THE ANNUAL CYCLE OF SNOW COVER EXTENT OVER THE NORTHERN HEMISPHERE AS REVEALED BY NOAA/NESDIS SATELLITE DATA

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Abstract The hemispheric distribution of the timing of appearance and disappearance of snow cover is obtained. Weekly digital data of snow cover for 17 years based on NOAA satellite observations are used. In plain areas, we find zonal pattern in median despite of patchy pattern in individual years. The phase lines are in general parallel to latitudinal circles, but there is considerable east-west gradient both in Eurasia and North America. Mountainous areas are characterized by late snowmelt, large variability or both.

Key words: snow cover, snowmelt, Northern Hemisphere, NOAA satellite data

1. Introduction

Snow cover is one of the most prominent features of the earth that vary seasonally. It affects the heat balance of the earth in several ways, as follows:

- Because of its high albedo (reflectivity), it absorbs less solar radiation than bare soil or vegetated surface.
- Melting snow acts as heat sink, and it keeps the ground temperature near 0 degree Celcius despite of diurnal variation of radiative fluxes.
- In middle to high latitudes, snow cover is stock of water substance almost immobile during wintertime, and source of soil moisture during springtime. The wetness of soil makes the surface heat balance of summertime considerably different.

Continental snow cover is also one of the major players in interannual variation of the climate system, together with sea water temperature and monsoon rainfall (Yasunari, 1991). Hahn and Shukla (1976) showed correlation between snow cover area

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over Eurasia and monsoon rainfall over India in the following summer. Since then, many studies have been conducted. They are reviewed in Morinaga and Yasunari (1993).

The seasonal variation of snow cover is much larger than the interannual one. We should have better understanding of seasonal variation and then we can perhaps better understand interannual anomalies too. We begin with a primitive idea that the "front" of snow cover advances from higher latitude to lower latitude, and that it retreats oppositely. We hope that we can draw isopleths of the timing of advance and retreat. Such studies for one continent or another have been published (Anonymous, 1960; Potter, 1965). They are based on ground observations. In this paper, we try to describe a standard seasonal cycle of snow cover in the hemispheric scale using weekly data of satellite observations.

A preliminary report of this study was published as a researh grant report (Masuda *et al*., 1989). We used 14 years' (1973-1986) data there. In this paper, the time period of analysis is extended to 17 years, and the analysis procedure is improved as discussed in Section 3.

2. Data

Data set

We used the weekly values of "Weekly digital northern hemisphere snow and ice product" compiled by NOAA (National Oceanic and Atmospheric Administration) NESDIS (National Environmental Satellite, Data and Information Service) of the United States. This is the data set of hemispheric-scale snow cover with the longest history that starts in November 1966. The data production at NESDIS is ongoing.

This data set contains information of existence (1) or non-existence (0) of snow cover at each of the 89×89 square grid boxes on a polar stereographic map that covers most part of the northern hemisphere. It is a digitized version of hard-copy charts. The hardcopy charts are created by manual analysis of satellite imageries-mainly those of visible channels. The satellites and sensors used for the production are listed in a table of Matson *et al*. (1986) and reproduced in Wiesnet *et al*. (1987). The digitization of data for 1966-1980 was done by Dewey and Heim (1982) and that for the following years is done annually within NESDIS. (This digital data set contains information of sea ice until 1980 but it does not since 1981). The size of a grid box is roughly 200 km × 200 km.

Data from the autumn of 1966 through the end of 1989 were avaliable to this study. Until 1971, data of some weeks were missing. Also, the sensor used until 1972 had lower spatial resolution (3 km) than newer VHRR and AVHRR (1 km) sensors (Matson *et al*., 1986). Considering these facts, we excluded these earlier years and studied the 17 year period of 1973-1989.

Problems

The method of production of this data set and its problems are discussed in the paper of Masuda and Morinaga (1990), based on Wiesnet *et al*. (1987) and other sources. Here, a few points that are relevant to this study are listed:

1. It just contains information about existence of snow cover, not about its depth.
2. No information can be obtained if a grid box is cloudy every day during a week. In such a case, the same condition as the previous week is assumed.
3. If multiple grid boxes are partially covered by snow, and if the sum of the areas is equivalent to one box, the analysts subjectively determine which box they should assign '1'.

3. Method of Analysis

Basic idea

In this paper, we calculate statistics at each grid box, and view the distribution of the statistic values geographically. It is contrary to the more popular approach that first calculates regional snow cover areas and second analyzes its time series.

The problems of the NOAA/NESDIS data set discussed above, in particular items (2) and (3), result in considerable statistical noise in time-series analysis at single grid boxes. We try to overcome them by using robust statistics as discussed below, and by paying attention to spatial pattern of the statistic values.

Definition of 'snowmelt week' and 'snowfall week'

At a certain place in a certain year, there may be multiple timings of appearance and disappearance of snow cover. We focus on the timing of the *last* disappearance, because we consider it more important in controling summer dryness of soil. For the appearance of snow cover, we pick up the *first* one. This decision does not have an independent rationale. We just wanted to treat the appearance and disappearance symmetrically. Our convention is different from that of the figures on Page 42 of USSR Agriculture Atlas (anonymous, 1960), where the first and last dates of 'stable' (*i.e.*, temporally continuous) snow cover are shown.

We define the 'snowmelt week' of a grid box of a year as the week when snow cover is lastly observed between Week 8 and Week 30. (This definition is slightly different from that adopted by the previous report of Masuda *et al*., 1989).

We define the 'snowfall week' as the week when snow cover is observed at the first time between Week 36 and Week 52. It actually corresponds to appearance of snow cover rather than just snowfall, but we use the short name for brevity.

Use of order statistics

When a batch of numerical values is sorted, the value that comes at the center is called the *median*. The value whose order is one fourth from the smallest [largest] is called the lower [upper] *quartile*, and the difference between the two quartiles is called the *quartile range*. It is known (*e.g.*, Mosteller and Tukey, 1977) that these order statistics are more robust to outliers (extraordinary values) than the average and the standard deviation.

In this paper, medians and quartile ranges are calculated using 17 years' data. Here, the median is the 9th largest case, and the quartile range is the difference between the

5th largest and the 13th largest cases.

In our previous report (Masuda *et al.*, 1989), we showed means and standard deviations of snowmelt and snowfall weeks. Then we had to exclude such cases from the numerator and the denominator where the grid box is always snow-covered or always snow-free during the period under examination. In this study, if it is always snow-covered [snow-free], an arbitrary large [small] number is assigned as flag values to preserve the order. Similarly, for 'snowfall week', an arbitrary small [large] number is assigned in such cases. With this convention, such terminal cases are taken into account properly.

Amendment of data

After writing the previous report (Masuda *et al.*, 1989), we made following additional revisions to the data.

- The data tape from NESDIS contained a land-sea template file used by Dewey and Heim. Time-series plot of snow cover values at each box revealed that the template used since 1981 must be a little different from it. In this study, only such grid boxes that are treated as land in both periods are taken into account.
- The data of Week 17 of year 1987 were damaged, where 0 and 1 are partly (but not completely) reversed. We obtained a hard-copy chart of that week and digitized it.
- In some weeks between 1983 and 1985, there are physically inplausible line-like patterns, such as a belt of 0's traversing Greenland. We corrected them subjectively. It is likely to be noise of scanning hardware, and there may be still other similar errors that cannot be subjectively corrected.

4. Preliminary Facts

Orography

As a background information, the orographic height is shown in Fig. 1. It is based on $1^{\circ} \times 1^{\circ}$ grid-box data set of Gates and Nelson (1975), but somewhat smoothed[1]. Names of major mountain ranges and other places discussed later are shown in Fig. 2.

Seasonal cycle of total snow cover area

The time series of weekly values of total snow cover area is shown in Fig. 3. The annual cycle is one decimal order-of-magnitude larger than interannual variability.

Figure 4 shows the same data differently. For each week of year, there are 17 values corresponding to 17 years (1973-1989). Maximum (1st), upper quartile (5th), median (9th), lower quartile (13th) and minimum (17th) values from the largest are selected for each week and connected. The curves do not correspond to the seasonal march of any single year. The range between the uppermost and the lowermost curves shows the whole range of sample values. The half of the sample values are contained within the range covered by the second and the fourth curves (the quartile range).

In a year, snow cover area reaches maximum at Week 1-8 (January to February), and minimum at Week 30-36 (about August). The growth in autumn season is about 1.

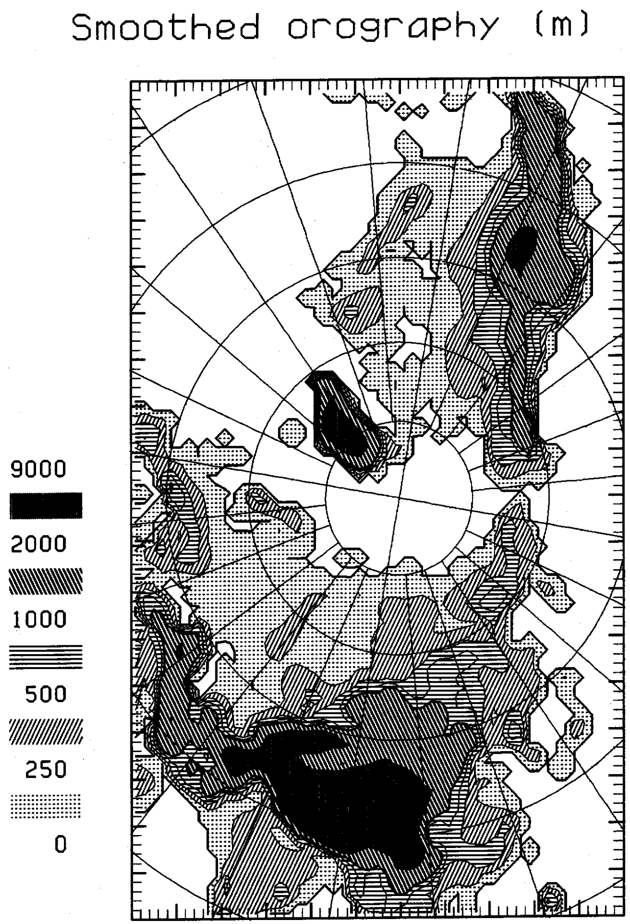


Fig. 1 Map of smoothed orographic height. The values are in metres. The interval between thick contours is 1000 m, and that between thin auxiliary contours is 250 m.

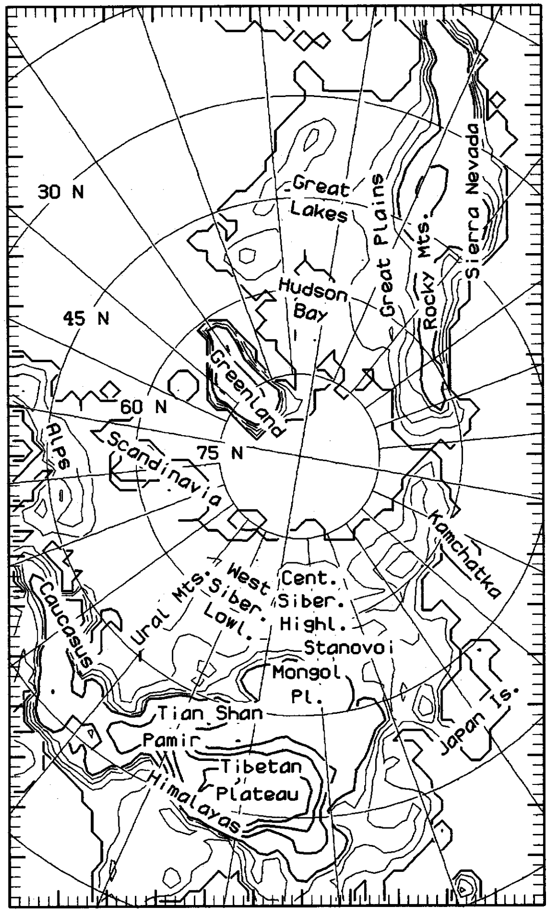


Fig. 2 Map of names of places discussed in the paper with the smoothed orography

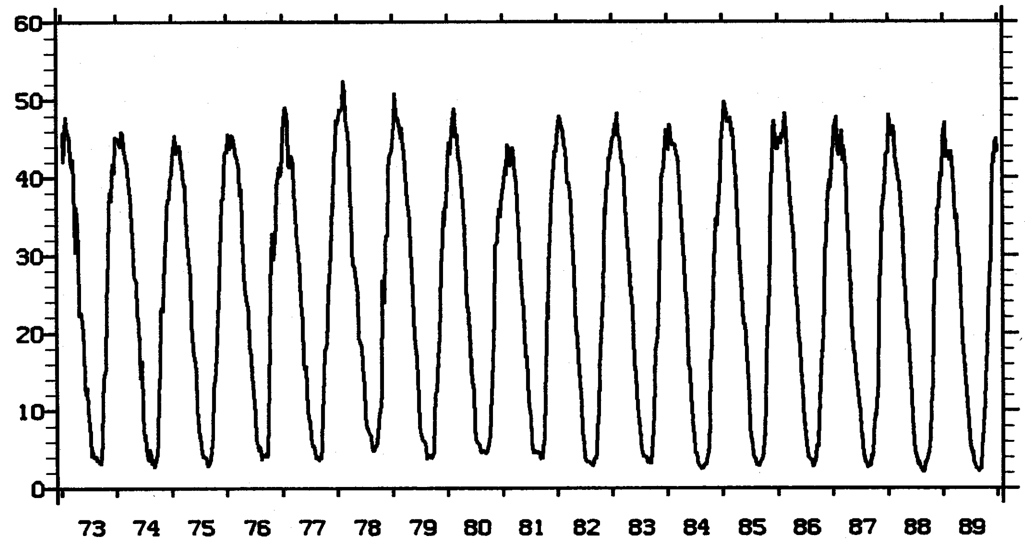


Fig. 3 Weekly time series of the total snow cover area over the Northern Hemisphere (in $10^{12} m^2$) from 1973 to 1989

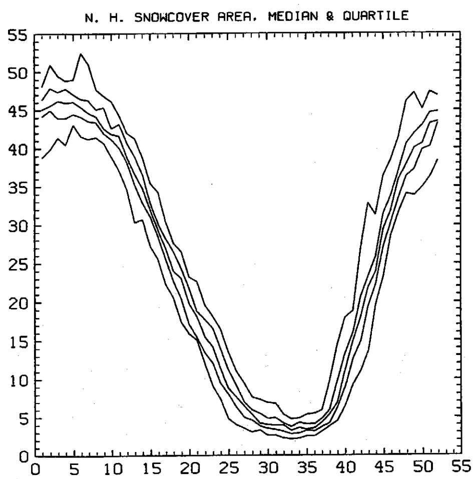


Fig. 4 Order statistics (maximum, minimum, median and quartiles) of weekly total snow cover area over the northern hemisphere (in 10^{12} m^2)

5 times faster than the decay in spring. This feature of the seasonal cycle is qualitatively the same as documented earlier by Dewey and Heim (1982).

Frequency of snow cover

The 'frequency', or empirical probability, of snow cover is the ratio of occurrence of 1's to the total count of samples in each grid box. Maps of geographic distribution of snow-cover frequency are presented by Matson *et al.* (1986), using data for 1967-1981. Our results are not much different from theirs.

Figure 5 shows the frequency of the whole year. Cross-hatches denote the areas where there is always snow cover. Such areas are limited to the interior of Greenland.

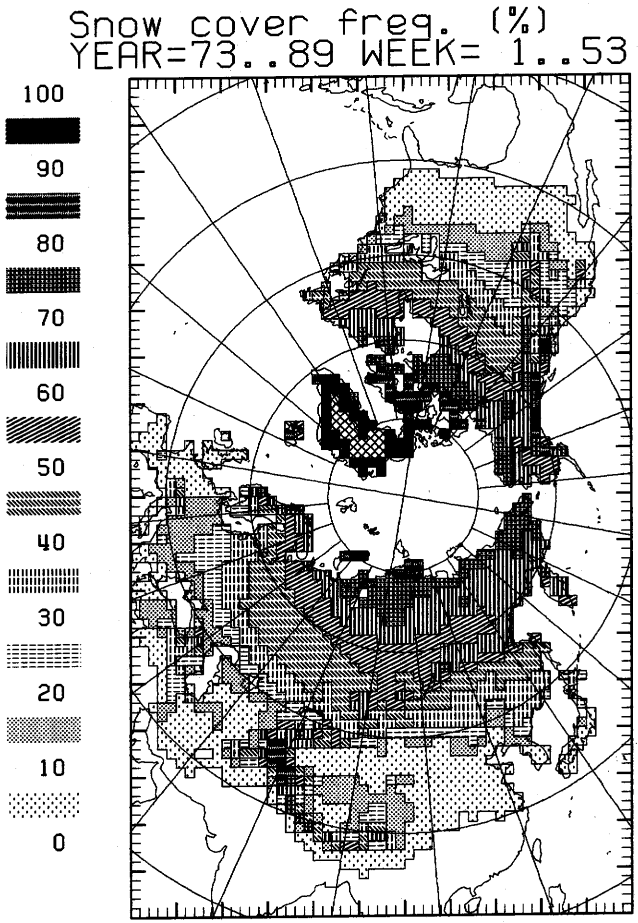


Fig. 5 Map of frequency (in %) of snow cover occurrence in Weeks 1-53, Years 1973-1989. Cross-hatched areas are always snow-covered, and white areas are always snow-free in these weeks.

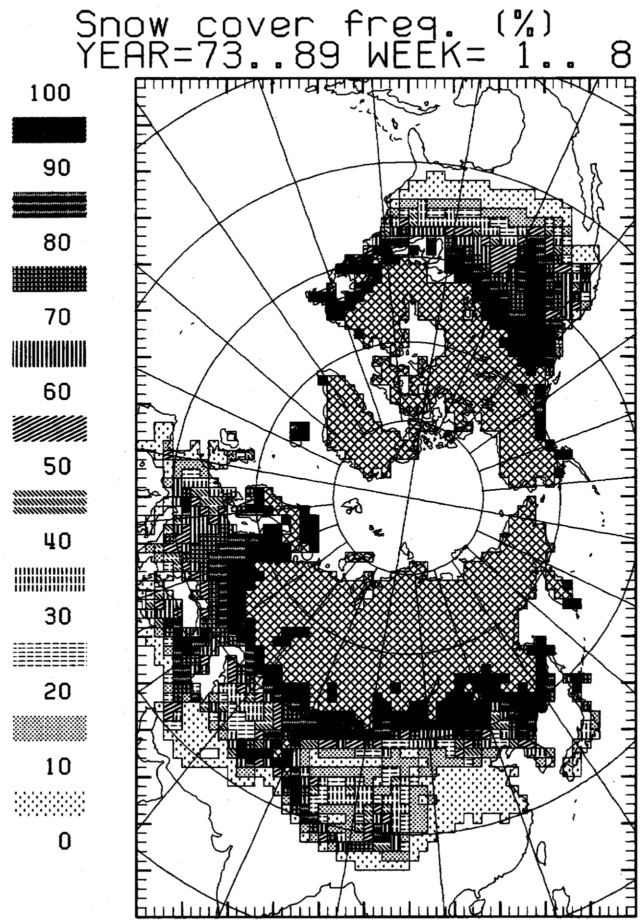


Fig. 6 Map of frequency (in %) of snow cover occurrence in Weeks 1-8, Years 1973-1989. Cross-hatched areas are always snow-covered, and white areas are always snow-free in these weeks.

Values larger than 90% are found in Greenland, Canadian Arctic Archipelago, and in limited parts of Himalayas and northern Rockies. The areas where no snow cover is observed at all are left white. Most of the area to the north of 30°N experience snow cover.

Figure 6 shows the snow cover frequency of Weeks 1-8, that is the season where the area attains the maximum. Most of the area in the higher latitudes has frequency larger than 90%. The boundary of this zone is approximately the 45°N parallel, but it is shifted northward of this latitude in the western part of each continent: *i.e.*, in western and central Europe and in the 'Great Plains'. To the north of this boundary, it can be assumed that stable snow cover exists continuously in winter.

5. Geographical Distribution of 'Snowmelt Week' and 'Snowfall Week'

Hemispheric distributions

Figures 7a and 7b are examples of the distribution of 'snowmelt week' in individual years. Figure 8 shows the median, and Fig. 9 shows the quartile range. Figures 10a and 10b are examples of the distribution of 'snowfall week' in individual years. Figures 11 shows the median, and Fig. 12 shows the quartile range.

Characteristics of maps for individual years

Both snowmelt and snowfall in a week occur in irregular patches. The size of patches that correspond to a single week is much larger in snowfall than in snowmelt. The typical spatial scale of snowmelt patch in one week is about 1000 km, while that of snowfall patch is about 3000 km or more. We consider it rational because snowfall is often caused by extra-tropical cyclones that moves about 7000 km in a week, while snowmelt is caused essentially by local heat balance. However, it may be partly artifact of the data set. When snow falls it is inevitably cloudy, and it is difficult to detect the accurate timing of snow cover set-up by observation of visible radiation.

The patterns are considerably different from year to year. We comment on just a few examples. The advance of snow cover in Eurasia from the Arctic coast to 45°N took only 4 weeks in 1976 (Fig. 10a) while it took 10 weeks in 1977 (Fig. 10b). Snow cover existed in a large area in the western Siberia and eastern Europe as late as Week 17 in 1987 (Fig. 7b) while it melted much earlier in 1975 (Fig. 7a) there.

Different nature of plain and mountainous areas

As a result of stacking 17 samples, the patterns of median snowmelt and snowfall weeks (Figs. 8 and 11) look much more zonal in areas with elevation generally below 500 m. We will call these areas "plain areas". The patterns are still irregular in mountainous areas (above 1000 m). The areas with elevation between 500 m and 1000 m can be considered as having transitional nature between plains and mountains. In plain areas, the isopleths are parallel to latitudinal circles as the first approximation, though the east-west gradient is evident over Europe and over the Great Plains of North America. The quartile range (Figs. 9 and 12) is generally less than 5 weeks in plain

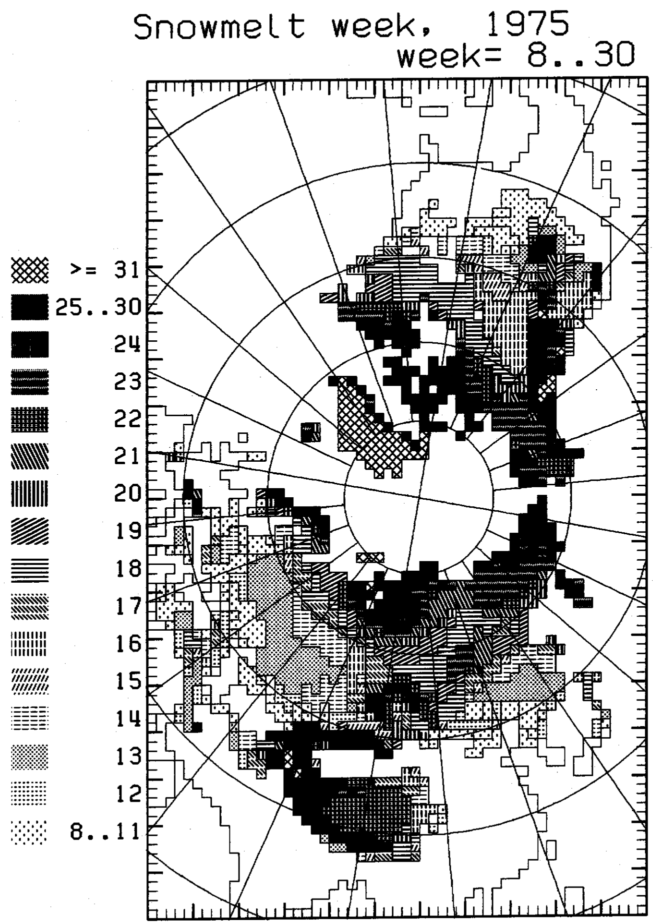


Fig. 7a Map of 'snowmelt week' of Year 1975. Cross-hatched areas are always snow-covered, and white areas are always snow-free in Weeks 8-30 of that year.

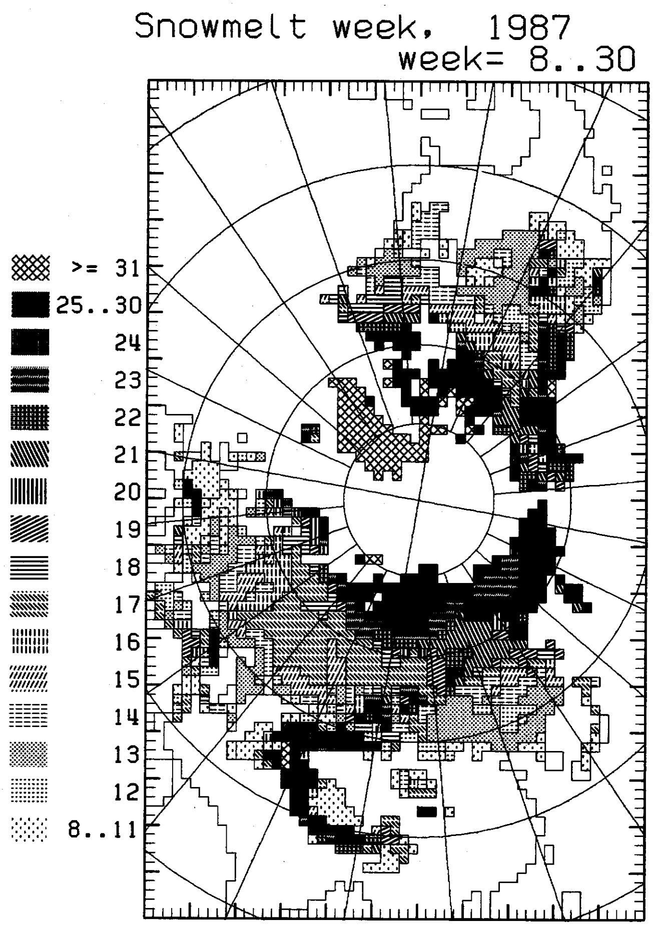


Fig. 7b Map of 'snowmelt week' of Year 1987. Cross-hatched areas are always snow-covered, and white areas are always snow-free in Weeks 8-30 of that year.

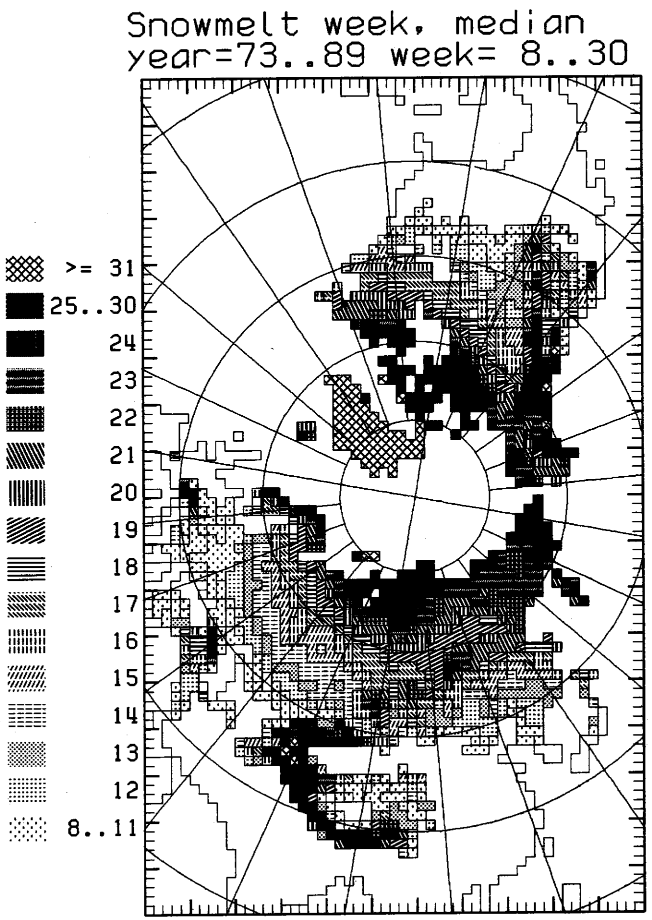


Fig. 8 Map of median of 17 cases of 'snowmelt week'. Cross-hatched areas are always snow-covered, and white areas are always snow-free in Weeks 8-30 in median case.

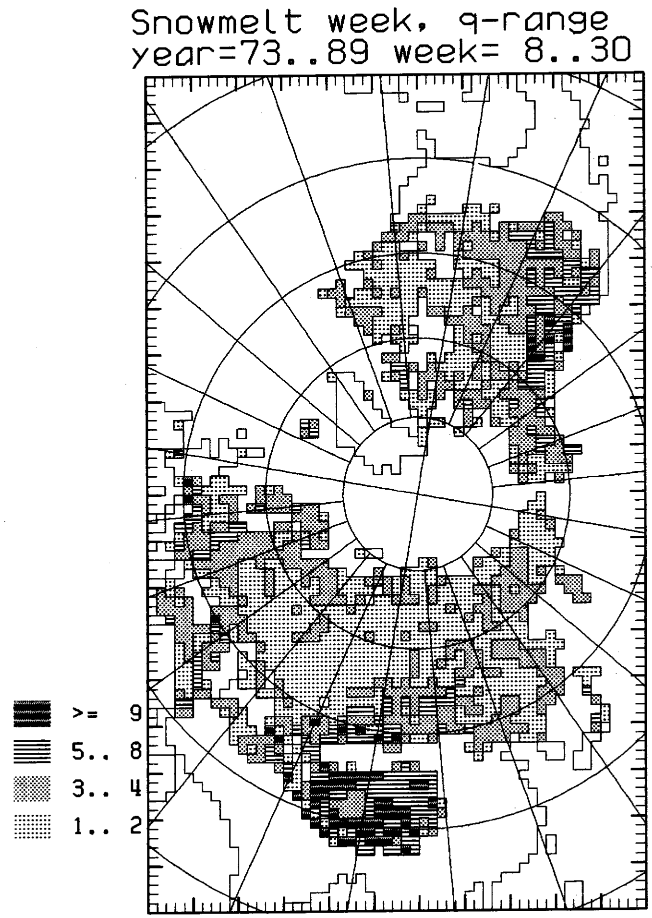


Fig. 9 Map of quartile range of 17 cases of 'snowmelt week'

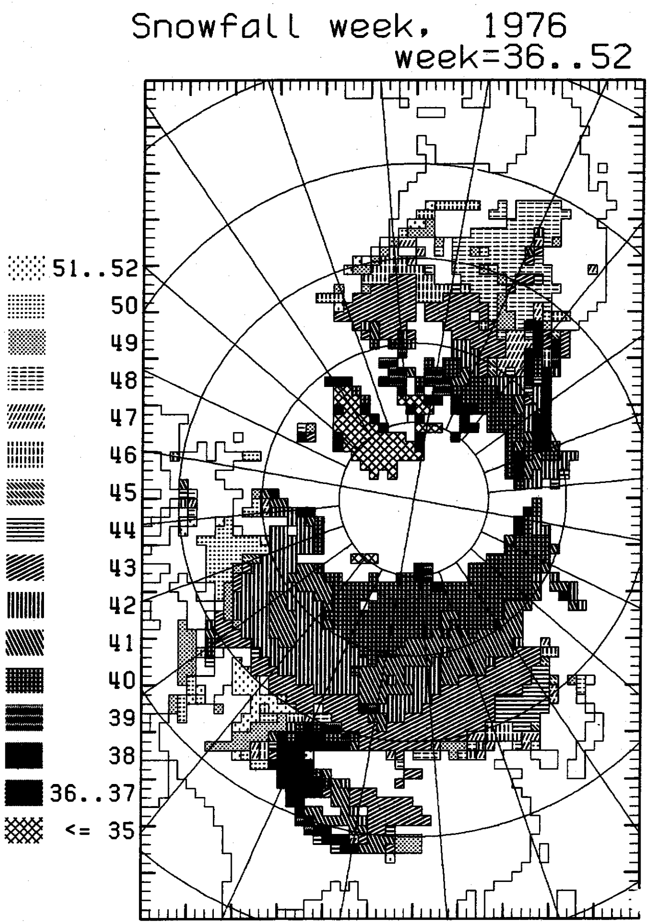


Fig. 10a Map of 'snowfall week' of Year 1976. Cross-hatched areas are always snow-covered, and white areas are always snow-free in Weeks 36-52 of that year.

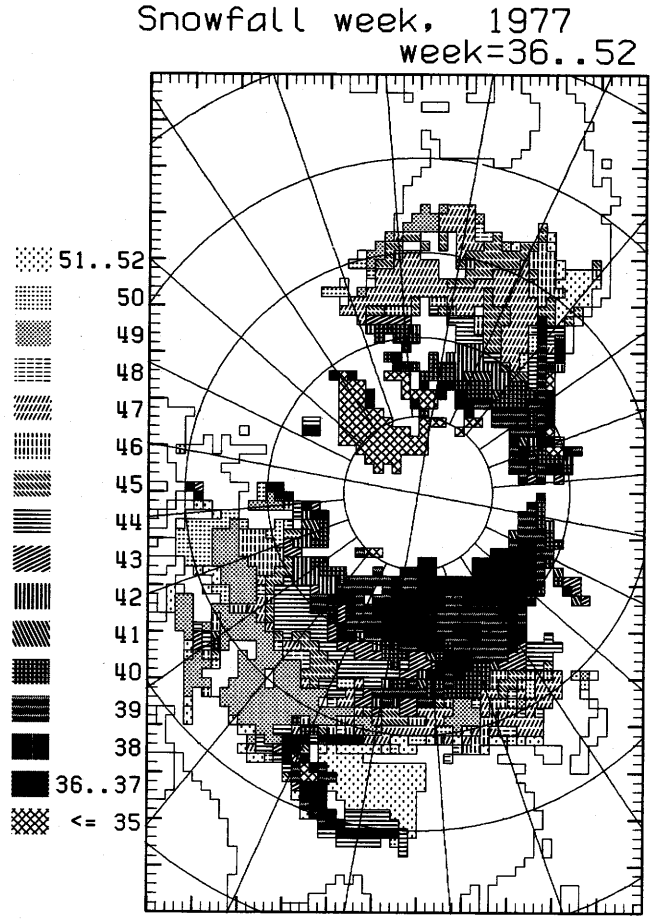


Fig. 10b Map of 'snowfall week' of Year 1977. Cross-hatched areas are always snow-covered, and white areas are always snow-free in Weeks 36-52 of that year.

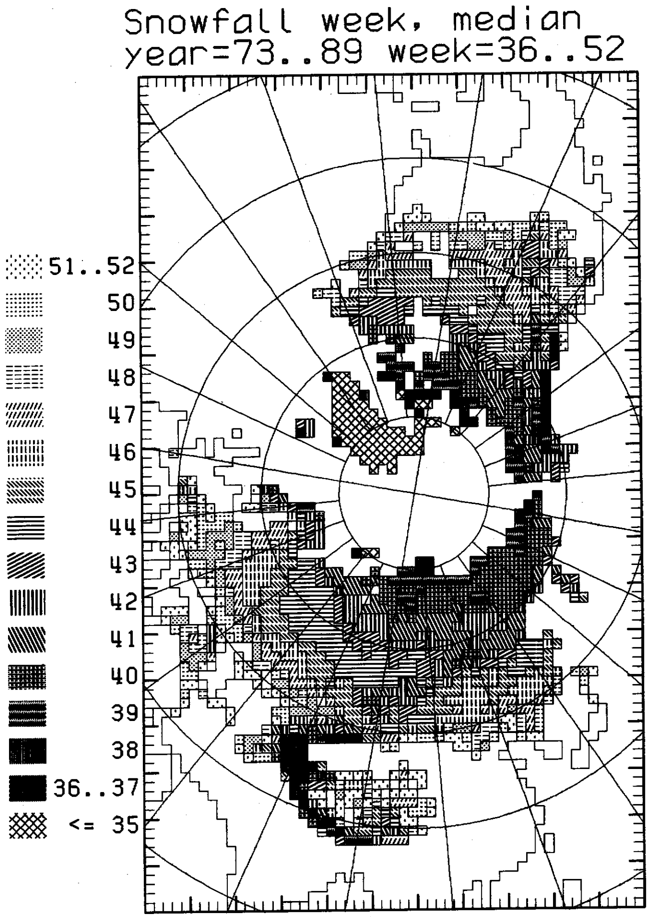


Fig. 11 Map of median of 17 cases of 'snowfall week'. Cross-hatched areas are always snow-covered, and white areas are always snow-free in Weeks 36-52 in median case.

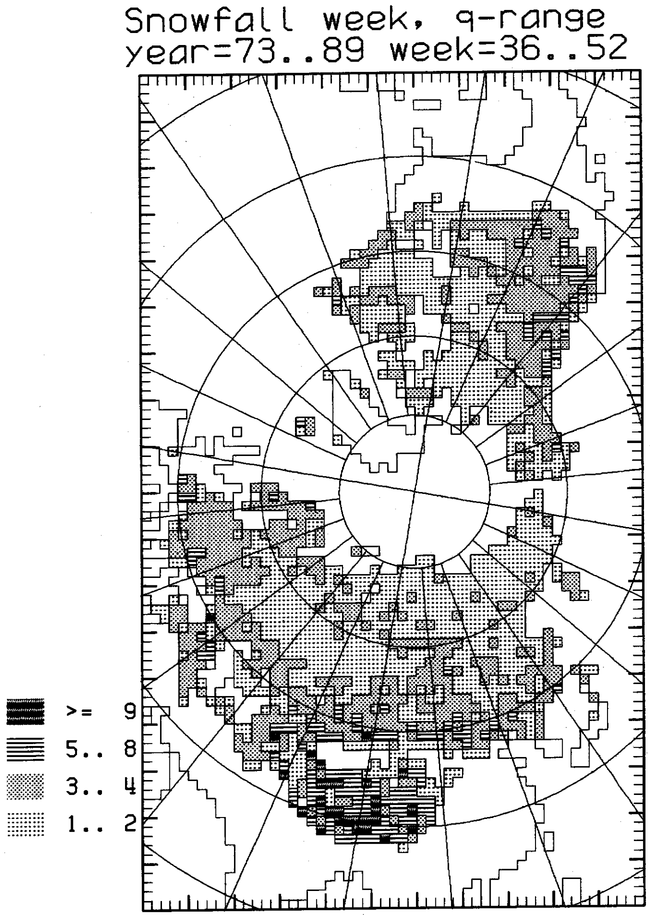


Fig. 12 Map of quartile range of 17 cases of 'snowfall week'

areas. In mountainous areas, large values of the quartile range are often found. Some mountain areas, however, do not show large quartile range but are rather characterized by late snowmelt and early snowfall (in median as shown in Figs. 8 and 11).

The characteristics in plain areas and mountainous areas will be discussed more in Sections 6 and 7, respectively.

6. Characteristics of Median 'Snowmelt Week' and 'Snowfall Week' in Plain Areas

Speeds of north-south propagation of snowmelt and snowfall

When we compare Figs. 8 and 11, we find some assymmetry between snowmelt and snowfall. As we have already seen with Fig. 4, snowfall proceeds more rapidly than snowmelt. We also see at Fig. 11 that in median large advance of snow cover occurs in a single week: Week 45 in North America and Weeks 40 and 44 in Eurasia.

In the following analysis, we take such grid boxes where both the median 'snowmelt week' and the median 'snowfall week' are defined (*i.e.,* not the terminal flag values) and plot the week numbers against latitude. In Fig. 13, we select the area of Eurasia, to the north of 40°N, and the longitude being between 30°E and 120°E. In this area, the isopleths can be regarded roughly parallel to the latitudinal circles. We will first look at the grid boxes with elevation less than 500m (+'s and o's in Fig. 13 together). 'Snowmelt' proceeds from 45°N to 70°N in 15 weeks, thus the speed is about 1.7° latitude/week. 'Snowfall' proceeds oppositely in the same interval in 10 weeks, the speed being 2.5° latitude/week. Accelerated 'snowfal' around Week 44 is also evident.

Dependence on elevation

The samples are sorted by the elevation of land. Difference between the 250 m - 500 m group (o's in Fig. 13) and the 0 m - 250 m group (+'s) is larger in snowmelt (about 4 weeks) than in snowfall (about 2 weeks). The samples with elevation higher than 500 m are also shown as small dots in Fig. 13. The distribution is much more irregular than

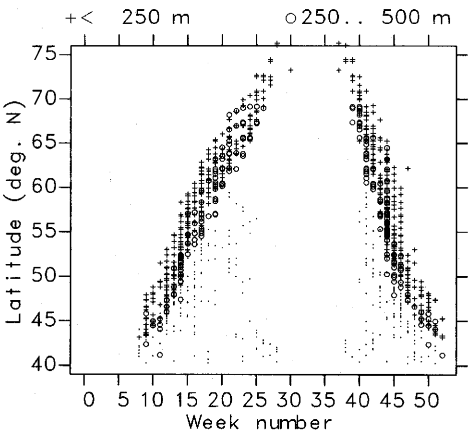
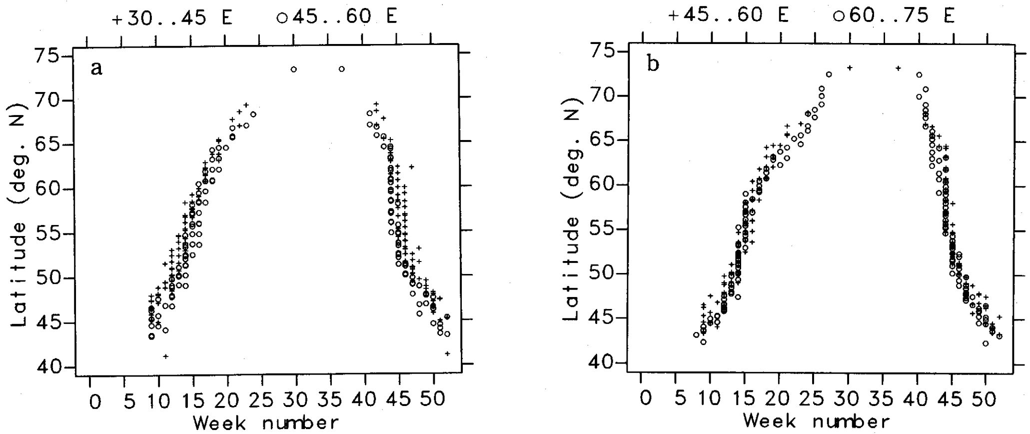


Fig. 13 Time-latitude scatterplot of median 'snowmelt week' and 'snowfall week' of grid boxes between 30°E and 120°E sorted by orographic elevation (+) 0m-250m; (o) 250m-500m; (.) over 500m.



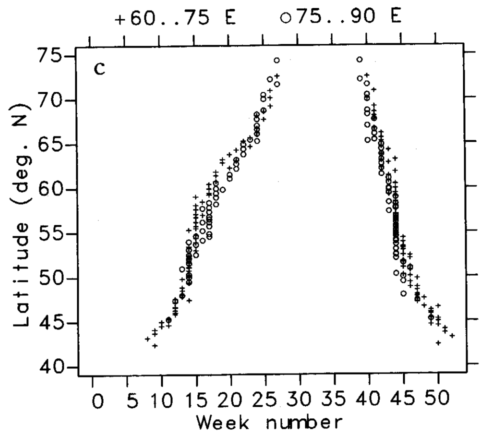


Fig. 14 Time-latitude scatterplot of median 'snowmelt week' and 'snowfall week', orographic elevation less than 500 m
14a: + 30-45°E; o 45-60°E
14b: + 45-60°E; o 60-75°E
14c: + 60-75°E; o 75-90°E

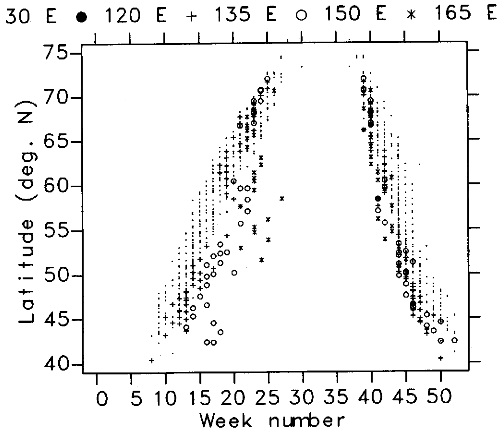


Fig. 15 Time-latitude scatterplot of median 'snowmelt week' and 'snowfall week', oro-graphic elevation less than 500 m
(.)30-120°E; (+)120-135°E; (o)135-150°E; (*)150-165°E

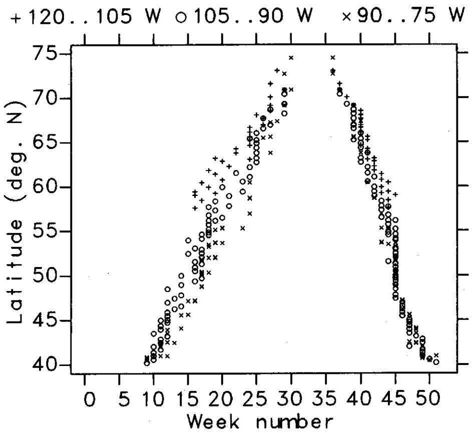


Fig. 16 Time-latitude scatterplot of median 'snowmelt week' and 'snowfall week', oro-graphic elevation less than 500 m
(+)120-105°W; (o)105-90°W; (*)90-75°W

o's and +'s and it is likely to be affected by regional orographic effects.

General east-west gradient

It is known that in middle and high latitudes in winter, western side of a continent tends to be warmer than eastern side. An easy but not complete explanation of this general trend is as follows:

- In winter, the interior of a continent is cooler than oceans;
- Accordingly, the surface air pressure is higher;
- By near-geostropic balance with pressure, the winds tend to be northerly in the eastern side and southerly in the western side.

Concerning snow cover here, too, the western side experiences earlier snowmelt and later snowfall than the eastern side in both Eurasia and North America. The slant of isopleths is evident in Figs. 8 and 11 in Europe and Western Siberia as well as in plain areas of North America. The phase propagation is very roughly 1 to 2 weeks/15° of longitude, though it is not constant as discussed below.

Regional east-west gradient in Eurasia

The constant east-west difference in Europe and Western Siberia breaks at the Ural mountain range at 60°E. Comparing Fig. 14a - 14c, we find that the belt of 45-60° Experience anomalously late snowmelt. The western side is a hilly region and the eastern side is plain area, but the difference of average elevation is less than 250 m. It is likely that the differnce of snow depth is the controling factor. The annual maximum snow depth is generally larger than 60 cm to the west of the Urals, with a maximum of 80 cm over the mountain range. It is smaller to the east, in particular, less than 40 cm to the south of 60°N. (Anonymous, 1960; Kotlyakov, 1968 quoted by Lydolph, 1971; Igarashi, 1992). It is likely that prevailing westerly winds are forced to uplift at the mountain range and result in large precipitation in windward and become drier in leeward.

The slanted zonal pattern appears to stop at 90°E. At 90°E, snowmelt is later than other places with similar latitude and elevation. There is a maximum of snow depth here to the west (windward) of the Central Siberian Highlands. The snowmelt/snowfall pattern to the east of this longitude is complicated, presumably due to complex orography.

The east-west gradient is again evident near the Pacific coast as shown in Fig. 15. Snowmelt is as much as 8 weeks later in the grid boxes of northern Japan and Sahalin (42-52°N, 135-150°E) and Kamchatka (53-60°N, 150-165°E) than the majority of the 30°E-120°E zone. Grid boxes to the east of 120°E and to the south of 60°N also have later snowmelt though the difference is smaller. In these areas, which are near oceans, snow depth are larger than the continental interior of eastern Siberia. It is likely that sea ice in Ohotsk and Bering Seas has also some influence, but our knowledge is insufficient to discuss it here. We just mention the fact that the seasonal cycle of sea ice has a different phase from that of snow cover. The total sea ice area of the northern hemisphere reaches maximum in March and minimum in September in the northern hemisphere (Parkinson and Cavalieri, 1987).

Regional east-west gradient in North America

Snowmelt is rapid in the 'Great Plains' region at the eastern slope of the Rocky Mountains, while it is much slower in the longitudes of the Great Lakes and the Hudson Bay. Figure 16 shows the difference in snowmelt is as large as 4 weeks/15° longitude, while the difference in snowfall is not so large. In this case, too, difference of snow depth is a likely cause of part of the large difference. According to Canada Department of Transport (1967) quoted by Bryson and Hare (1974), annual sum of snowfall is 80 to 120 cm in the 'Great Plains' region of Canada and 200 to 300 cm in the area between the Great Lakes and the Hudson Bay. Influence of sea ice and lake ice in the eastern region may also be suggested, though we have not examined it yet.

7. Characteristics in Mountainous Regions

Three categories

Comparing Figs. 8, 9, 11 and 12 with the orography (Fig. 1), mountainous regions are characterized by

1. late snowmelt and early snowfall, or
2. large variability of snowmelt and snowfall seasons.

By 'large variability', we mean both large values of the quartile range and large spatial inhomogeneity in the median. We often find these two features together. We consider that the coincidence is probably real. But it is possible to be an 'aliasing' effect of this data set (problem (3) mentioned in Section 2). In case when there are snow patches of the scale smaller than a grid box, variability in judgements of the analysts who produced the digital product can result in apparent temporal variability.

In our previous report (Masuda *et al.*, 1989), we tried to classify mountainous regions into the above two categories (1) and (2). However, in that study we calculated the means and standard deviations excluding such cases that 'snowmelt' or 'snowfall' could not be defined. We were not confident about the representativeness of these statistics. This time, based on the figures of medians and quartile ranges, we consider that we should classify the regions into three categories rather than two, though the boundaries between them are gradual.

A tentative categorization is shown in Fig. 17. This figure is made by the following process. Using Fig. 8, the grid boxes where median 'snowmelt week' is Week 22 or later are marked. Also, using Figs. 9 and 12, the grid boxes where the quartile range of either snowmelt or snowfall week is 5 weeks or larger are marked. Grid boxes are classified according to the two criteria as follows:

- (a): late snowmelt, small variability
- (b): late snowmelt, large variability
- (c): not late snowmelt, large variability
- (others): not late snowmelt, small variability

The resultant spatial distribution of categories is generalized by omitting isolated grid boxes and replacing rectangular border lines by smooth curves. Note that the generalization is subjective and that spatial details smaller than the NOAA/NESDIS grid boxes are meaningless in this figure.

The regions around the Arctic Sea and Scandinavia and Kamchatka (hatched with horizontal lines ('d') in Fig. 17) have characteristics of 'a'. These are treated separately, however, because these regions include both mountainous and plain areas.

Category 'a' includes Alaska Range, small parts of Canadian and U.S. Rockies in North America, Pamir highlands and part of Himalayas, Altay and Sayan Mountains and Stanovoi Highlands in Eurasia (painted black in Fig. 17). Most of these are very high mountains or mountains in higher latitudes.

Category 'b' includes Canadian Rockies and Sierra Nevada in North America, part

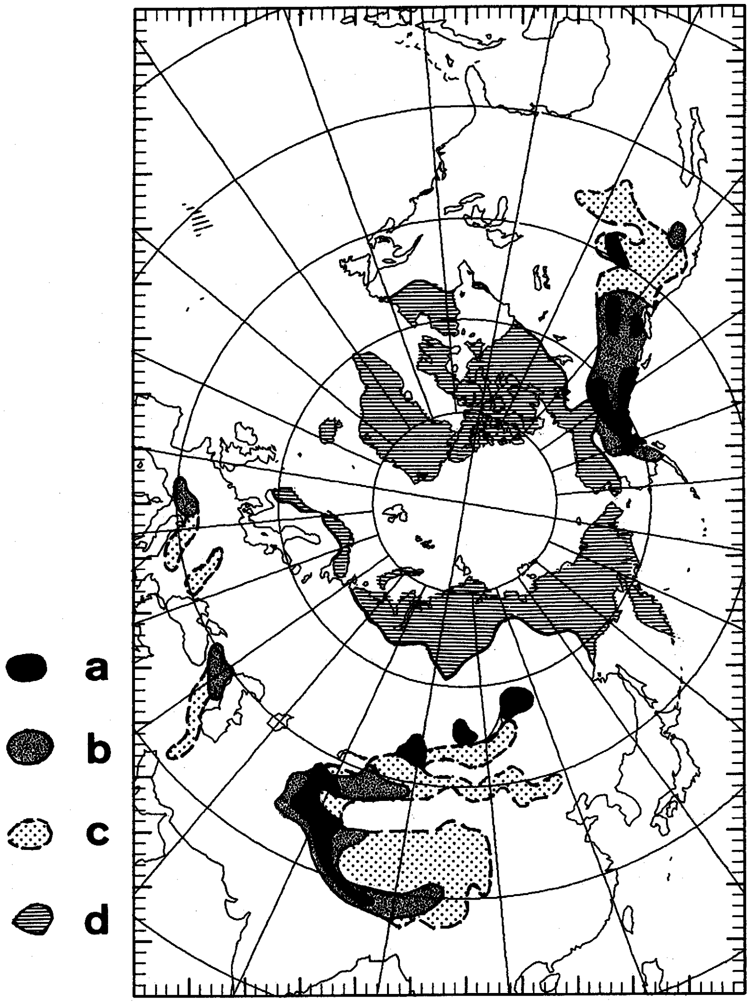


Fig. 17 A tentative categorization
a: Late snowmelt, small variability;
b: Late snowmelt, large variability;
c: Large variability;
d: Same as (a), but distinction between mountains and plain areas is not clear.

of Himalayas, Tian Shan, Caucasus and Alps in Eurasia (shaded with random dots in Fig. 17). This category probably includes such sub-grid-scale areas that should be included in Category 'a' if the data have higher spatial resolution.

Category 'c' includes most of U.S. Rockies in North America, and Tibetan Plateau, part of Mongolian Plateau, and Zagros Mountains (in Iran) in Eurasia (shaded with sparse dots in Fig. 17). The common factors of these areas are relatively low latitudes and low supply of water vapor which causes precipitation. Some ranges in eastern Europe also happen to be in this category. These areas are not typical mountainous areas. The elevation is generally less than 1000 m (Fig. 1). The area of large variability actually extends to plain areas near the Baltic Sea (Fig. 9) but it is truncated in Fig. 17.

Remark about Stanovoi Highlands

In the Stanovoi Highlands (about 55°N, 115°E, to the east of Lake Baikal), snowmelt occurs as late as Week 23 to 25 (June) in median. The smoothed height does not reach 1000 m, though the highest peak is nearly 3000 m high. The late snowmelt is confirmed by ground-based studies: anonymous (1960) also shows that in this region 'stable' snowcover exists until the third 10-day period of May, and that the total duration of snowcover is 240-280 days per year. Though we cannot discuss causal relationships, this area is also known as the southernmost part of the continous permafrost zone of the world (*e.g.,* Pēwē, 1983).

8. Concluding Remarks

Summary

In plain areas, average elevation being less than approximately 500 m, we find zonal pattern of the progress and retreat of seasonal snow cover by stacking 17 years' data. The phase lines are in general parallel to latitudinal circles, but there is east-west gradient both in Eurasia and North America, with considerable regional anomalies.

Mountainous areas, elevation generally being more than 1000 m, are characterized by late snowmelt, large variability or both. A tentative categorization is shown. It should be noted, however, that temporal variability may be aliased as spatial variability, or vice versa, because of the nature of the data set used.

Remaining problems

We cited information of snow depth from existing literature, because the NOAA/NESDIS data do not tell it. We consider we should examine the distribution of snow mass more throughly by combining microwave and ground-based data. An attempt in this direction was made by our colleague, Igarashi (1992).

We should have discussed the cause of the patterns, but we are not able to do it. The results of this study suggest that following subjects should be more clarified.

- Surface heat balance
- Development of seasonal mean atmospheric pressure system
- Development and movement of cyclones

- Effects of mountain ranges on the distribution of snowfall amount
- Behavior of sea ice and its interactions with snow cover
- Behavior of permafrost and its interactions with snow cover.

Discussion of the signals of interannual variations is also an interesting matter that is left to future studies.

Note

1. Actually, we assigned at each snow cover grid box the average of heights of 1° elevation data within a circle whose radius is equal to one grid interval of the snow cover grid.

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(* : in Japanese; ** : in Japanese with English abstract; *** : in Russian)