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HEMISPHERIC CHANGE OF THE STRATOSPHERIC TEMPERATURE AT MIDDLE LATITUDES IN WINTER

By

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Abstract

Hemispheric analysis of monthly mean thickness pattern of 10-25 mb layer in 1958-59 winter indicates that the zonal mean temperature at middle latitudes rises from November to January and falls from January to February, opposite to the seasonal change of insolation. Similar changes of temperature are confirmed for all the 8 winters analyzed. The change in 1958-59 winter is most remarkable over Siberia and Europe where the troughs exist on monthly mean 10 mb maps.

1. Introduction

One of the most remarkable, characteristic variations of the atmospheric conditions is annual march of temperature. Such variation of the stratospheric temperature has been fairly well disclosed with substantiation of the radiosonde network. Several analyses were made for annual march of 3-month averaged conditions (Murakami [1962], Peng [1963, 1965]). Although the results of analyses could show the general features of the seasonal variations in the stratospheric temperature conditions, the characteristic changes of relatively shorter period may be smoothed out by the 3-month averaging processes.

In this paper, the month-to-month change of hemispheric temperature conditions, particularly in winter season, is studied by using the thickness pattern in stratospheric layer. Thickness or height difference between two isobaric surfaces can be easily transformed into the mean temperature of a layer bounded by the both surfaces, under assumption of no influence of moisture.

Concerning the accuracy of temperature observations with radiosonde, Finger, *et al.* [1963] describe that the observed data corrected for solar heating effect of the instrument at a given station may fluctuate in an unreasonable manner as much as 6°C to 8°C from one observation to the next. On the other hand, in contour analysis at the stratospheric levels, the wind data are usually

given most weight, while the reported height is employed primarily to determine the numerical value used in labeling the contour. If the error of rawin observation in the middle stratosphere may be regarded as 3 m/sec after Ference [1951], the error of geopotential gradient may be approximately 20 gpm/1000 km at middle latitudes under geostrophic balance. Since 10-25 mb layer has a thickness of about 6000 gpm, the rawin observation may give, to estimation of the thickness, the error of 3 % (≒6°C 200°K) for a horizontal distance of 4500 km$\left(=\frac{6000\ \text{gpm}\times 0.03}{20\ \text{gpm}\times 2/1000\ \text{km}}\right)$. In the IGY and IGC periods, the distance between two adjacent radiosonde stations is, in the most cases at high and middle latitudes, shorter than 4500 km. This permits us to mention that the hemispheric temperature conditions may be shown rather reliably by using thickness pattern, although it obliges us to overlook some small scale phenomena.

2. Annual march of the zonal mean temperature of 10-25 mb layer

Hemispheric contour maps, daily and monthly mean, at 10 mb, and so on, have been published by R. Scherhag. Using the monthly mean maps at 10 mb and 25 mb (Warnecke [1962a] and Scherhag, *et al.* [1962]), the zonally averaged temperature of 10-25 mb layer is obtained from July 1958 to June 1959 (Fig. 1). The general features of high temperature in summer season and low temperature in winter can be found at all the latitudes, from 30°N to 80°N. And there are equatorward gradient in summer, poleward gradient in winter, and the reversals of gradient between August and September, and between February and March. Annual range of zonally averaged temperature change increases with increasing latitude, and is nearly equal to 7°C at 30°N and to 31°C at 80°N.

At 70°N and 80°N, one of the most noticeable month-to-month change of temperature is an increasing or non-decreasing from October to November 1958. This change may be accompanied with appearance of Aleutian anticyclone (Boville [1960]), which can be actually seen on 10 mb map in late October (Finger, *et al.* [1963]). Another remarkable change at high latitudes is a rapid rise of temperature from February to March and the following fall. This may be caused by the final warming in early March, which was observed significantly at Alert (82° 20′N, 62°20′W) (Hare [1960]).

A noticeable month-to-month change of temperature at middle latitudes is a rise from November to January and the following fall. Our attentions are focused at this phenomenon, and some detailed description will be given in the following sections.

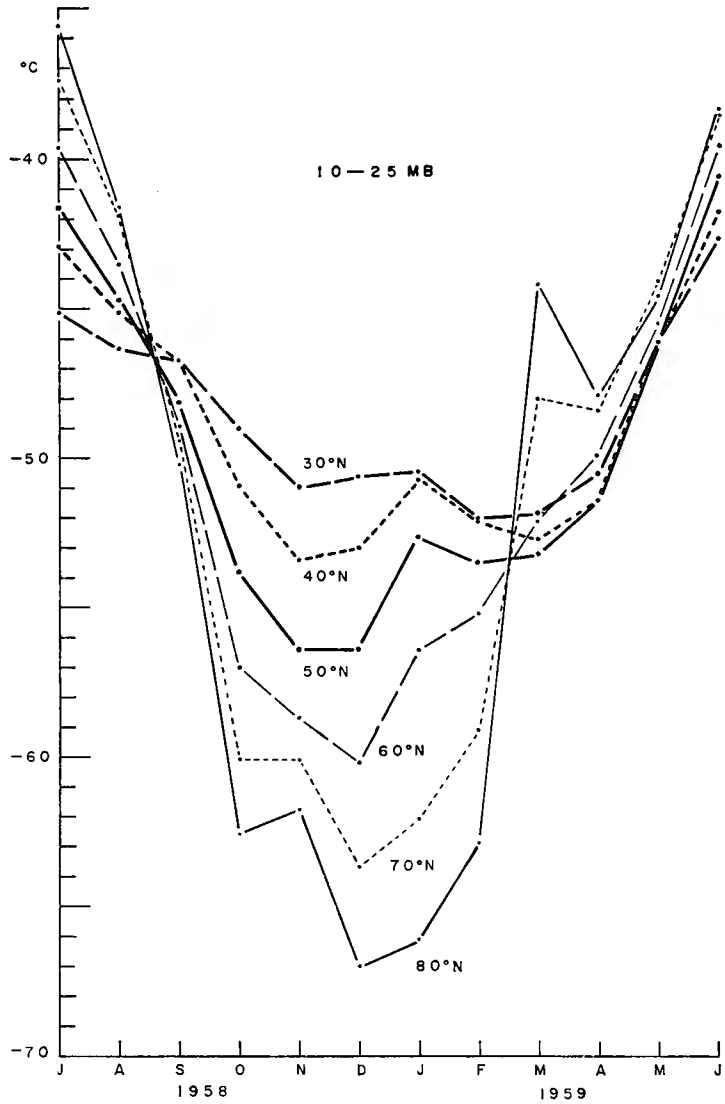

Fig. 1. Monthly mean temperature of 10–25 mb layer averaged zonally, derived from thickness pattern which is obtained from Warnecke [1962a] and Scherhag, *et al.* [1962].

3. Change of the stratospheric temperature at middle latitudes in winter

It is noticed in Fig. 1 that the monthly mean temperature averaged zonally at 30°N, 40°N and 50°N in the 1958–59 winter has a rising tendency before January and a falling one afterwards. The fact that this change of the stratospheric temperature has an opposite sense to the seasonal change of insolation

requires us to study this phenomenon. The temperature curve at 40°N in Fig. 1 has minimum values in November and March, and a maximum in January, while the curve at 80°N has maximum in November and March, and minimum in December. The fact that month-to-month changes of temperature are nearly out of phase between middle and high latitudes makes us analyze hemispherically this phenomenon. Remarkable amplitude of semi-annual oscillation of temperature above height of 30 km or 50 km at 30°N was reported by Toth [1963] and Batten [1963]. The results of harmonic analysis of the temperature given in Fig. 1 are shown in Table 1. The amplitude of semi-annual component at

Table 1. Harmonic analysis of annual march of the zonal mean temperature of 10-25 mb layer for the period from July 1958 to June 1959

Latitude (°N)	Annual mean temperature (°C)	Annual component		Semi-annual component	
		Amplitude (°C)	Phase of maximum temperature	Amplitude (°C)	Phase of maximum temperature
80	−51.9	14.7	middle June	2.0	middle February middle August
70	−51.1	12.5	late June	1.8	early February early August
60	−50.6	9.4	late June	2.4	late January late July
50	−49.9	7.6	early July	2.5	middle January middle July
40	−48.9	5.1	middle July	2.4	middle January middle July
30	−48.5	3.7	middle July	1.4	late December late June

middle latitude is nearly equal to 2.5°C, and larger than that at higher and lower latitudes, and the amplitude is approximately half of that of annual component at 40°N. Although the phase of this semi-annual component at middle latitudes falls in the range from late December to middle January and does not agree with that above 30 km or 50 km height reported by Toth and Batten, the relationship between them, if it might exist, will be very interesting.

The zonal geostrophic wind speeds at 10 mb level are given in Fig. 2. The curves have such a shape as the westerly winds in winter and easterly in summer. Concerning the month-to-month change in winter, the zonal winds at 25°N reach maximum in November and April, and minimum in January, while the winds at 65°N minimum in November and April, and maximum in February. These features of wind change correspond well with that of the

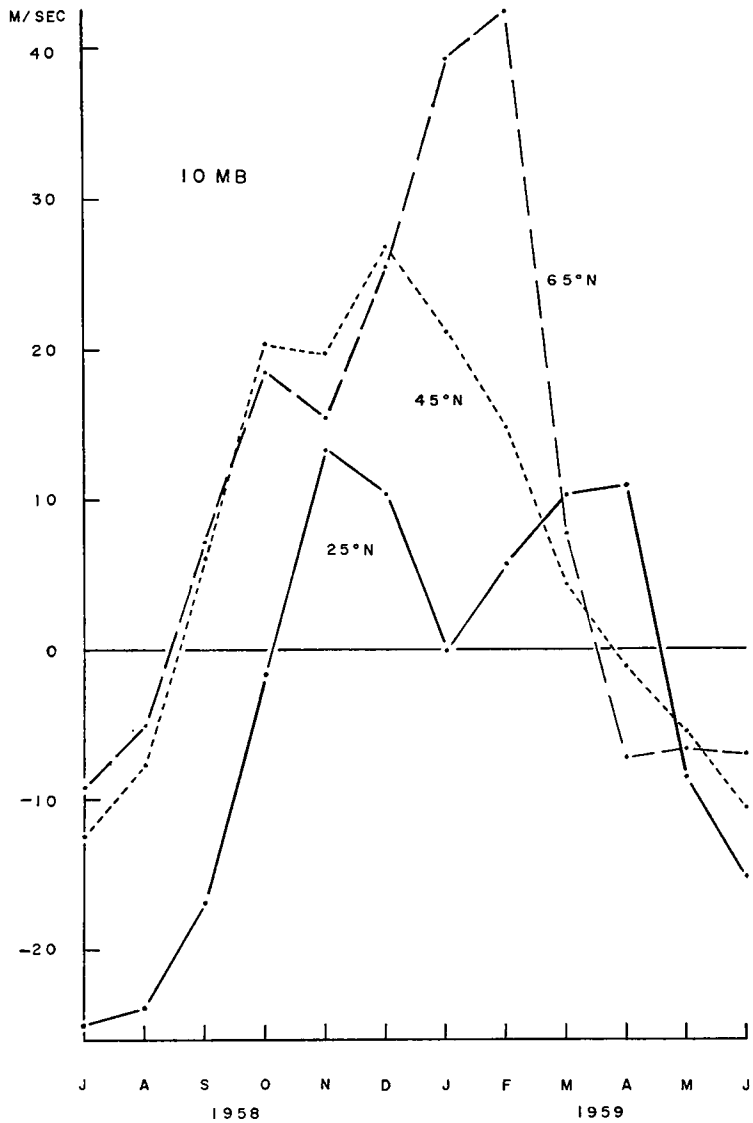

Fig. 2. Monthly and zonal mean speed of geostrophic wind at 10 mb. Westerly wind is positive.

temperature change at middle latitudes shown in Fig. 1. This fact suggests that the temperature change in question may have a close connection with the change of the circulation.

Warnecke [1962 b] noticed a similar maximum temperature in mid-winter, not by global analysis, but by an examination of data at a single station or Tateno (36°03′N, 140°08′E). He presumed Aleutian anticyclone as a cause of this temperature change, but his opinion should be examined by further studies.

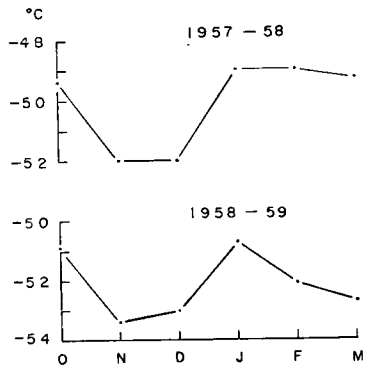

Fig. 3. Monthly mean temperature of 10–25mb layer averaged zonally, derived from thickness pattern which is obtained from maps by Warnecke [1962a, 1965] and Scherhag, *et al.* [1962].

Figs. 3 and 4 show the temperature curves of 10–25 mb or 10–30 mb layer from October to March, for the winters of 1957–58, 1958–59, 1959–60, 1960–61, 1961–62, 1962–63, 1963–64 and 1964–65, which are obtained from Scherhag, *et al.* [1961, 1962, 1963, 1964, 1965, 1966] and Warnecke's 1962a maps. Temperature changes similar to that in 1958–59 winter can be seen in all the winters, although the maximum temperatures appear in November 1959, February 1961, Dcember 1963 and December 1964. This suggests that the temperature change in question is not occasional, but is a characteristic of the normal seasonal variation at middle latitudes.

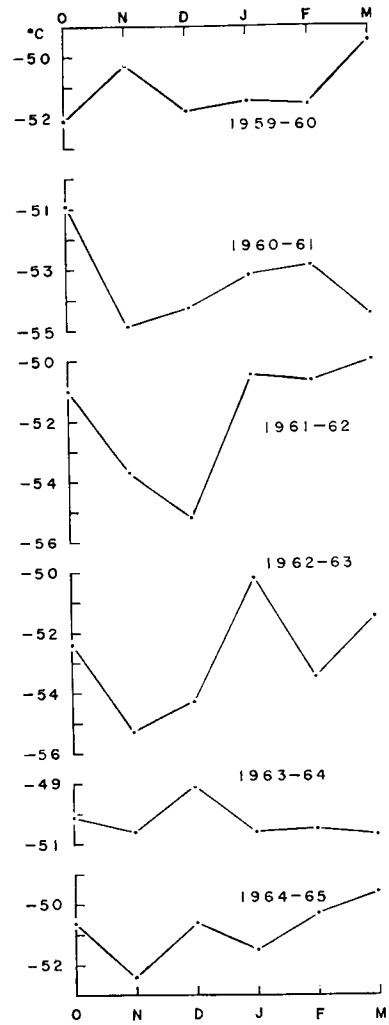

Fig. 4. Monthly mean temperature of 10–30mb layer averaged zonally, derived from thickness pattern which is obtained from maps by Scherhag, *et al.*, [1963, 1964, 1965].

4. Hemispheric change of the stratospheric temperature from December 1958 to February 1959

Hemispheric analysis of the temperature conditions in the stratosphere is attempted for 1958–59 winter. Meridional cross-sections of monthly mean value of the zonally averaged temperature are obtained for December 1958, January

1959 and February 1959 (Figs. 5a, 5b and 5c), using the thickness patterns of 10-25 mb and 25-50 mb layers derived from Warnecke's [1962a] and Scherhag, *et al.* [1962] maps and isothermal patterns on 25 mb, 50 mb and 100 mb surfaces by Muench [1962]. Here, it is assumed that the temperature averaged over a layer represents that at middle level of the layer. In all the 3 months, the minima of temperature appear near 30 mb or 40 mb, 80°N, and near 100 mb, 20°N. The maxima of temperature can be found at the highest level near 20°N

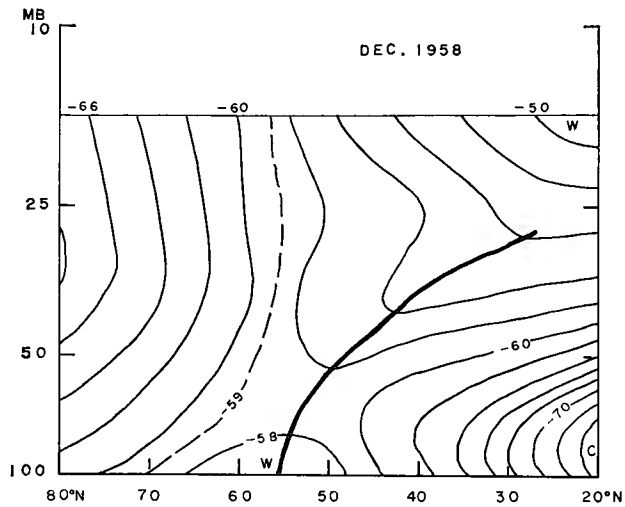

Fig. 5a. Meridional cross-section of monthly mean temperature, averaged zonally in December 1958. Warm belt is shown by thick line. The unit is °C.

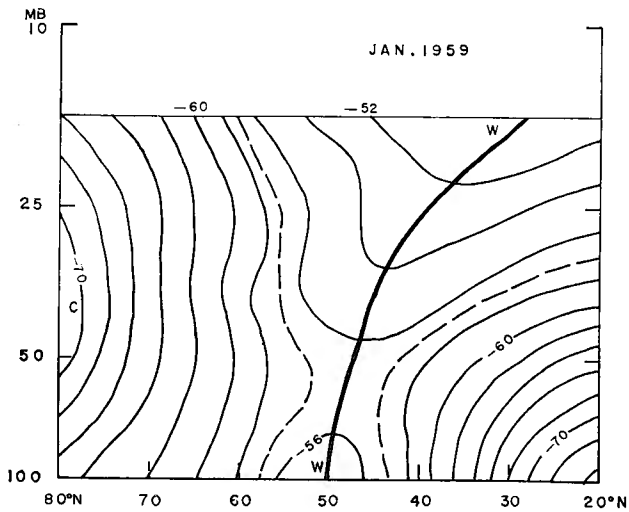

Fig. 5b. Same as Fig. 5a, except in January 1959.

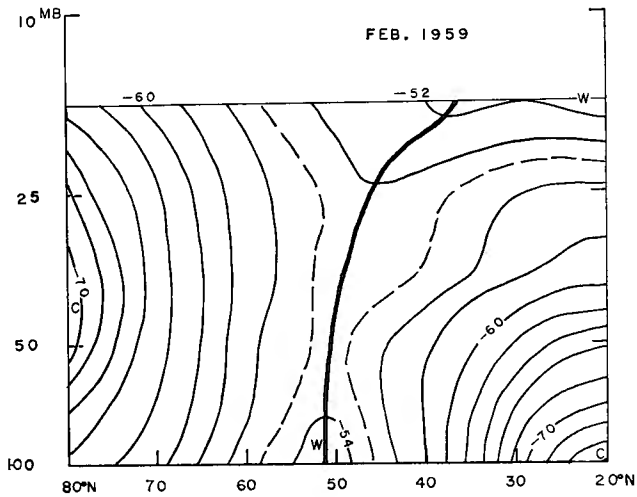

Fig. 5c. Same as Fig. 5a, except in February 1959.

or 30°N, and at the lowest level near 50°N. The values of these maxima and minima have no remarkable change from December 1958 to February 1959.

The warm belt can be found and shown by thick line in Figs. 5a, 5b, and 5c. Such warm belt in December tilts southwards with increasing height from about 56°N at 100 mb to about 26°N at 30 mb. With the progress of season, the southward tilt of the warmest region becomes weak.

Meridional cross-sections of month-to-month change of the zonally averaged

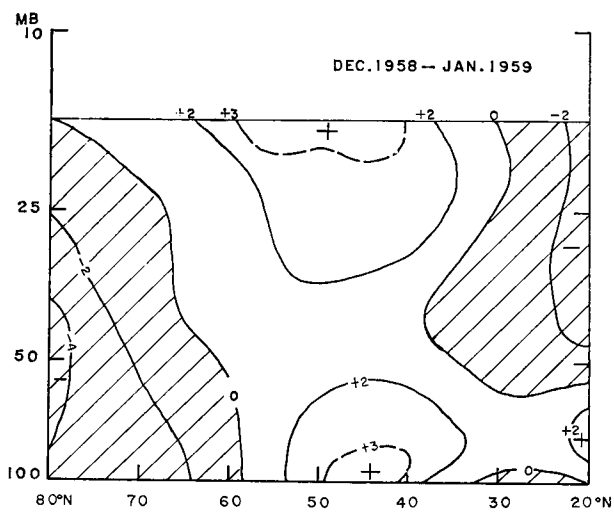

Fig. 6a. Meridional cross-section of month-to-month change of zonal mean temperature from December 1958 to January 1959 (°C/month). Region of cooling is shaded.

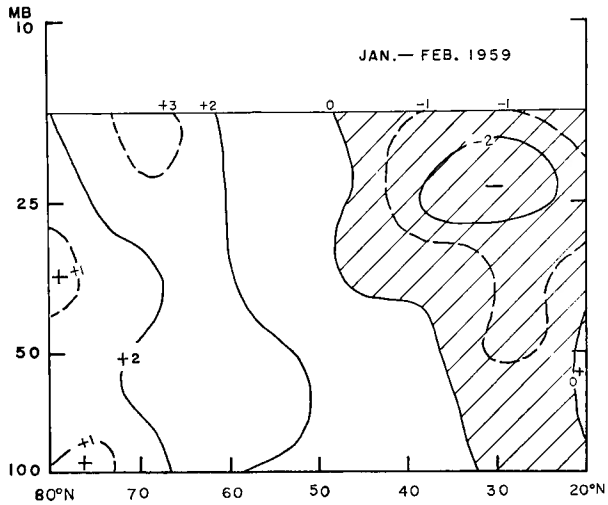

Fig. 6b. Same as Fig. 6a, except from January to February 1959.

temperature are drawn (Figs. 6a and 6b), using same data as in Figs. 5. From December to January, warming near 50 mb appears in the region approximately from 35°N to 60°N, and near 17.5 mb in the region from 30°N to 75°N. The greatest rates of warming are located near 100 mb, 45°N and 18 mb, 50°N, each of which might extend downwards and upwards. The temperature change from January to February is negative in the lower latitudes, and the minimum

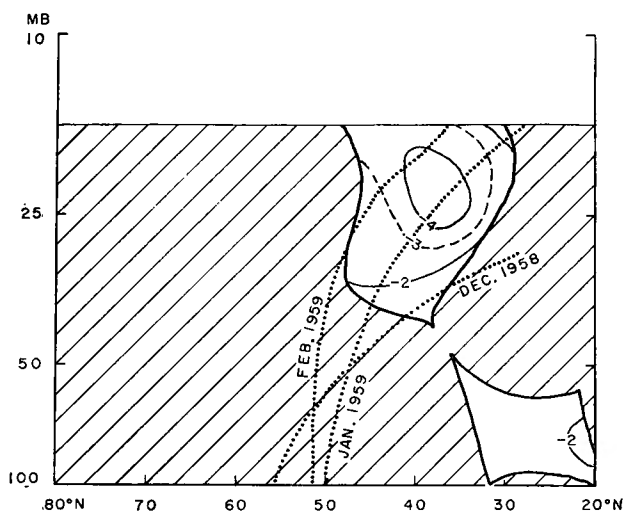

Fig. 7. Location of the region where monthly mean temperature averaged zonally rises from December 1958 to January and falls from January to February 1959. Within the region, the value of $\partial^2 T/\partial t^2$ is shown in unit of °C/(month)^2. The region without such temperature change is shaded. Dotted lines are the warm belts shown in Figs. 5a, 5b and 5c.

rate exist near 25 mb, 30°N. The remarkable increase located near 17 mb, 70°N may be related with the sudden warming in early February 1959 (Hare [1960]).

The region where the zonal mean temperature rises from December to January and falls from January to February is shown in Fig. 7. This region extends approximately from 30°N to 47°N at 25 mb level, and from 37°N to 45°N at 40 mb level. The value of $\partial^2 T/\partial t^2$, which may represent the remarkableness of the maximum temperature in January, is also shown in Fig. 7. Here T and t signify temperature and time, respectively. The absolute value of $\partial^2 T/\partial t^2$ more than 4°C/(month)^2 is found near 25 mb, 37°N. This region is scanned by the warm belt shifting meridionally from December to February, as seen in Fig. 7.

Figs. 8a, 8b and 8c illustrate the hemispheric distributions of monthly mean temperature of 10-25 mb layer in December 1958, January and February 1959, respectively. In December, the minimum temperature lower than −70°C can be found over the north of Europe, and the maximum warmer than −45°C near

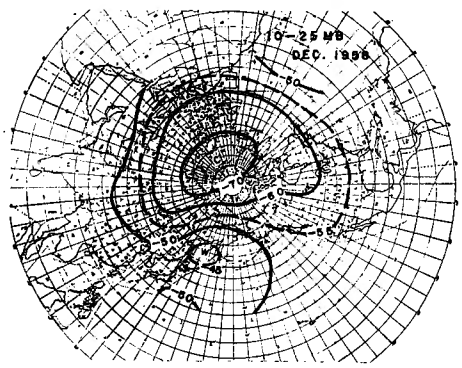

Fig. 8a. Monthly mean temperature of 10-25mb layer in December 1958 (°C).

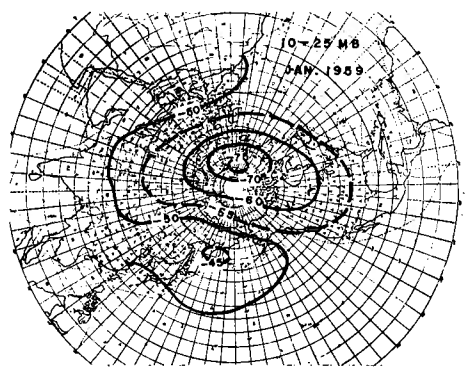

Fig. 8b. Same as Fig. 8a, except in January 1959.

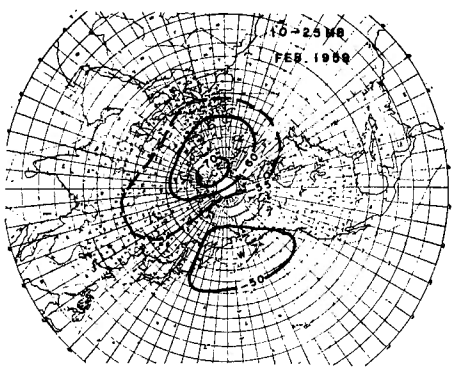

Fig 8c. Same as Fig. 8a, except in February 1959.

Kamchatka. The minimum temperature colder than −75°C appears, in January 1959, over Greenland, and the maximum temperature area remains stationary near Kamchatka. From January to February 1959, the both areas of the maximum and minimum temperature move slightly eastwards. In all the 3 months, the areas of maximum and minimum temperatures are located slightly the west of the centers of Aleutian anticyclone and polar vor-

tex on monthly mean 10 mb maps, respectively, except the area of minimum temperature in February which appears over nearly same area as the center of vortex (Figs. 9a, 9b and 9c).

The hemispheric distributions of the change of monthly mean temperature of 10–25 mb layer for December 1958-January 1959 and January-February 1959 are shown in Figs. 10a and 10b. From December to January, remarkable increase of temperature greater than

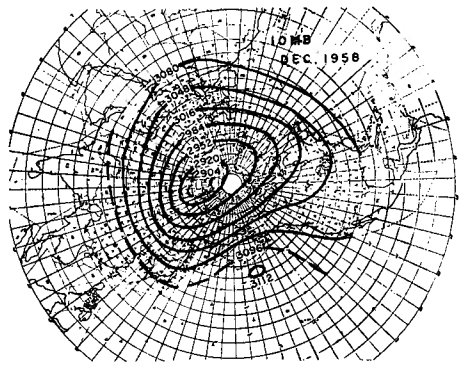

Fig. 9a. Monthly mean contour map at 10 mb in December 1958 (10 gpm).

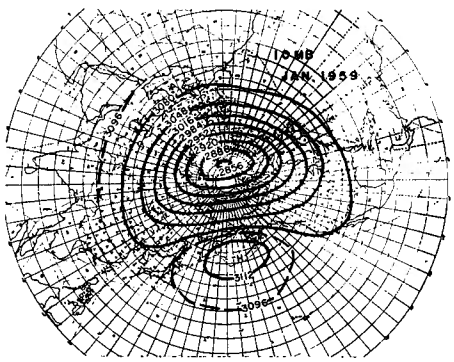

Fig. 9b. Same as Fig. 9a, except in January 1959.

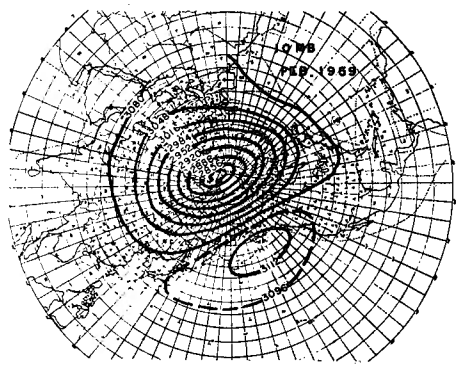

Fig. 9c. Same as Fig. 9a, except in February 1959.

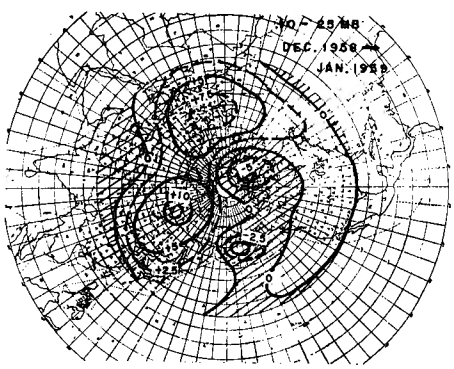

Fig. 10a. Change of monthly mean temperature of 10–25mb layer from December 1958 to January 1959 (°C. month). Area of cooling is shaded.

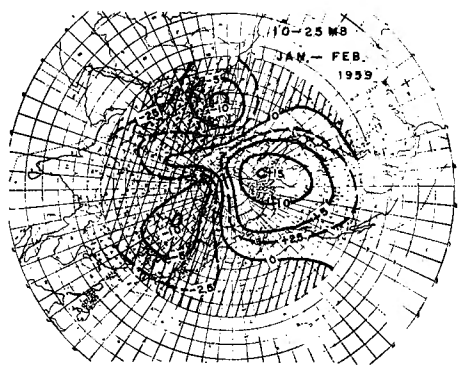

Fig. 10b. Same as Fig. 10a, except from January to February 1959.

12.5°C/month and 7.5°C/month can be found over Siberia and Europe, respectively. The banded area extending from northern Canada to central Pacific has decreasing temperature. From January to February, the greatest decrease of temperature is found over the same areas as the greatest increase from December to January. Warming stronger than 15°C/month exists over northern Canada where the strongest cooling is located in the previous months. The areas of warming from December to January and cooling from January to February is shown in Fig. 11, and the value of $\partial^2 T/\partial t^2$ within the area is also shown. It is clear that Siberia and Europe are the most active areas for the temperature change in question here, with $\partial^2 T/\partial t^2$ lower than -20 and -15°C/(month)^2, respectively.

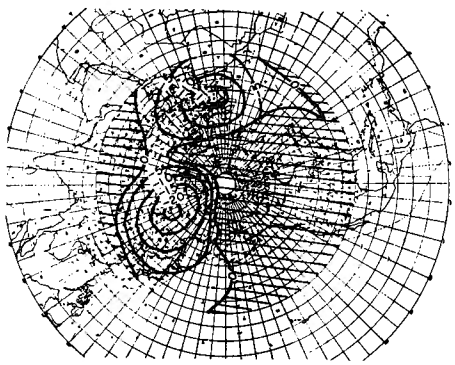

Fig. 11. Location of the area where monthly mean temperature of 10–25mb layer rises from December 1958 to January 1959 and falls from January to February 1959. Within the area, the value of $\partial^2 T/\partial t^2$ is shown in unit of °C (month)^2. The area without such temperature change is shaded.

Monthly mean contour patterns at 10 mb shown in Figs. 9a, 9b and 9c show that two deep troughs are located over Siberia and eastern Canada. Another trough with less intensity is located east of Europe. Significant change of the temperature in question does not appear over Aleutian anticyclone, suggested by Warnecke [1962b], but over or near troughs.

5. Concluding remarks

Hemispheric analysis of monthly mean thickness of 10–25 mb layer for 1958–59 shows that the zonal mean temperature at middle latitudes has a maximum in January and its associated change. The fact that similar changes can be found in all the winters analyzed makes us presume that this is a characteristic phenomenon in the normal seasonal variation. Exploration of dynamical and physical processes should be made, in addition to more detailed and extensive analyses of this phenomenon.

Acknowledgements

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