MEAN AND EXTREME SEMI-MONTHLY NORTHWESTERN HEMISPHERIC SNOW BOUNDARIES FROM SATELLITE RECORDS (1966-1979) AND SOME SURFACE DATA COMPARISONS 1/

By

M.O. Berry and P.R. Scholefield 2/

Introduction

The growing concern in recent years about climatic fluctuations and their impacts on society has generated considerable interest in monitoring anomalies of various climatic parameters on a near real-time basis. Monitoring the advance and retreat of the continental snowline and comparing the position with predetermined average and extreme positions is a useful climate monitoring technique which has been used in Canada for the past two years.

The National Environmental Satellite Service (NESS) has been producing Northern Hemisphere snow and ice cover maps on a weekly basis since November, 1966. It was decided to use these maps to monitor the snowline because of their large-scale hemispheric coverage and the availability of a reasonable set of historical maps, as well as current maps on a near real-time basis. Maps from 1966-76 were initially used to develop mean and extreme northern hemispheric positions of the snow boundary on a semi-monthly time interval. These boundaries have been updated and reanalysed for the western half of the northern hemisphere using maps up to and including March 1, 1979. Most of the work has been completed on a similar updating of the snow boundaries for the eastern half of the hemisphere.

After the initial set of boundary maps had been completed in early 1977, it was decided to make a preliminary comparison between the satellite-derived snowline maps and snowline maps that had been produced from conventional surface weather observations. The conventional snowline data used were maps of mean date of snow cover formation and loss which appear in the Hydrological Atlas of Canada (Fisheries and Environment Canada - 1978). The preparation of these maps was described in detail by B.F. Findlay (1975) at the Western Snow Conference in Coronado, California.

Determination of Mean and Extreme Snow Boundaries

Wiesnet and Matson (1975 and 1976) have aptly described the methodology used in the preparation of the weekly snow and ice boundary maps prepared by the Analysis and Evaluation Branch of NESS. Since 1975, there have not been major changes in NESS's photo interpretation procedures. They note that technological advances since 1972 have resulted in more accurate and detailed delineation of the snow and ice cover. For their 1975 paper they constructed mean monthly snowline maps south of 52°N for the four months December through March based on 1966-74 data.

Snow cover on the weekly charts is described by three degrees of reflectivity with 1 being the lowest. Areas of scattered mountain snow are so labelled. For the purposes of this analysis, the snow boundary was defined as the line separating land areas labelled with any one of the three degrees of reflectivity and areas with no reflectivity indicated (including areas of scattered mountain snow).

For monitoring purposes, it was decided to determine the mean and extreme boundary positions for specific semi-monthly dates throughout the year, which are the 1st and 15th day of each month (except the 14th day was used for February). The dates on each chart are those for the Monday and following Sunday of each week which means that the labelled dates change from year to year. If the 1st or 15th day of the month fell between the two dates on the weekly charts then that chart was used to represent the snow conditions on that respective semi-monthly date. If the 1st or the 15th appeared on a

1/ Presented at the Western Snow Conference, April 18-20, 1979, Sparks, Nevada

2/ Canadian Climate Centre, Atmospheric Environment Service, Downsview, Ontario.

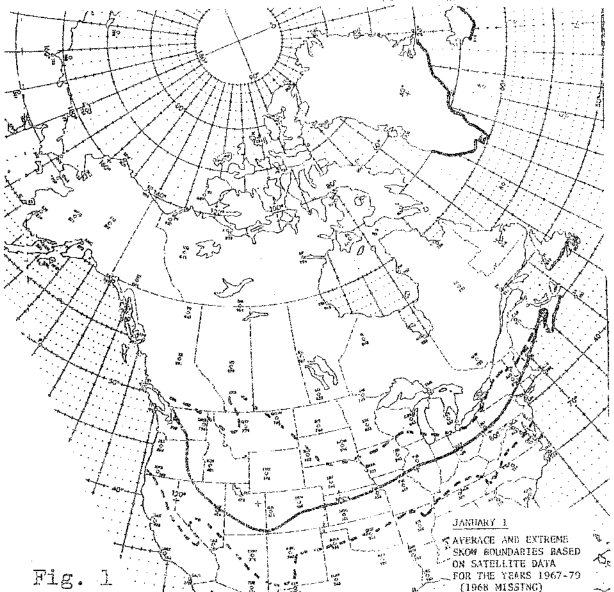

Fig. 1

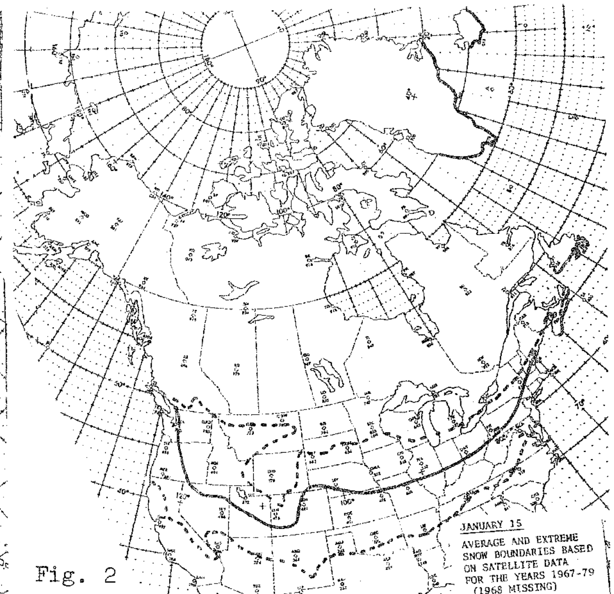

Fig. 2

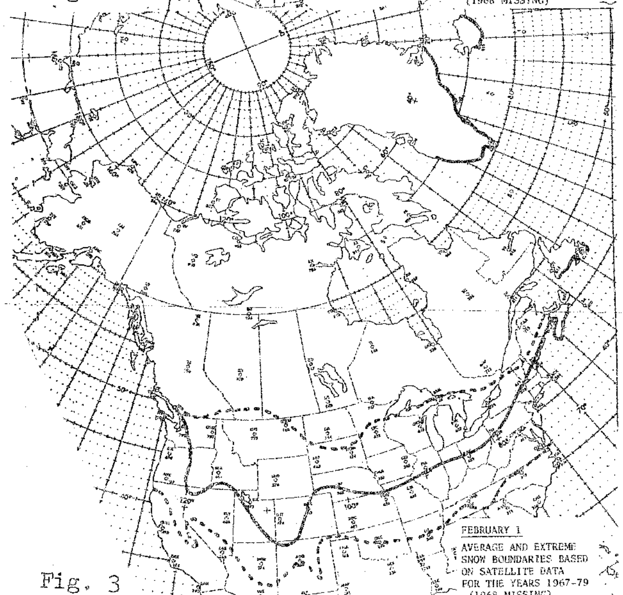

Fig. 3

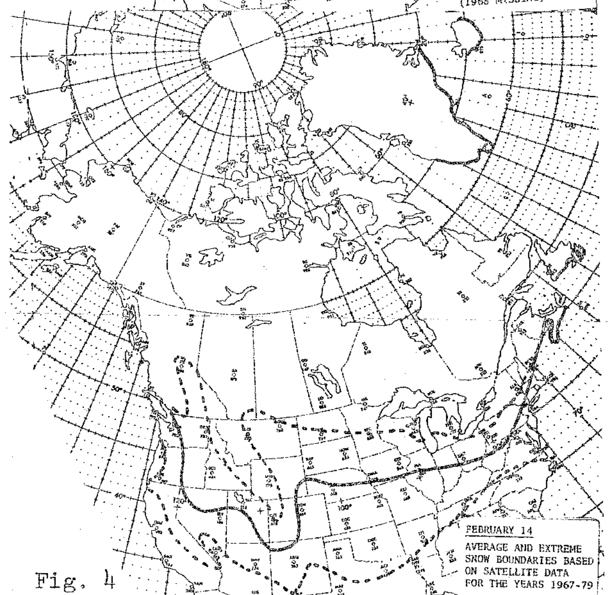

Fig. 4

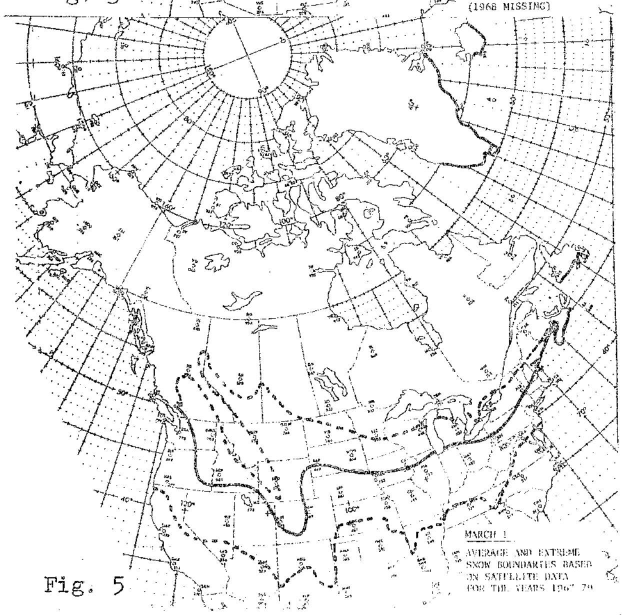

Fig. 5

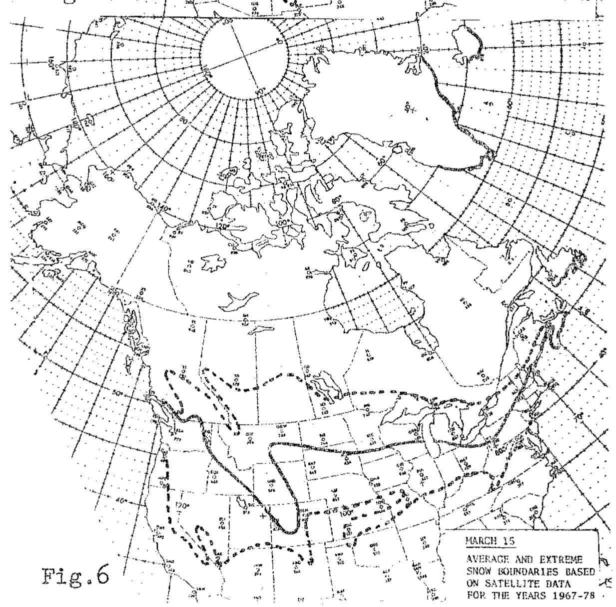

Fig. 6

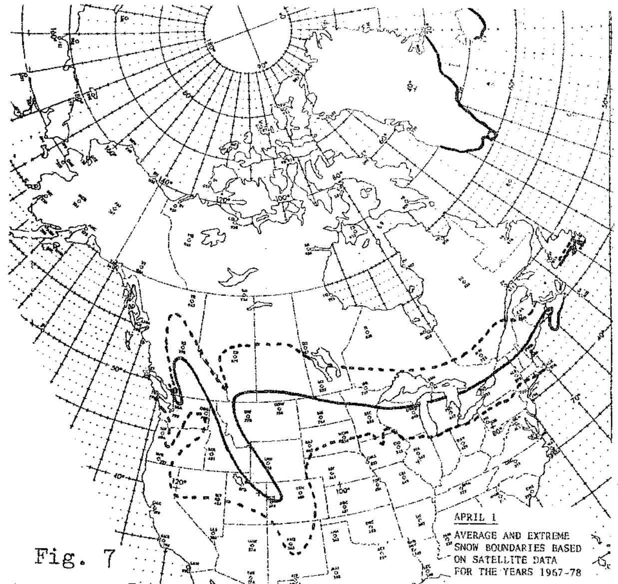

Fig. 7

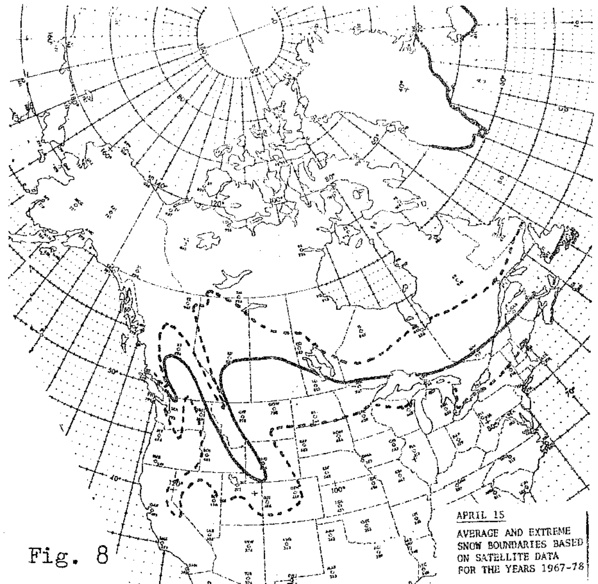

Fig. 8

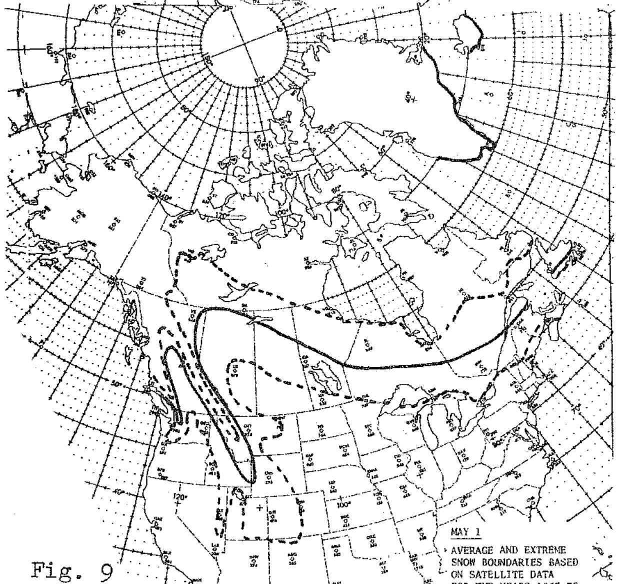

Fig. 9

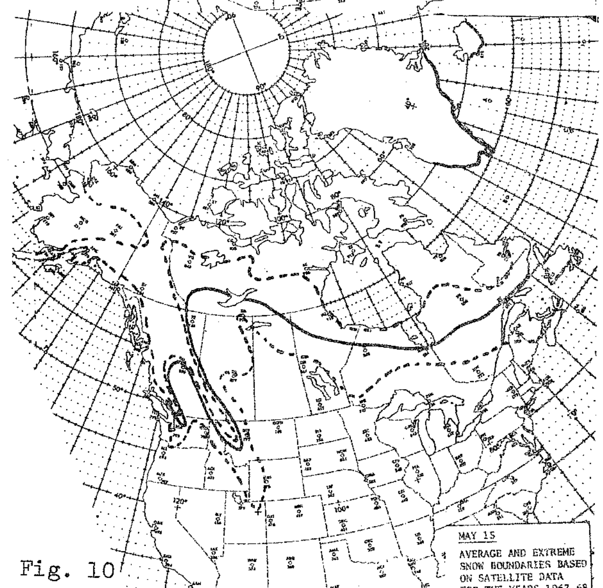

Fig. 10

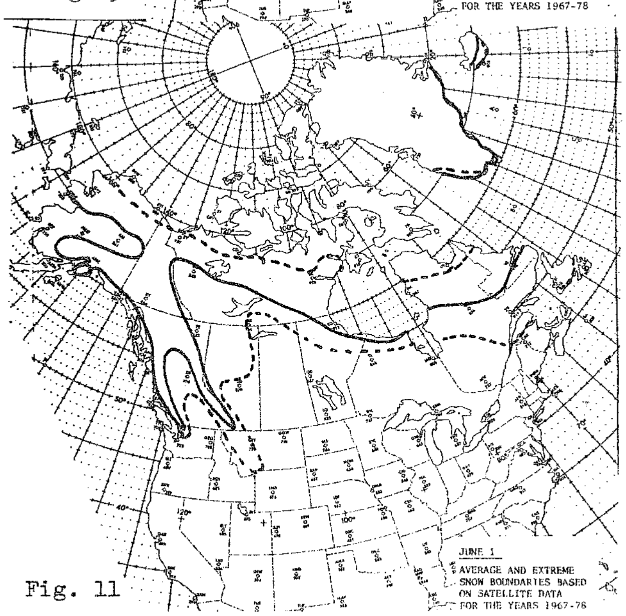

Fig. 11

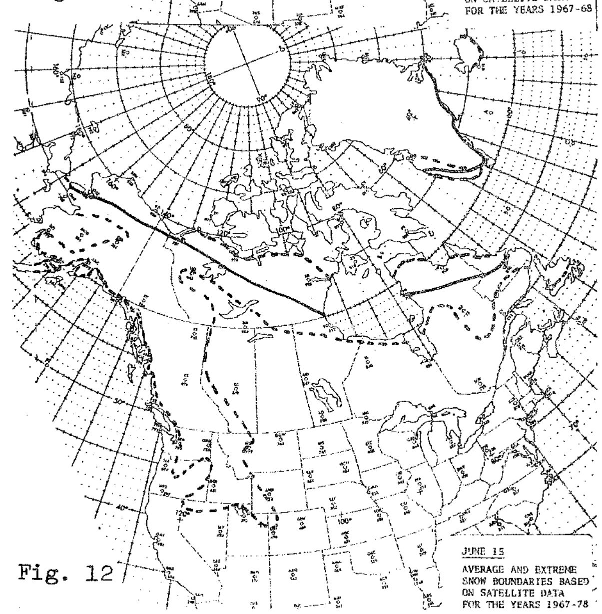

Fig. 12

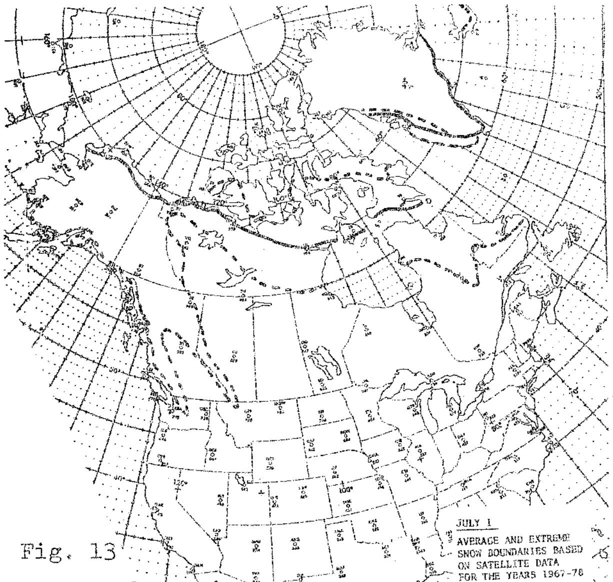

Fig. 13

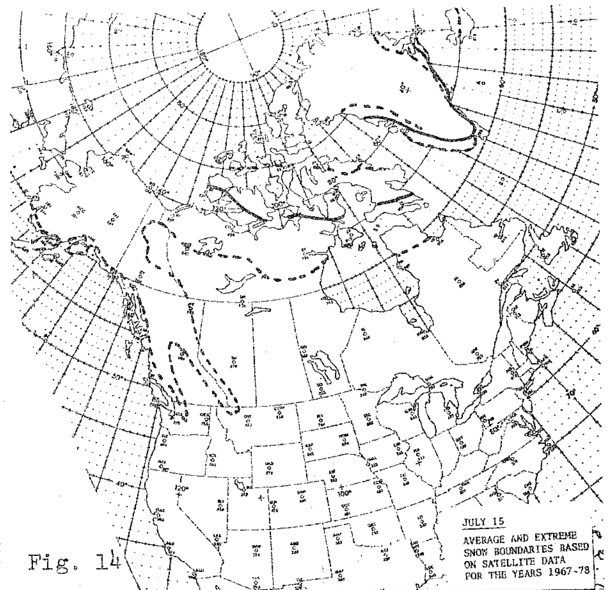

Fig. 14

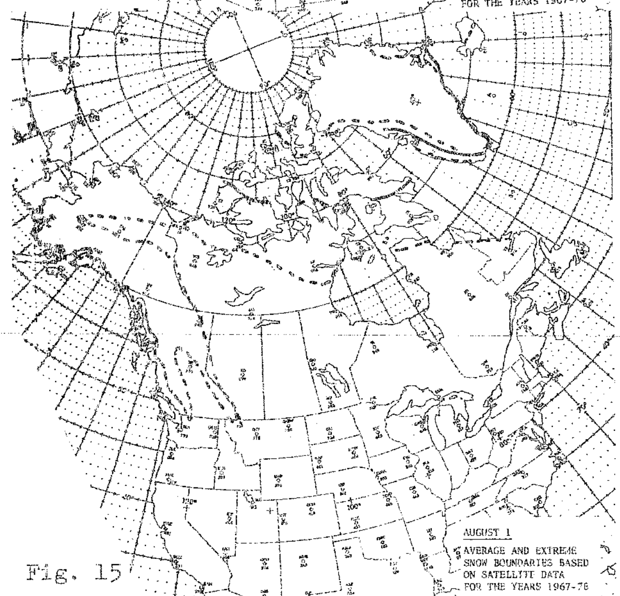

Fig. 15

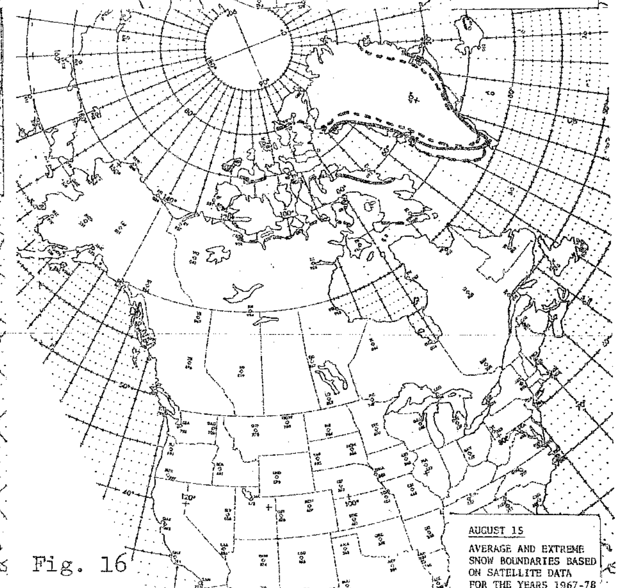

Fig. 16

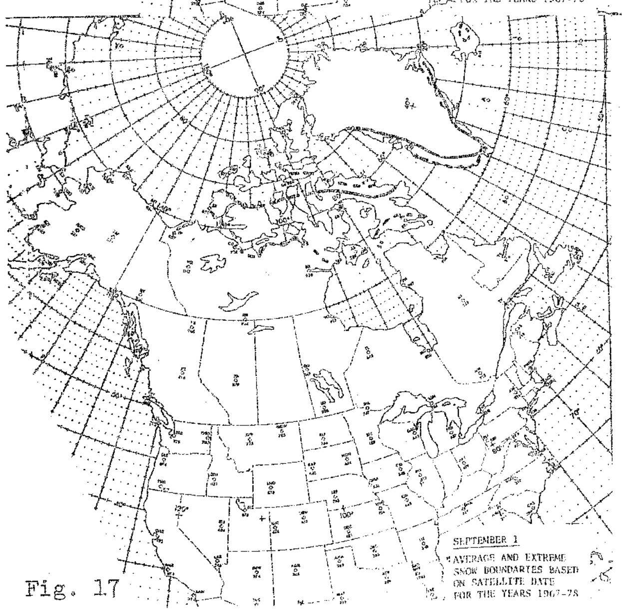

Fig. 17

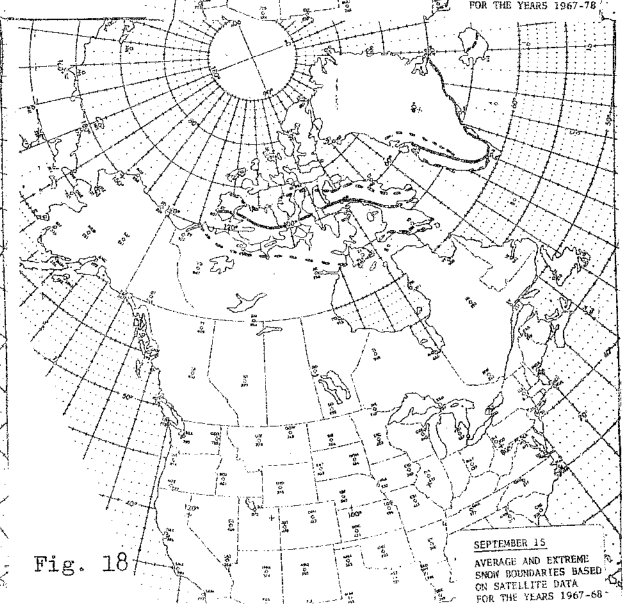

Fig. 18

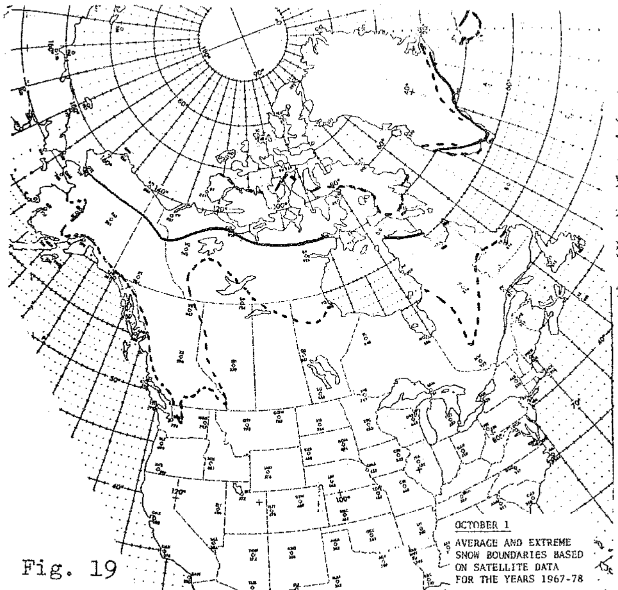

Fig. 19

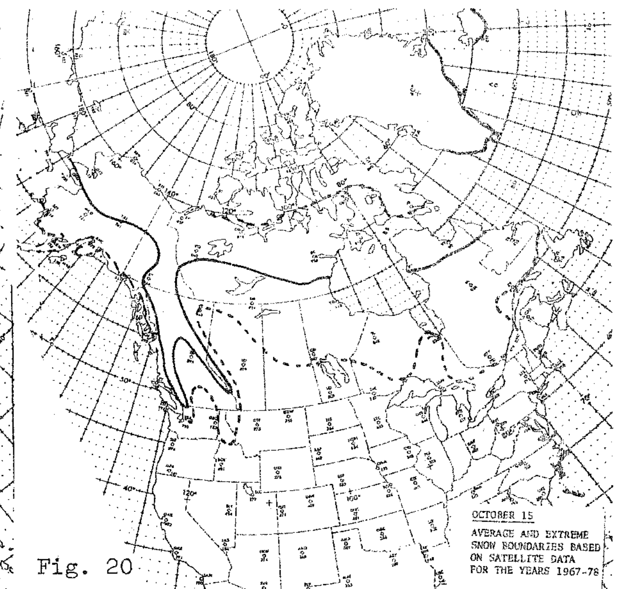

Fig. 20

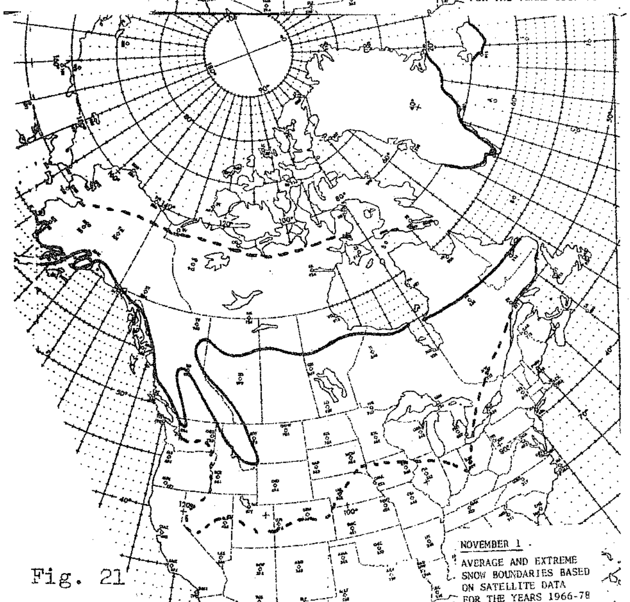

Fig. 21

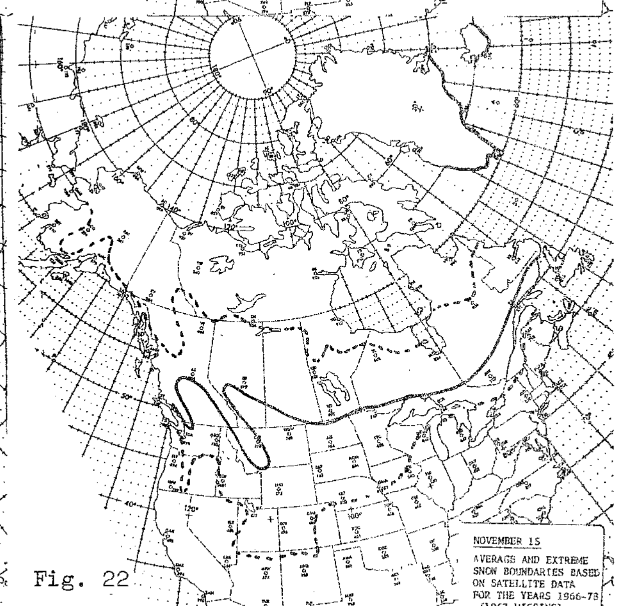

Fig. 22

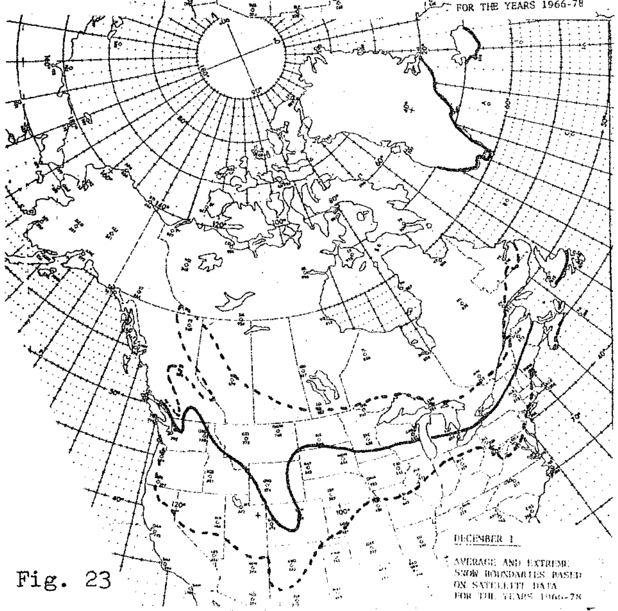

Fig. 23

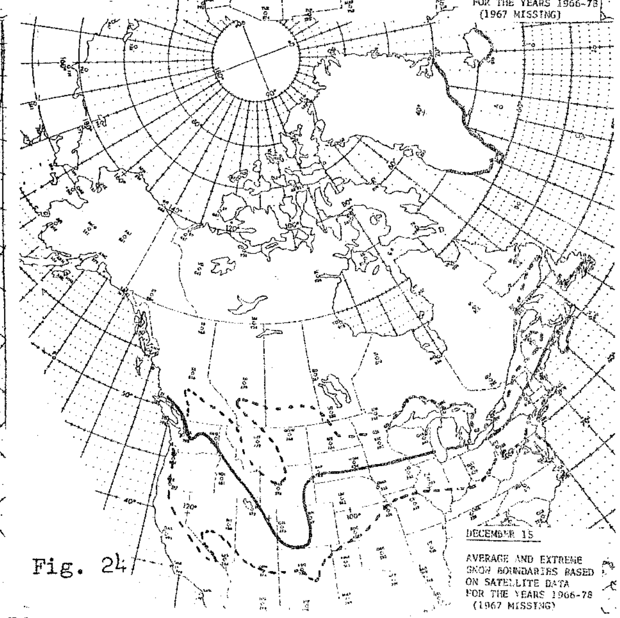

Fig. 24

chart as one of the dates defining the beginning or end of the period, then that chart and the respective previous or subsequent weekly chart were subjectively averaged to determine the snow boundary for the semi-monthly dates.

To incorporate a measure of objectivity into the averaging procedure, the latitudinal position of the snow boundary was recorded at longitudinal intervals of five degrees. Averages and standard deviations were calculated based on the 12 or 13 years of record. To arrive at the average, most northerly continuous boundary of snow, which is desired for hemispheric monitoring, the following procedures were followed:

(i) Patches of snow that were isolated south of the continuous snow boundary were not recorded.
(ii) Where isolated patches without snow appeared north of the apparent continuous snow boundary, the latitude of the northern boundary of the patch was recorded.
(iii) In cases where the continuous snow boundary intercepted a meridian of longitude more than once, the most northerly one was recorded.

In addition to this objective procedure, the continuous snow boundary for each semi-monthly date was transcribed onto one base map using a different colour for each year, forming a composite map.

The final, averaged positions of the snow boundaries were constructed by first plotting the average latitudinal positions on a base map (approximate scale 1:40,000,000). The average snowlines were then drawn with a solid line by first joining these points and then using the composite map to subjectively adjust the position where necessary. Considerable subjective adjustment was required over the western cordillera where the boundary tended to be more meridional.

The extreme positions were drawn by referring only to the composite charts and drawing a continuous dashed line joining the most extreme northerly and southerly extensions of the snow boundary for each semi-monthly date.

The results of this procedure are shown in Figs. 1-24. It should be noted that apparent absence of an average snow boundary over the Canadian western cordillera from June 15 through October 1 is due to the snowline becoming isolated from the continuous boundary further north. In the initial (1966-76) snow boundary analysis, the cordilleran snow boundary was kept on the averaged charts as a separate entity. For this analysis it was decided to be consistent by adhering to a continuous snow boundary.

Method for Comparing Snow Boundaries Determined from Satellite and Conventional Data

For Canada, the average areal extent of snow cover, derived on a semi-monthly basis from satellite data (see Figs. 1-24) was compared with the average extent derived from conventional surface data. The most recent analyses using the latter type of data were published by Fisheries and Environment Canada (1978) and these were used for the comparison. As illustrated in Figs. 25 and 26, these maps depict areal extent in terms of isopleths of the beginning and end of snow cover, with a basic interval of twenty days. Differences between the analyses based on the two types of data were calculated in terms of number of days difference between the beginning and end dates of snow cover derived from each.

One problem in comparing these two data types was a difference in periods of record. The satellite data used were collected between 1967 and 1976 while the conventional data were primarily for the period 1955-72, with some data collected over shorter periods being used on a supplemental basis. To assess the magnitude of potential errors from this source, a selection of sites upon which the conventional analyses were based was chosen, and the average dates of beginning and end of snow cover, computed from the periods of record used, were compared with the values for the 1967-76 period. Fig. 27 indicates the locations of the sites chosen, while Table I gives the computed differences. As can be seen from the table, differences are less than a week in all but five of the 46 values listed.

There is also a difference between the methods of analysing the satellite data, as described earlier, and the conventional data, where seven-day continuities, as defined in Figs. 25 and 26, were used to determine formation and loss dates. No attempt was made to assess this aspect since the objective of this work is to compare analyses currently in

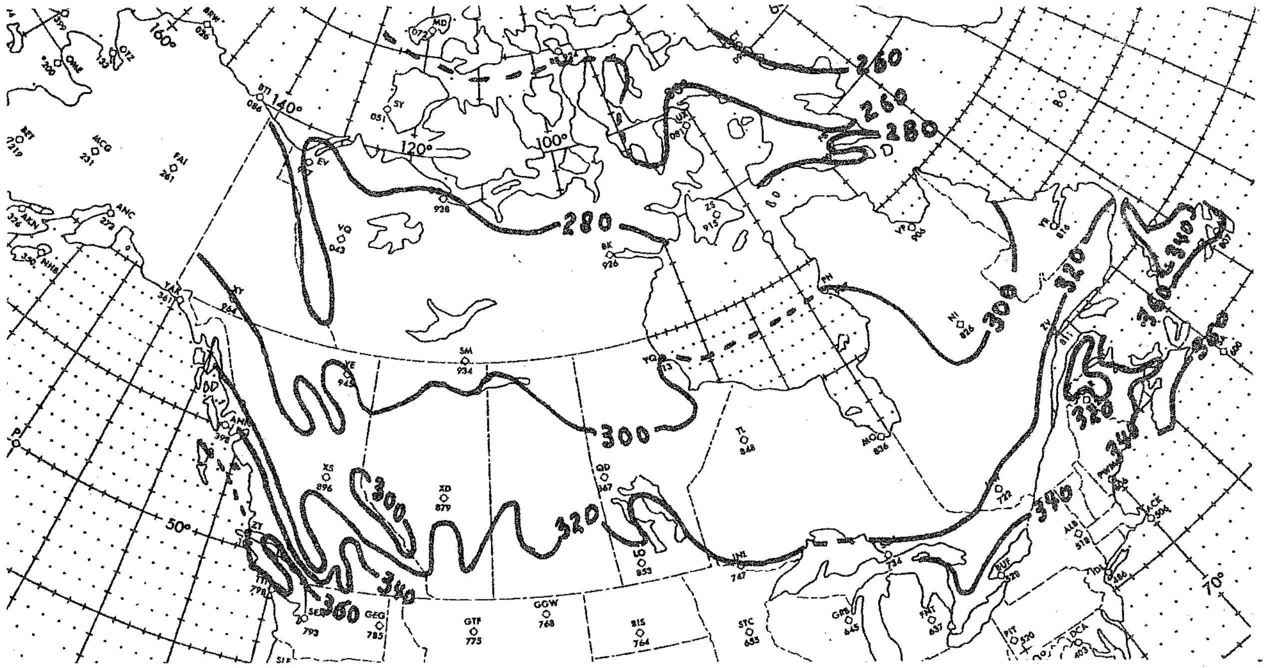

Fig. 25 Day of year when ≥ 2.5 cm of snow occurs and remains for > 7 days.

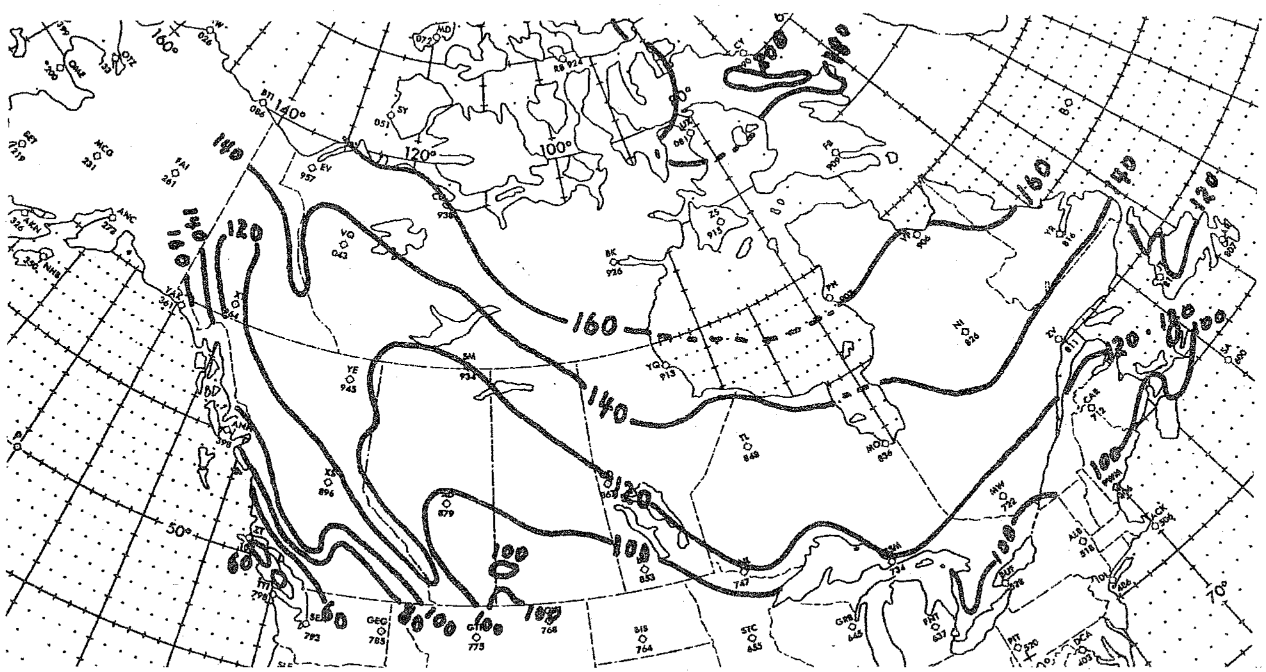

Fig. 26 Day of year when ≤ 2.5 cm of snow occurs and remains absent for 7 or more days.

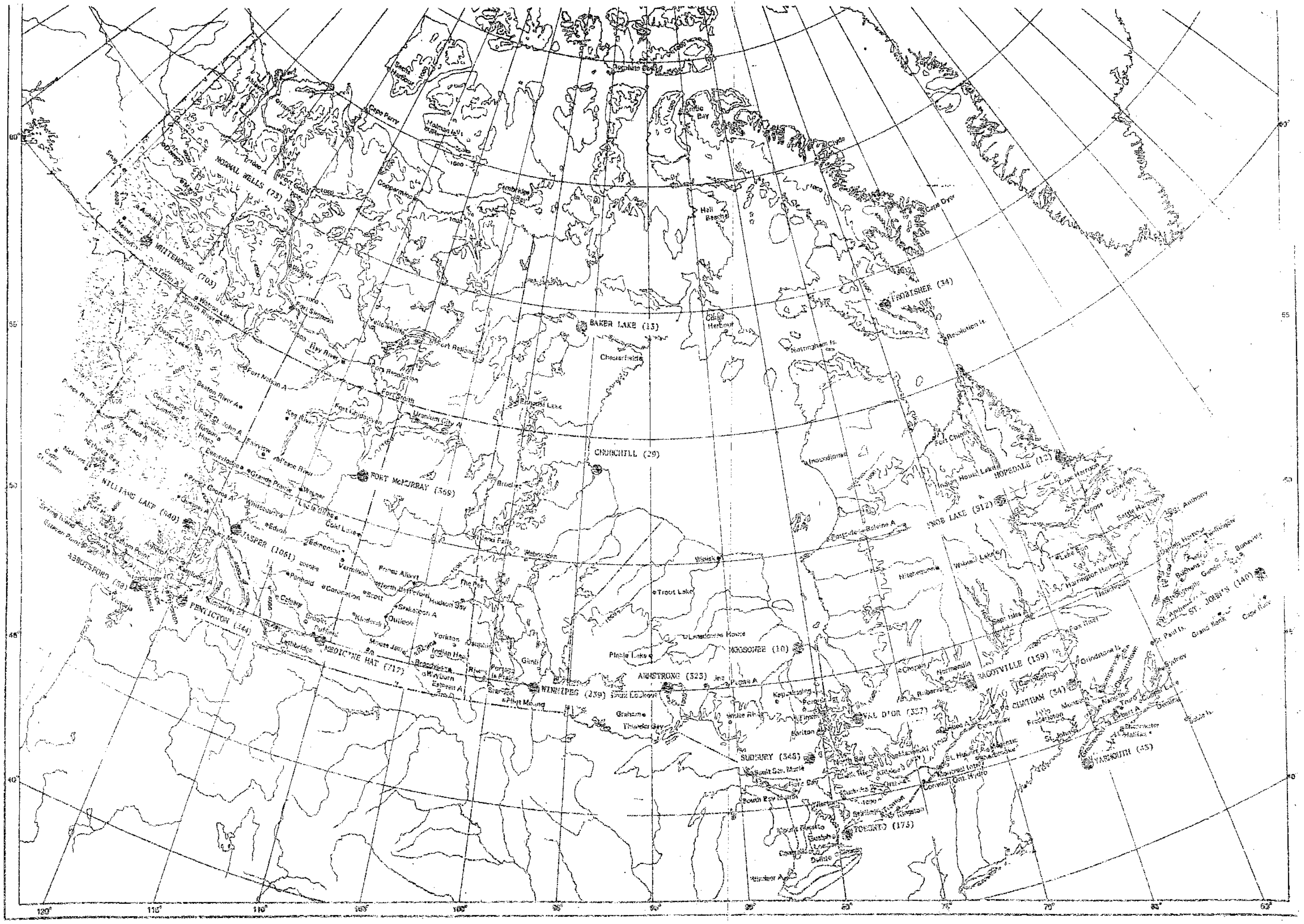

Fig. 27 Location of observing sites listed in Table I and II (elevations in metres are indicated in parentheses).

TABLE I. Difference in dates of beginning and end of snow cover for some of the sites used in preparing Figs. 25 and 26. Values are the difference in days between the average used in the figures and the 1967-76 average.

Station*	Difference		Station*	Difference	
	First	Last		First	Last
Abbotsford, B.C.	7	7	Winnipeg, Man.	0	2
Penticton, B.C.	-14	1	Armstrong, Ont.	5	4
Williams Lake, B.C.	3	-3	Moosonee, Ont.	4	3
Whitehorse, Y.T.	0	0	Sudbury, Ont.	2	3
Norman Wells, N.W.T.	2	4	Toronto, Ont.	2	2
Baker Lake, N.W.T.	-3	8	Val d'Or, Que.	6	0
Frobisher, N.W.T.	-2	-2	Bagotville, Que.	4	1
Fort McMurray, Alta.	-1	9	Knob Lake, Que.	3	3
Jasper, Alta.	-1	3	Hopedale, Nfld.	-2	-3
Churchill, Man.	6	6	Chatham, N.B.	6	2
Medicine Hat, Alta.	6	-1	Yarmouth, N.S.	-6	6
			St. John's, Nfld.	4	3

* For locations, see Fig. 27

use. It should be noted however that, in the author's opinion, the seven-day criteria used are good ones for analyses based on conventional data and designed for general use, i.e. by a variety of users. Of course, in specific applications where different analysis methods are needed, the following comparison would likely not be valid.

Initially, the maps using conventional data, with a basic isopleth interval of 20 days (Figs. 25 and 26), were compared with the semi-monthly satellite-based averages by a direct differential analysis of superimposed fields, and also by transposing the fields to a grid-point format. The former technique was felt to be more successful and the following results are based upon it. Differences in the two fields were found to be much larger in British Columbia and the southern half of the Yukon than further east, hence the following discussion is divided accordingly.

Results: British Columbia and the Southern Yukon

The differences between the beginning and end dates of snow cover from the two types of analyses are depicted for British Columbia and the southern Yukon in Figs. 28 and 29. When examining these figures, it must be kept in mind that the analyses are course, i.e. the scale of maps from which the satellite data were derived (1:50,000,000), combined with the large areal variations in some regions, made it impossible to prepare analyses depicting more than the general features of the variation in differences. Analyses of Vancouver Island and the Queen Charlottes were considered unsatisfactory because of these difficulties, and hence were omitted.

However, it can be seen that there are major differences in beginning and end dates, particularly the latter, over much of the area depicted. In the case of the end of snow cover, the analysis based on satellite data indicates dates about three months later than that based on conventional data, over a substantial part of the Coast Range south of the Alaska Panhandle. The difference is one to two months over much of northwestern B.C., part of the southwestern Yukon, and over much of the Rockies in the southeast. In the case of the beginning of snow cover, differences are less, however, the analysis based on satellite data indicates snow forming one to two months earlier over much of the Coast Range, and roughly a month earlier over a substantial part of the Rockies.

The largest differences in both beginning and end dates occur over the southern part of the Coast Range. In this area, many of the surface observing sites are located near sea level, along the coast. A smaller number are located inland, in most instances at elevations below 1000 m. In contrast, most of the terrain is predominantly above 1000 m with a substantial proportion east of Vancouver Island above 2000 m. This coastal nature of many of the sites, combined with the elevation differences, is probably the main cause of the large discrepancies between the two types of analyses in this region. Although the

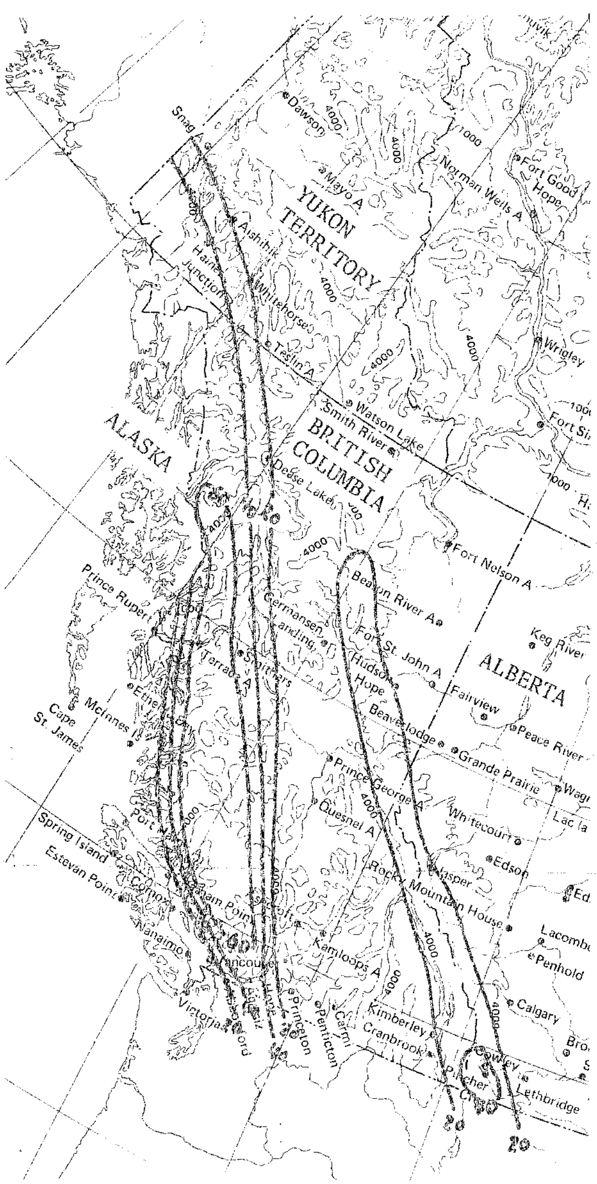

Fig. 28 The number of days that the date of the beginning of snow cover as determined from conventional data lags that determined from satellite data.

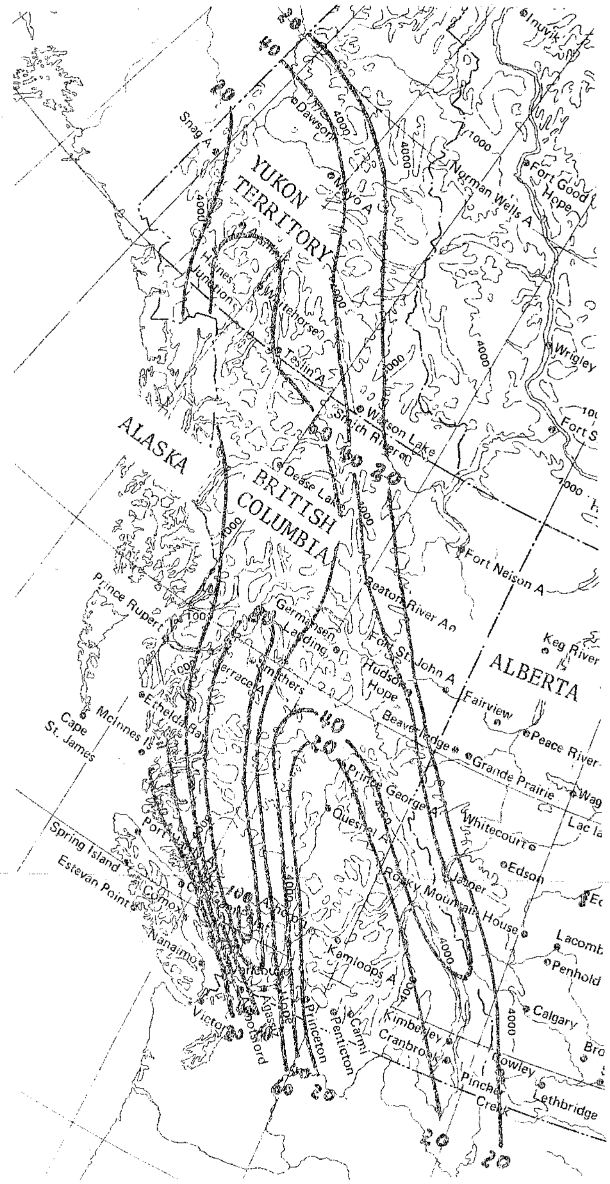

Fig. 29 The number of days that the date of the end of snow cover as determined from satellite data lags that determined from conventional data.

area roughly within 150 km of the southern half of the B.C. - Alberta border has higher terrain (predominantly above 2000 m) than the Coast Range to the west, differences in dates of both first and last snow cover are considerably less. Perhaps the fact that observing sites in this part of the Rockies tend to be higher (1000-1400 m), and the lack of maritime influences, are factors. Over the northern half of B.C. and the southern half of the Yukon, differences in beginning and end dates tend to decrease toward the north and northeast, despite the fact that major areas of high terrain, for example near the Yukon-Northwest Territories border, exist well inland. Interestingly, particularly large values of differences do not occur over the very high terrain of the Coast Range in the southwestern Yukon. A review of the working charts used to prepare the analyses based on conventional data suggests that the analysts, either subjectively or using supplementary data, made greater adjustments for terrain here than further south.

Results: Canada East of the Rockies

East of the Rocky Mountains, differences between analyses based on conventional and satellite data were found to be much less, and no clear relationships between differences and topography or geographic location were apparent in this preliminary assessment. Consequently, rather than presenting areal analyses, it was decided to present differences between dates of beginning and end of snow cover in tabulated form for a set of sites preselected from throughout the region, as in Table II. The values in the table were derived by interpolation from Figs. 25 and 26, and from the previously discussed averages derived from satellite data. With the exception of two sites, differences between the two types of analyses were less than two weeks for both the beginning and end of the snow cover, with median values of four days and zero days respectively. Much of the variation in the differences is probably attributable to the different periods of record used (see Table I), to the above-mentioned interpolation process, and to the previously mentioned limitations in the resolution of the analyses based on satellite data. Consequently no consistent difference between the two types of analyses was apparent other than a rather tenuous suggestion that the beginning of snow cover derived from satellite data may yield a slightly earlier date. While a more detailed analysis would be needed to reach a definite conclusion, tentatively it appears that the two types of analyses yield quite comparable results, for both beginning and end of snow cover in most parts of Canada east of the Rockies.

Conclusion

1. Over large parts of the mountainous regions of western Canada, the most recently prepared areal analyses of snow based on conventional data from surface observing sites indicate snow cover beginning one to two months later, and ending two to three months earlier, than do analyses derived from satellite data. A large part of these differences are probably attributable to nonrepresentativeness of the conventional data. If this is the case, use of analyses based on the latter type of data, for applications where regionally representative patterns of snow cover are important, may cause major difficulties. It is apparent that a review of both types of analyses are needed to determine the extent to which modifications should be made to improve compatibility.

2. Over most of Canada east of the Rockies, it can be stated tentatively that the two types of analyses yield results which are quite comparable.

3. This assessment is preliminary in nature: a more detailed analysis is needed using better resolution satellite data or analyses, and giving more detailed consideration to regional and local topographic and other influences.

Table II. Differences in dates of beginning and end of snow cover (in days). Negative values indicate that the analyses using satellite data depict formation later or disappearance earlier, than those using conventional data.

Station	Difference		Station	Difference	
	First	Last		First	Last
Norman Wells, N.W.T.	7	12	Sudbury, Ont.	2	-7
Baker Lake, N.W.T.	8	6	Toronto, Ont.	11	-8
Frobisher, N.W.T.	15	18	Val d'Or, Que.	3	-5
Fort McMurray, Alta.	5	-1	Bagotville, Que.	3	2
Churchill, Man.	-4	7	Knob Lake, Que.	0	12
Medicine Hat, Alta.	-7	-4	Hopedale, Nfld.	5	6
Winnipeg, Man.	9	5	Chatham, N.B.	-10	-5
Armstrong, Ont.	1	-11	Yarmouth, N.S.	7	-40
Moosonee, Ont.	2	1	St. John's, Nfld.	6	-10
			Median	4	0

References

Findlay, B.F., 1975: Snow maps for the Canadian Hydrological Atlas. Proceedings of the Western Snow Conference, pp. 79-86.

Fisheries and Environment Canada, 1978: Hydrological Atlas of Canada. Supply and Services Canada, Ottawa., Cat. No. EN37-26/1978.

Wiesnet, D.R. and M. Matson, 1976: A possible forecasting technique for winter snow cover in the northern hemisphere and Eurasia. Mon. Wea. Rev., 104, 828-835.

Wiesnet, D.R., and M. Matson, 1975: Monthly winter snowline variation in the northern hemisphere from satellite records 1966-1975. NESS Tech. Memo. NESS 74, 19 pp.