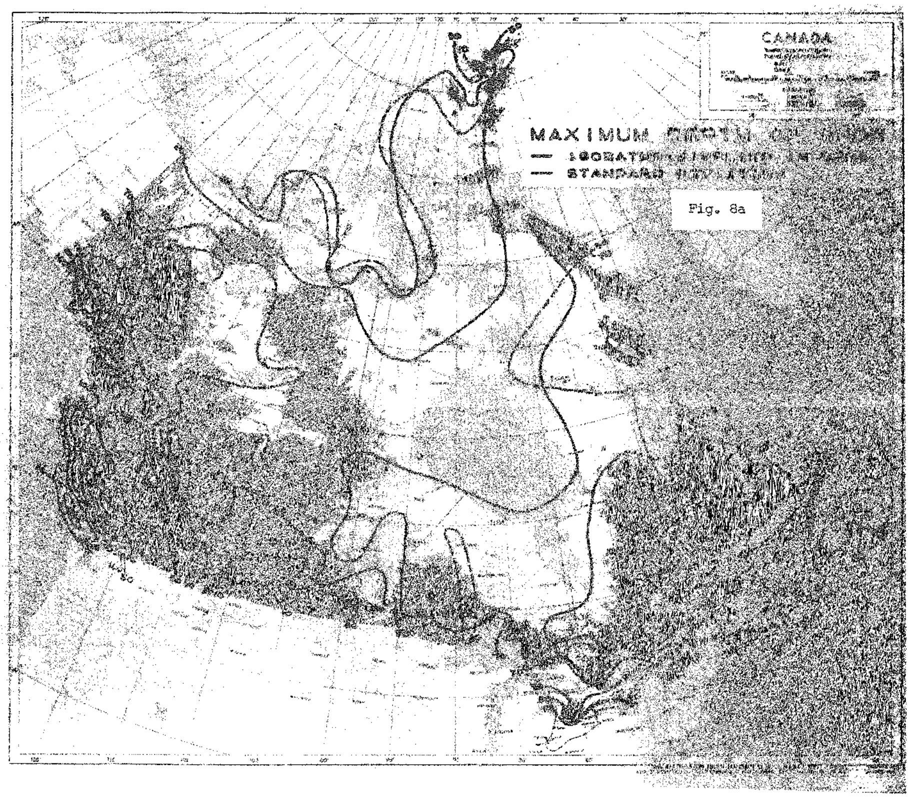

CANADA
MAXIMUM

Fig. 8a

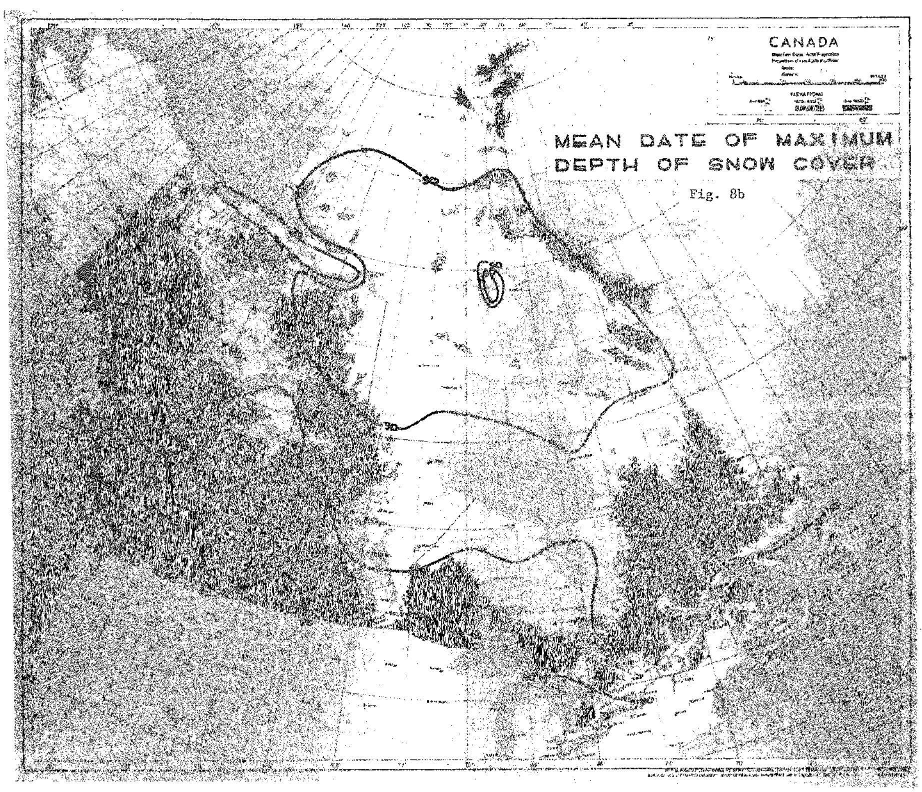

CANADA
MEAN DATE OF MAXIMUM
DEPTH OF SNOW COVER

Fig. 8b

for a quality evaluation of station data, a maximum available period of 17 years can only approximately describe the time series of this heterogeneous parameter. Unfortunately, there was not enough time to do a hand-analysis of the total record. In the case of the maximum depth map, direct reference could be made to the 1941-60 tabulations, but for the formation/loss maps the change in seasonal definition preclude use of the earlier records.

It was possible to refine the snow cover maps by reference to a clerically-prepared tabulation of records from 230 snow courses existing in the period 1961-70 (McKay and Findlay 1971), but there is a need to establish a computerized data bank in order to bring the real qualities of snow course measurements into national mapping.

In brief, the principal differences in the new maps relate to better regional definition and provide a more compact information source for absolute values, expressions of confidence, and time of occurrence.

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