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ANNUAL VARIATION OF HEMISPHERICAL DISTRIBUTIONS OF TEMPERATURE IN THE MIDDLE STRATOSPHERE

BY

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ABSTRACT

It is discussed that for determination of large-scale distribution of temperature in the stratosphere, analysis of thickness of layer bounded by two isobaric surfaces is more promising than analysis of the observational data of temperature. Monthly mean temperature patterns up to about 18 mb surface in the stratospere are presented for 15 months from April 1958 to June 1959. The main characteristic features of the annual variation of temperature in the stratosphere are depicted.

1. Introduction

Seasonal variation of the atmospheric general circulation is one of the most important problems in science of meteorology. Concerning the lower atmosphere or the troposphere, fairly dense observational network has been established and it makes us possible to depict the features of the general circulation, except the tropical zone where the network is still now sparse. Much efforts of meteorologists are now directed to establish numerical models of the general circulation and its characteristic variation in the troposphere.

Since discovery of the stratosphere by Teisserenc de Bort in 1902, the observational network has been too sparse to describe the hemispherical conditions in the stratosphere for a long time. Recent substantiation of radiosonde network makes us possible to analyze the hemispherical conditions up to 10 mb surface or about 30 km height. Several attempts of analysis have been made for temperature, wind and pressure conditions [T. Murakami (1962), A. D. Belmont (1963) and L. Peng (1963 and 1965)]. Many of them treated 3-month averaged conditions. Although the results of these analyses could show the rough features of the annual variation, it might oblige us to overlook some characteristic change of shorter period. In this paper, hemispherical analyses of monthly mean temperature conditions and their changes in the middle stratosphere will be attempted by the aid of thickness pattern.

2. Determination of temperature conditions by analysis of thickness of a layer bounded by two isobaric surfaces

Air temperature measurement with radiosonde is usually sufferred from the various sources of error, and the overall probable error of the measurement might be about ±0.5°C, after M. Ference, Jr. (1951). F. G. Finger, et. al. (1963), however, describe that the observed temperature data in the stratosphere corrected for solar heating effect of the instrument at a given station fluctuates in an unreasonable manner as much as 6°C to 8°C from one observation to the next. Such fact makes us hesitate to analyze hemispherically the temperature conditions in the stratosphere with temperature data of radiosonde, unless the error might be diminished by averaging in time or space.

Temperature averaged over a layer bounded by two isobaric surfaces can be easily obtained from thickness of the layer, under a reasonable assumption that moisture influence to the thickness is negligibly small in the stratosphere. The thickness pattern can be easily got by graphical or numerical subtraction of the contour patterns between two isobaric surfaces. Large-scale analysis of pressure or contour pattern may generally be given more reliability than that of temperature by meteorologists.

In an analysis of contour of an isobaric surface in the stratosphere, the wind data are usually given most weight, while the reported height of the surface is employed primarily to determine the numerical value used in labeling the contour [Finger, et. al., (1963)]. If the error of rawin (radio-wind) observation in the middle stratosphere may be regarded as 3 m/sec after Ference (1951), the corresponding error of the geopotential gradient of an isobaric surface may, under the geostrophic balance, be equal approximately to 40 gpm/1000 km at 60°N, 30 gpm/1000 km at 40°N and 15 gpm/1000 km at 20°N, respectively. Since the thickness of 10−25 mb layer is equal to about 6000 gpm and proportional to the mean temperature of the layer (=200°K∼240°K), estimation of the temperature within error of 3 % requires an error less than 180 gpm for thickness determination, and the error less than 90 gpm for the contour of each isobaric surface. The error of geopotential gradient given above shows that the error of 90 gpm for the contour might be given by horizontal distance of 2300 km at 60°N, 3100 km at 40°N and 6000 km at 20°N, respectively. During the periods of IGY and IGC, the distance between two adjacent stations may, in the most cases, be shorter than such distance, except over Asia. It may be more promising to adopt the thickness pattern for determination of large-scale temperature pattern than to use the observational data of temperature itself.

3. Annual variation of the zonal mean temperature in the stratosphere

A series of hemispherical contour maps, daily and monthly mean, of 10 mb, 25 mb and so on, has been published by R. Scherhag. Using the monthly mean maps of 10 mb and 25 mb [G. Warnecke (1962) and Scherhag, et. al. (1962)], the zonal mean temperature of 10−25 mb layer is obtained from April 1958 to June 1959 for latitudinal range from 20°N to 80°N (Fig. 1).

It is well known that some stratospheric conditions in same season varies remarkably year to year [C. V. Wilson and W. L. Godson (1963)]. Some general features of the annual variation, however, can be seen from analysis of a particular year. Establishment of the normal annual variation of the stratosphere should be made in the future.

In Fig. 1, general feature of high temperature in summer season and low temperature in winter can be found at all the latitudes from 20°N to 80°N. In summer, an equatorward gradient of temperature predominates, and the greatest difference between 20°N and 80°N is about 11°C in July 1958. A poleward gradient can be found in winter, and the greatest contrast appears in December 1958, with a temperature difference of about 18°C between 20°N and 80°N. Reversal of the gradient occurs in spring (about May 1958, and between February and March 1959) and in early fall (between August and September 1958).

Concerning the month-to-month change of the zonal mean temperature at high latitudes, warming or non-cooling from October to November 1958 is noticed. This change appears only at 80°N and 70°N, and may probably be accompanied with appearance of Aleutian anticyclone [B. W. Boville (1960)]. Very strong warming from February to March and cooling from March to April 1959 occur at 80°N and 70°N. These changes may be resulted from the *final warming* [E. F. Hare (1960)].

At the middle latitudes, the temperature rises from November 1958 to January 1959, and falls subsequently. The fact that this change has an opposite sense to seasonal change of insolation attracts the present author's interests. Some detailed analysis of this phenomenon will be presented elswhere [R. Yamamoto and K. Kawahira (1966)].

The results of harmonic analysis of the zonal mean temperature are shown in Table 1. Annual mean temperature decreases with increasing latitudes, and −48.0°C

Table 1. Harmonic analysis of annual variation of the zonal mean temperature of 10−25 mb layer, for 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
20	−48.0	1.8	middle July	1.5	early December early June

at 20°N and −51.9°C at 80°N, respectively. The annual oscillation generally predominates at all the latitudes. The amplitude increases from low to high latitudes, and the phase is earlier at higher latitudes. The amplitude of semi-annual oscillation has no monotonic profile, but a maximum at the middle latitudes. The amplitude at 20°N is nearly equal to that of annual oscillation, and that at 40°N is nearly equal to a half. The phase is earlier at the lower latitudes, in contrast with that of the annual oscillation.

Meridional cross-sections of the monthly and zonal mean temperature are constructed above 100 mb surface (Figs. 2-1∼2-15), using the thickness pattern of

10−25 mb and 25−50 mb layers derived from Warnecke's (1962) and Scherhag's (1962) maps, and isothermal patterns on 25 mb, 50 mb and 100 mb surfaces by H. E, Muench (1962). Here, it is assumed that the temperature averaged over a layer represents that at the middle level of the layer.

This series of cross-sections show the characteristic features of the temperature distribution in summer season such that the warmest region appears at highest latitude and level, and the coldest one at the lowest latitude and level, as seen in June, July, August 1958 and June 1959. In winter season, a warm belt can be found at the high and middle latitudes, as in October, November, December 1958, January, February and March 1959. The belt generally tilts southwards with altitude, and the tilting becomes greater with progress of season until December 1958. In September 1958 or transitional period from summer to winter, a relatively cold region appears near 30 mb surface from 50°N to 70°N, and warm region at 80 °N in the lower layer. Transition from winter to summer may be seen in period from March to May 1959. The temperature distribution at the high latitudes in March 1959 may be essentially influenced by the *final warming*, and the warmest region is located near 80°N, 20 mb. In April and May 1959, relatively warm region appears near 80°N in the layer lower than 25 mb surface.

Figs. 3-1∼3-14 are the meridional cross-sections of month-to-month change of the zonal mean temperature drawn by using the same data as in Figs. 2-1∼2-15. Warming from spring to summer is remarkable at higher latitudes, but cooling can be found at the lower latitudes particularly in lower and higher layers (April-May, May-June, June-July 1958). From summer to fall, cooling occurs in almost whole region, except the lower and higher layers at the middle and low latitudes (July-August, August-September, September-October (1958). A warming at the high latitude and level from October to November 1958 may be accompanied with appearance of Aleutian anticyclone. The temperature changes from fall to winter at the middle and lower latitudes are rather complex, and the detailed analysis will be found elswhere [Yamamoto and Kawahira (1966)]. From January to March 1959, the temperature rises at the latitudes higher than 40°N, and falls at the lower latitudes. In a banded region extending from middle latitudes northward-upwards cooling appears from March to April 1959. From spring to summer, warming occurs in the whole region, except the lowest layer.

4. Annual variation of the hemispherical temperature distributions in the middle stratosphere

Hemispherical distributions of the monthly mean temperature of 10−25 mb layer have been obtained from the contour maps of 10 mb and 25 mb for April 1958 to June 1959 (Figs. 4-1∼4-15). The distribution in summer has such general feature that the temperature is highest near the pole and it decreases with decreasing latitudes (June, July and August 1958 and June 1959). In a transitional period from summer to fall, the highest temperature can be found at the middle latitudes (September 1958). From October 1958 to February 1959, the temperature distribution may be called winter type, in which the coldest region is located near the pole and the temperature increases with decreasing latitude, except warm area in the northern Pacific where Aleutian anticyclone appears. During the transitional period from winter to summer, warmest area can be found near the pole or northeastern Siberia, and the coldest one over Ural or Europe (March, April and May 1959).

Hemispherical distributions of month-to-month change of temperature of 10–25 mb layer are given in Figs. 5-1～5-14. Warming can be found in the whole area from spring to summer, except lowest latitudes (April-May and May-June 1958). The rate of warming is larger at the higher latitudes. After the mid-summer, cooling predominates with larger rate at the higher latitudes from July to October 1958. From October to November 1958, a warming can be found over the northeastern Siberia, which may be connected with appearance of Aleutian anticyclone, although cooling appears in other area.

The pattern of temperature change from November 1958 to February 1959, which is closely connected with appearance of maximum of zonal mean temperature in January 1959 at the middle latitudes, is rather complex [Yamamoto and Kawahira (1966)]. A strong warming occurs near the pole from February to March 1959, which may be resulted from the *final warming*. It is noticed that the area of strong warming is surrounded by an area of cooling at the middle latitudes. From March to April 1959, cooling appears in the area where strong warming occured in the previous months. Such features may perhaps be connected with mechanism of the final warming.

5. Concluding remarks

The distributions of monthly mean temperature and its changes in the middle stratosphere are presented by the aid of the thickness pattern for 15 months. These results give a reliable basis for research about the mechanisms of annual variation and the characteristic changes of shorter period. More extensive analyses in the stratosphere should be made in order to establish the normal feature of annual variation for wind and pressure fields in addition to temperature.

Acknowledgements

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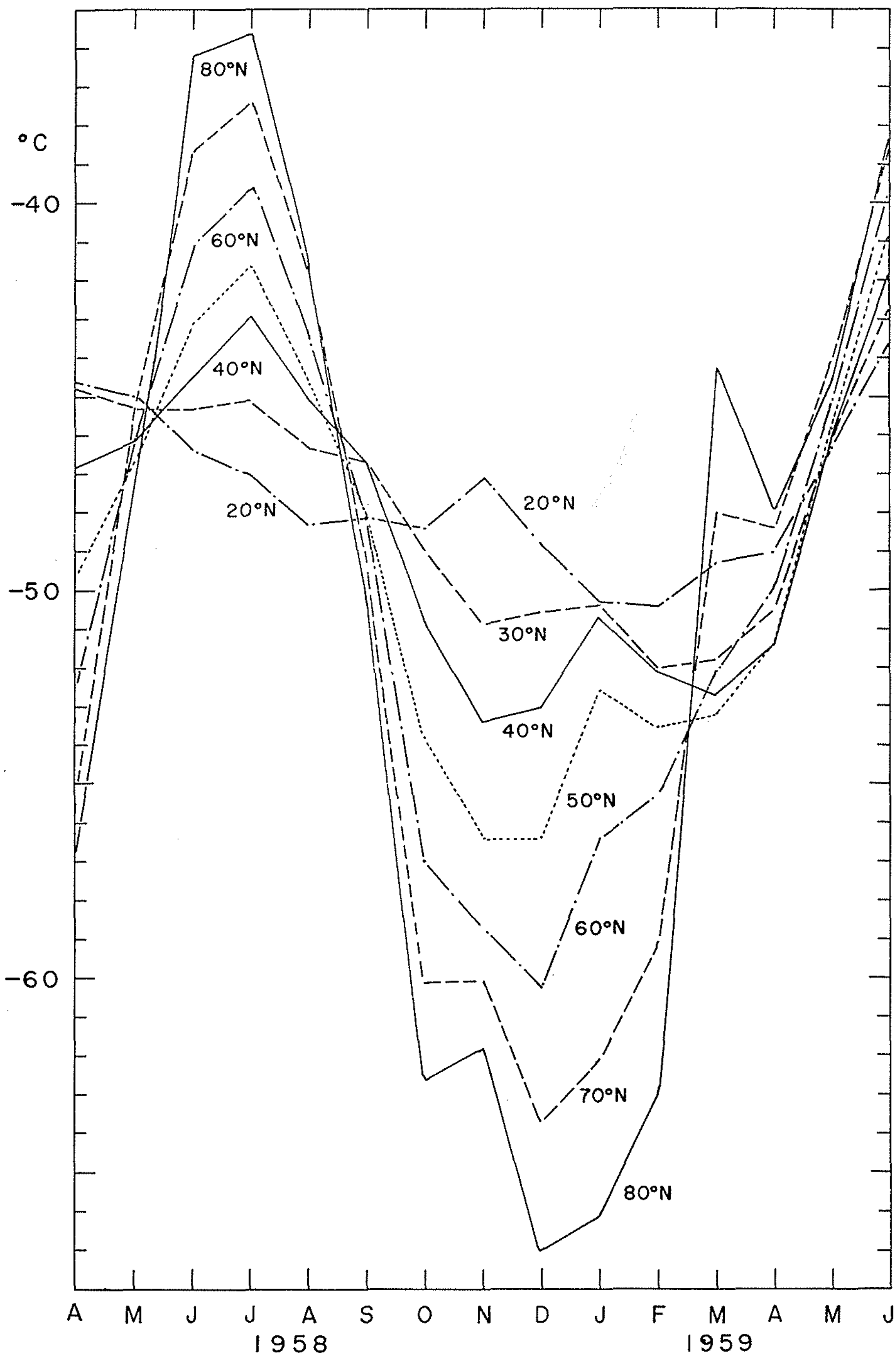

Fig. 1 Monthly mean temperature of 10−25 mb layer averaged zonally, derived from thickness pattern obtained from the stratospheric maps by G. Warnecke (1962) and R Scherhag, et. al. (1962)

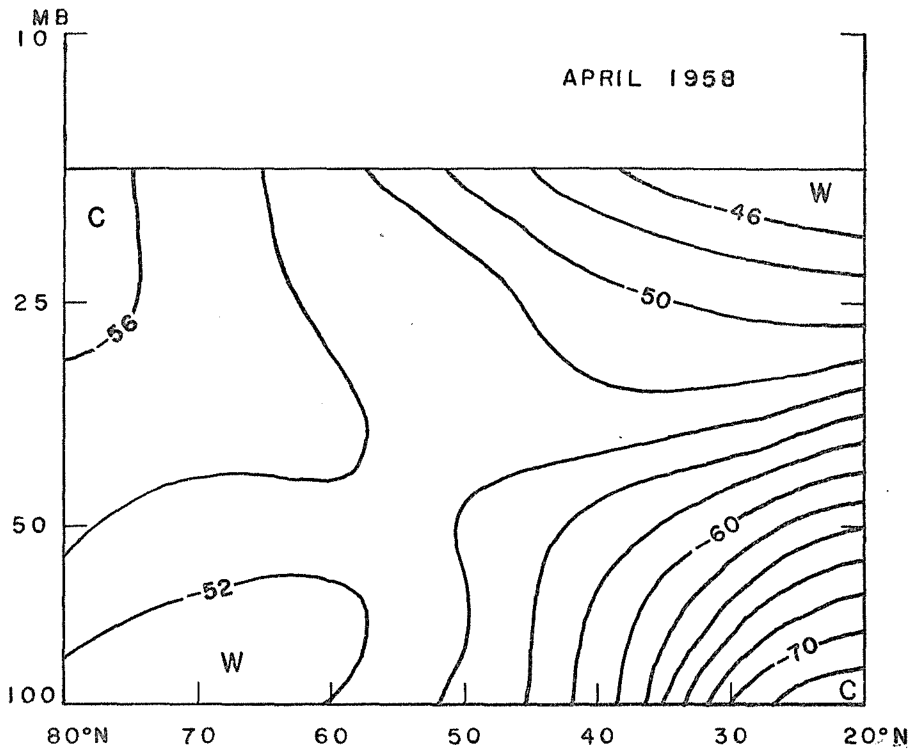

Fig. 2–1 Meridional cross-section of monthly mean temperature, averaged zonally in April 1958. The unit is degree centigrade.

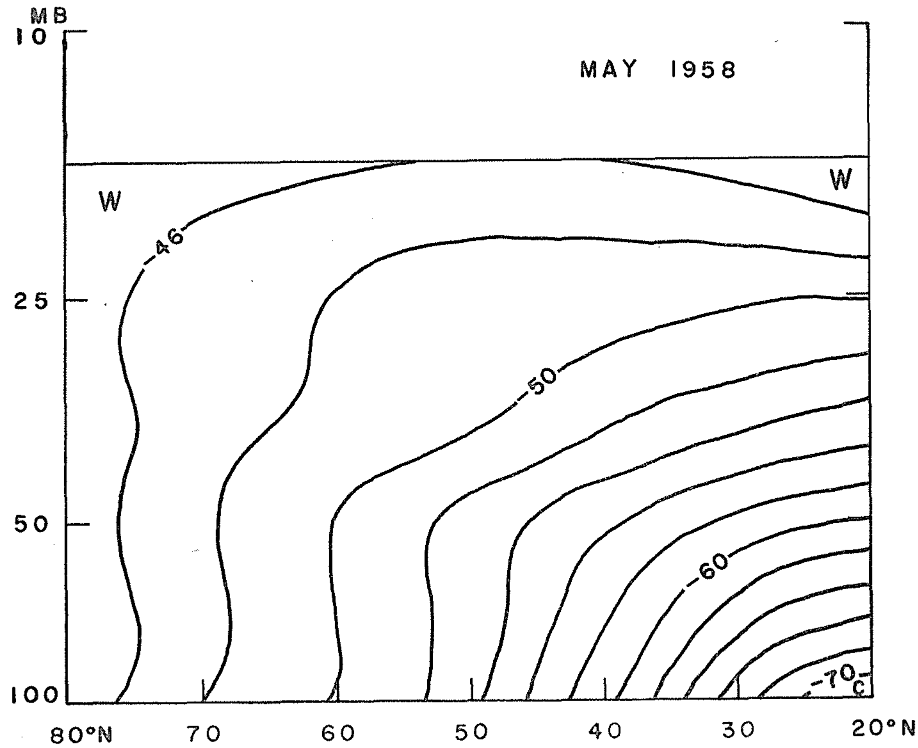

Fig. 2-2 Same as Fig. 2-1, except in May 1958.

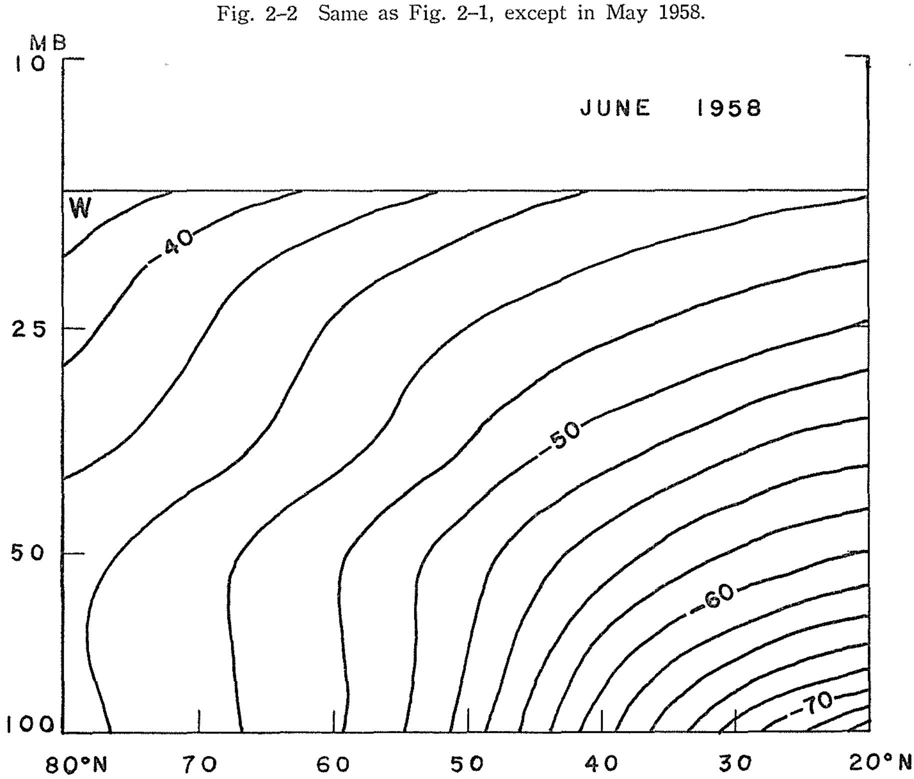

Fig. 2-3 Same as Fig. 2-1, except in June 1958.

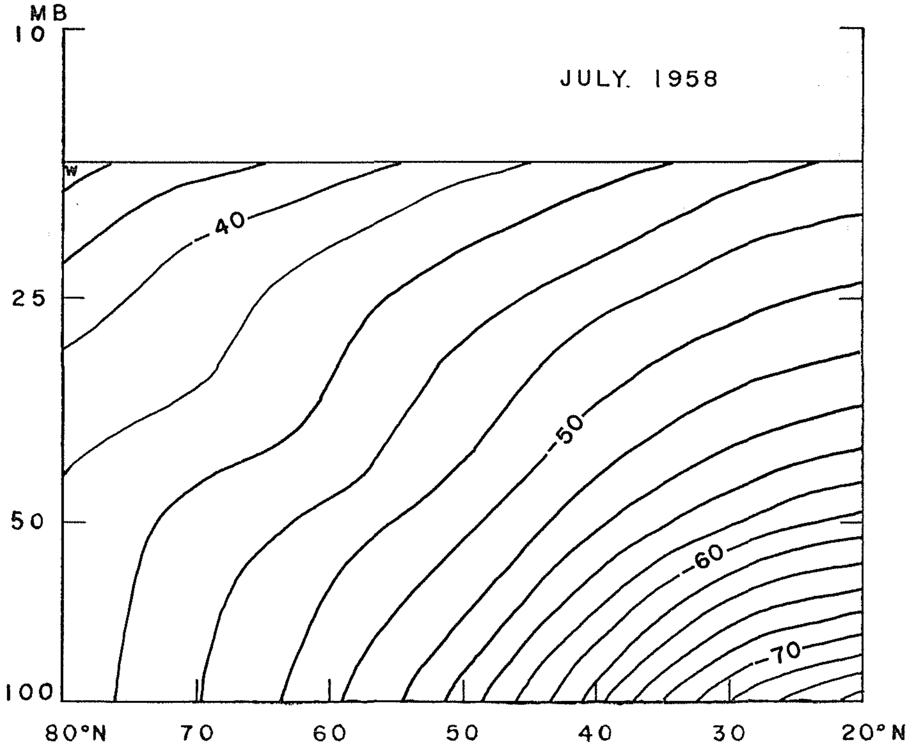

Fig. 2-4 Same as Fig. 2-1, except in July 1958.

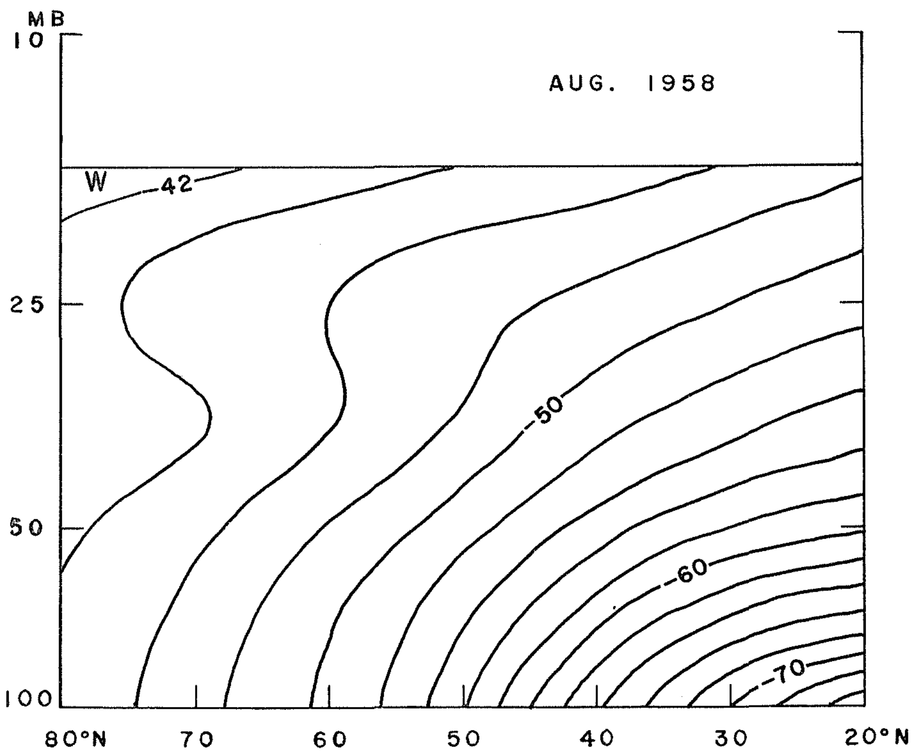

Fig. 2-5 Same as Fig. 2-1, except in August 1958.

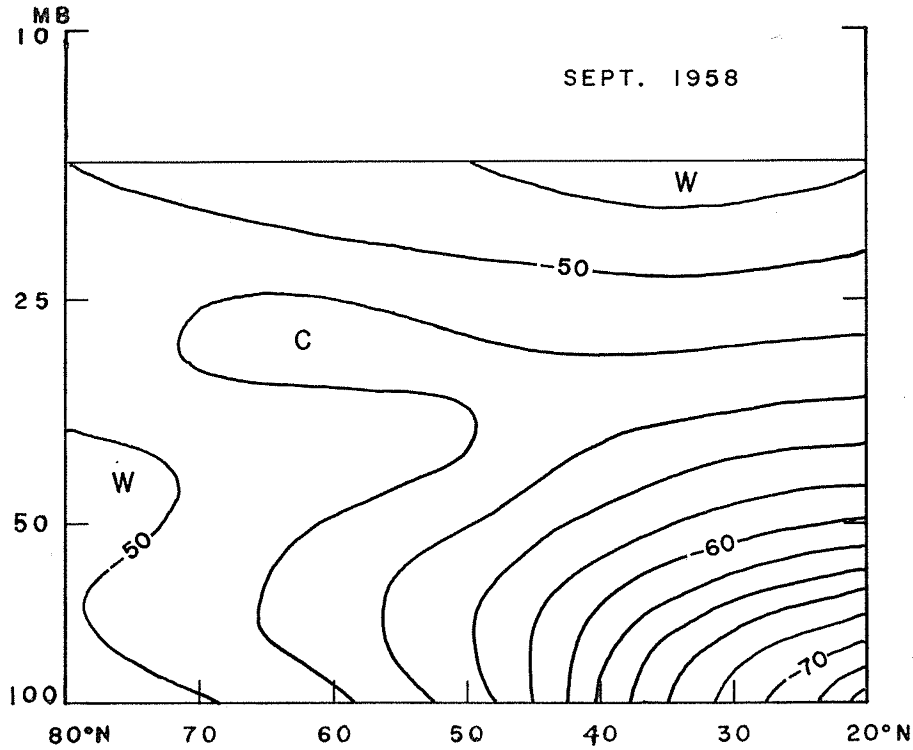

Fig. 2-6 Same as Fig. 2-1, except in September 1953.

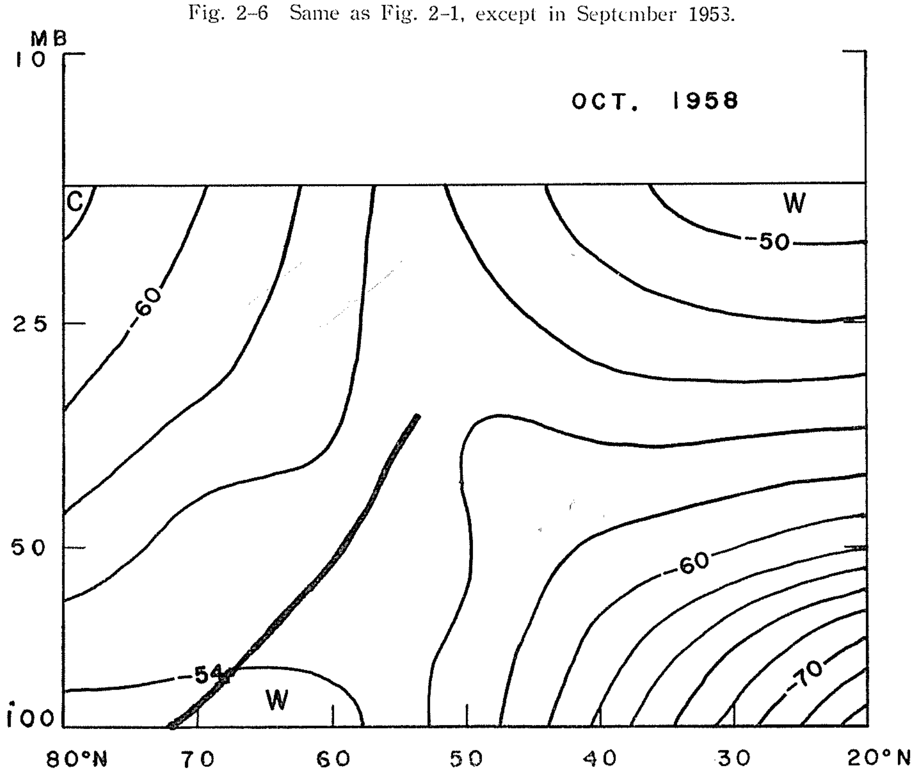

Fig. 2-7 Same as Fig. 2-1, except in October 1958.
The warm belt is shown by thick line.

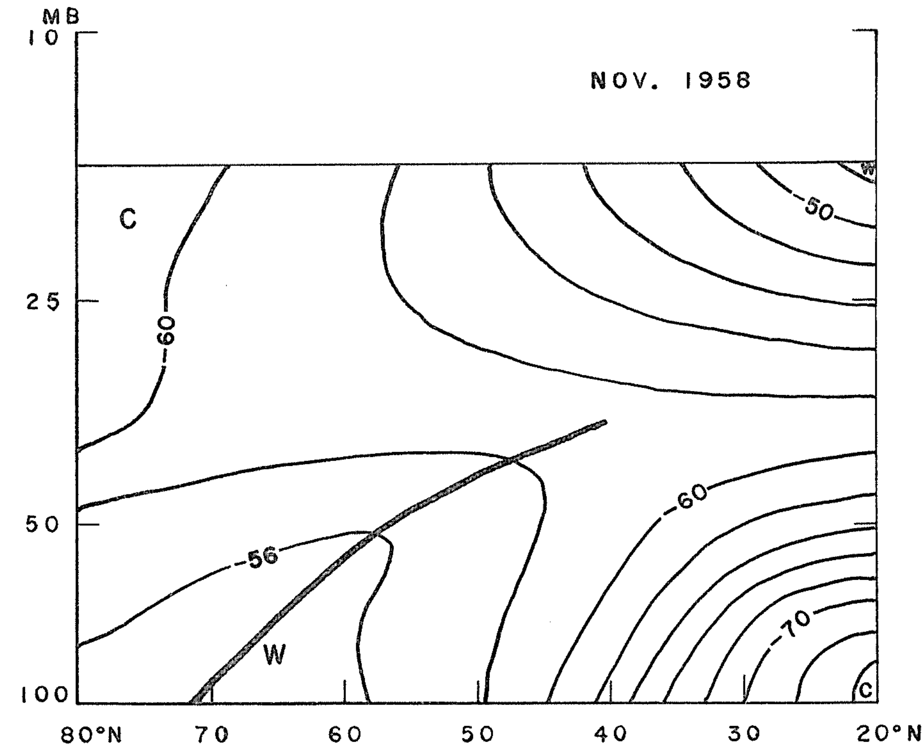

Fig. 2-8 Same as Fig. 2-7, except in November 1958.

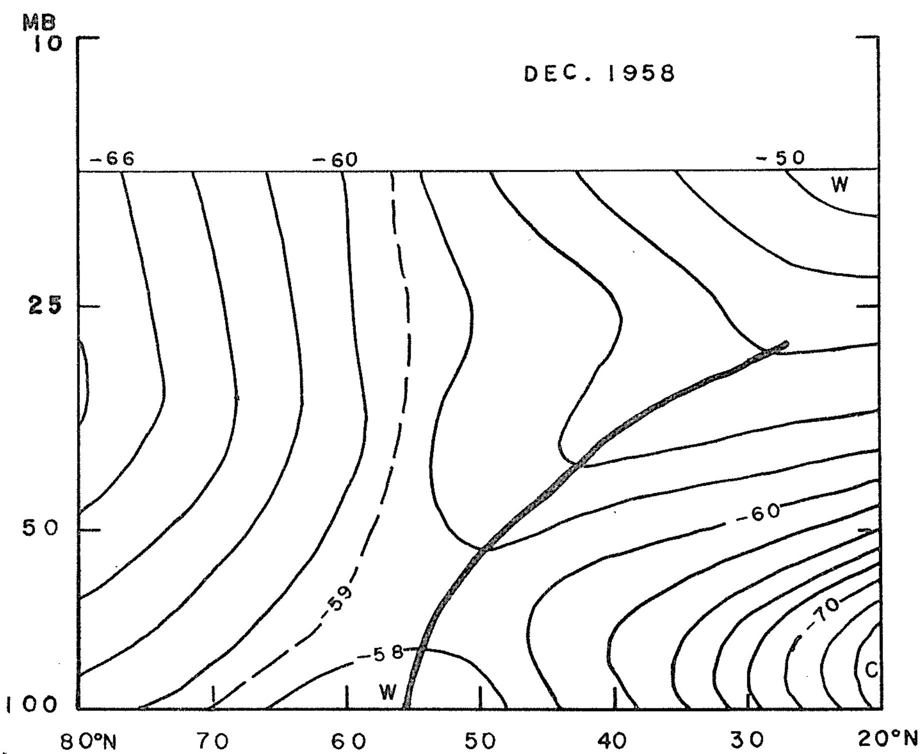

Fig. 2-9 Same as Fig. 2-7, except in December 1958.

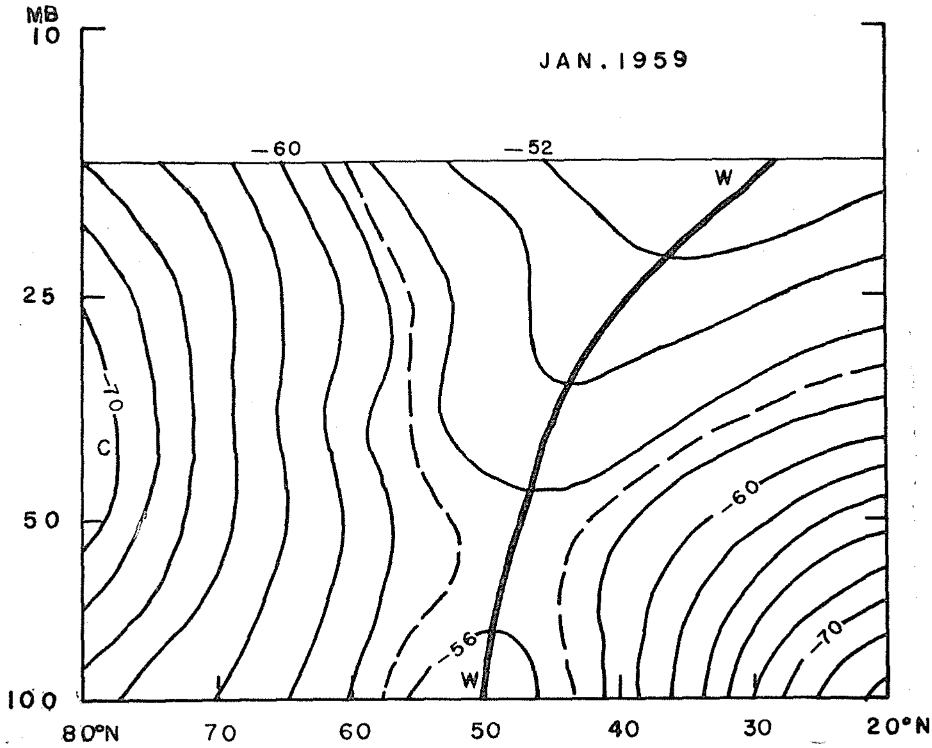

Fig. 2–10 Same as Fig. 2–7, except in January 1959.

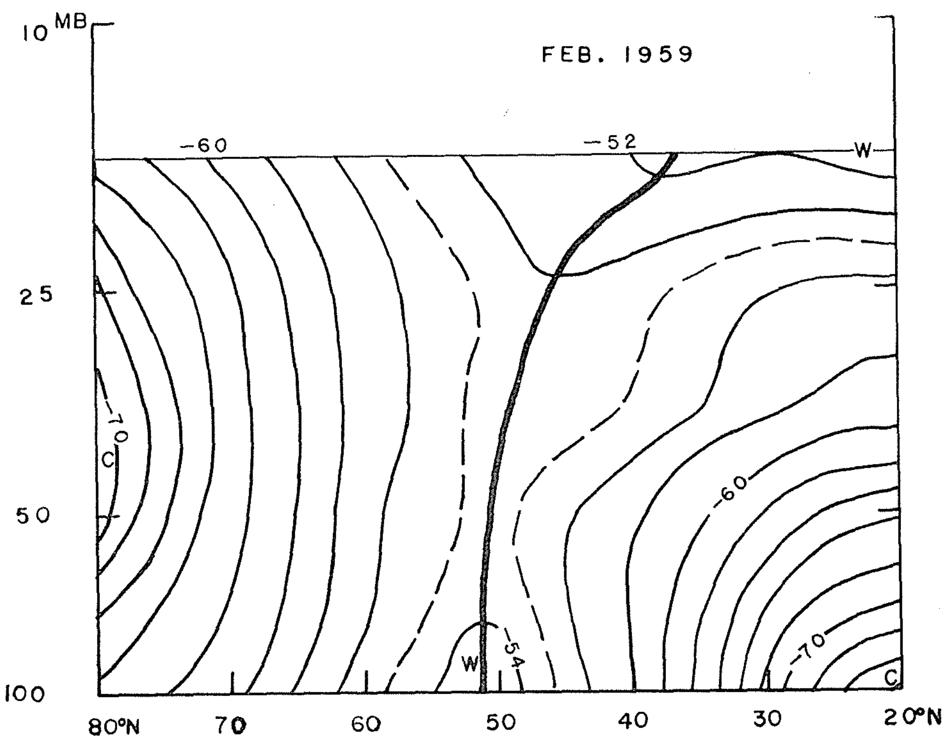

Fig. 2–11 Same as Fig. 2–7, except in February 1959

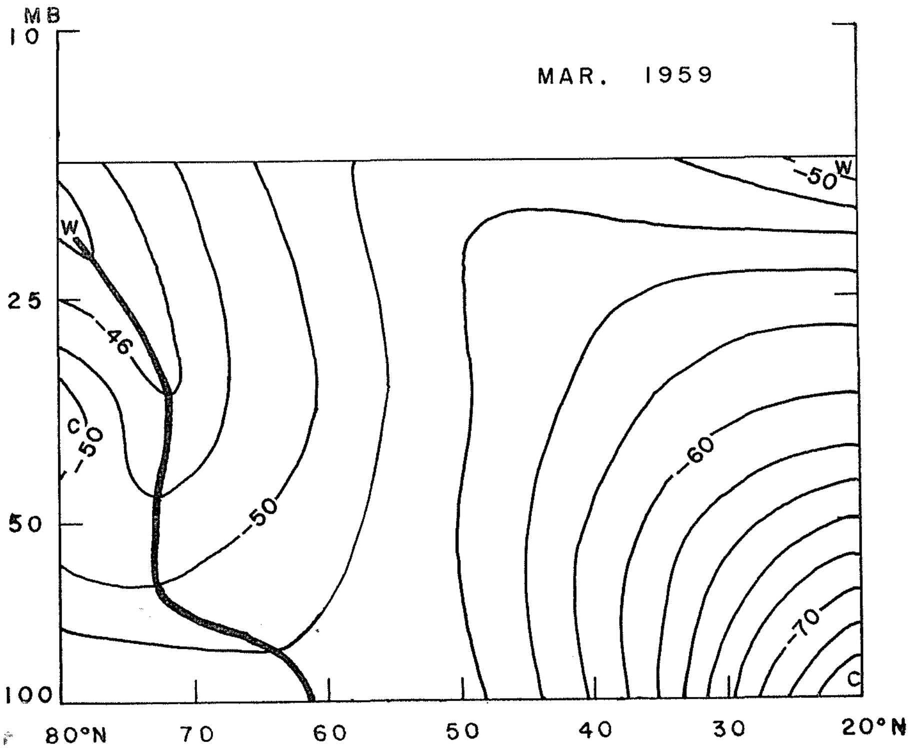

Fig. 2-12 Same as Fig. 2-7, except in March 1959

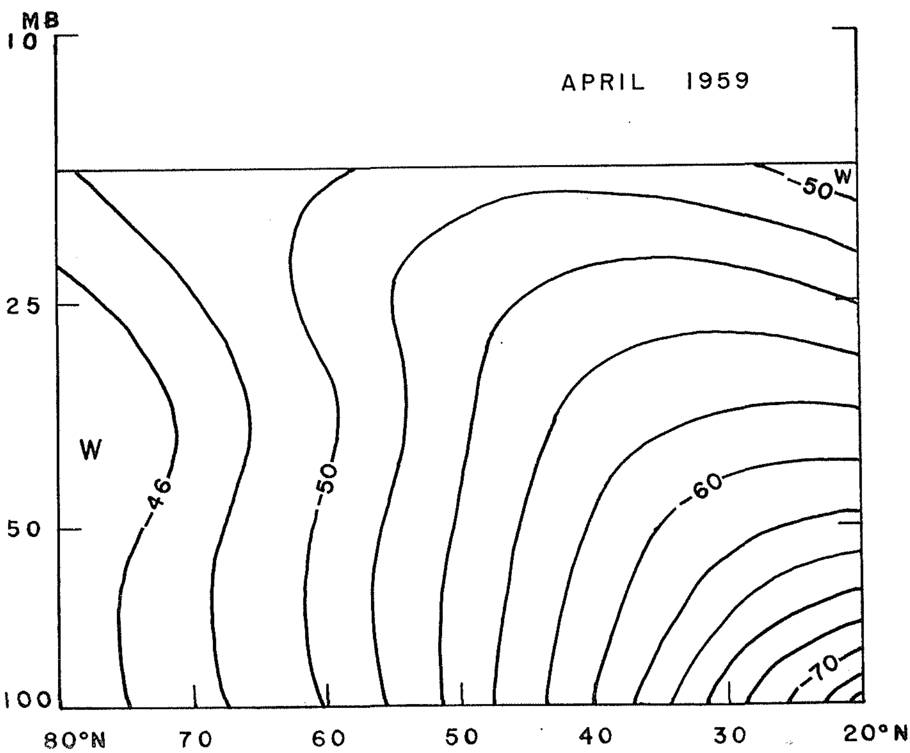

Fig. 2-13 Same as Fig. 2-1, except in April 1959.

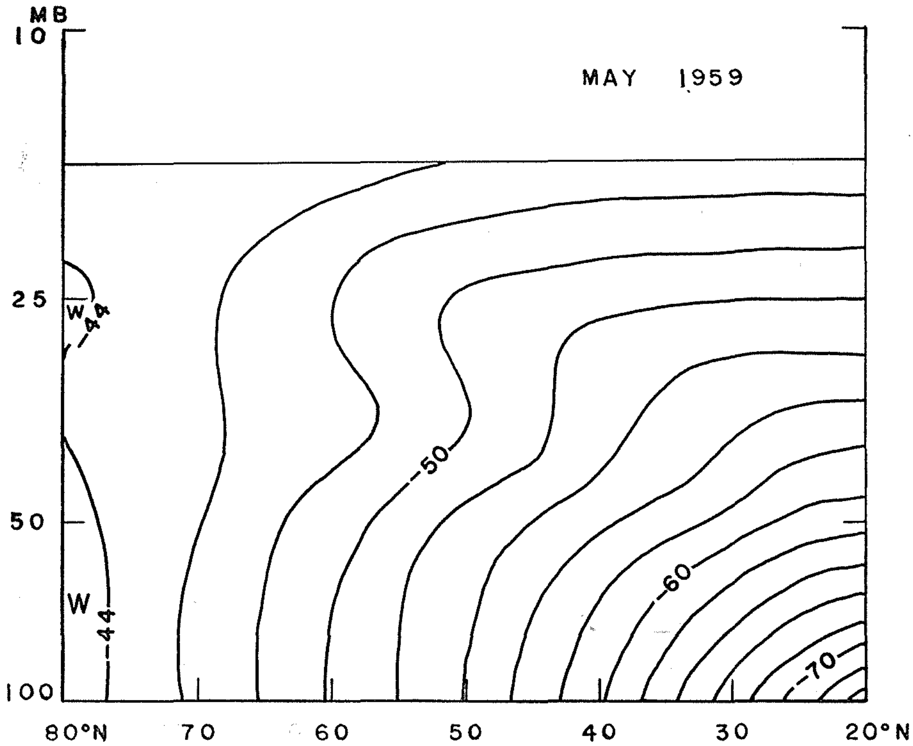

Fig. 2-14 Same as Fig. 2-1, except in May 1959.

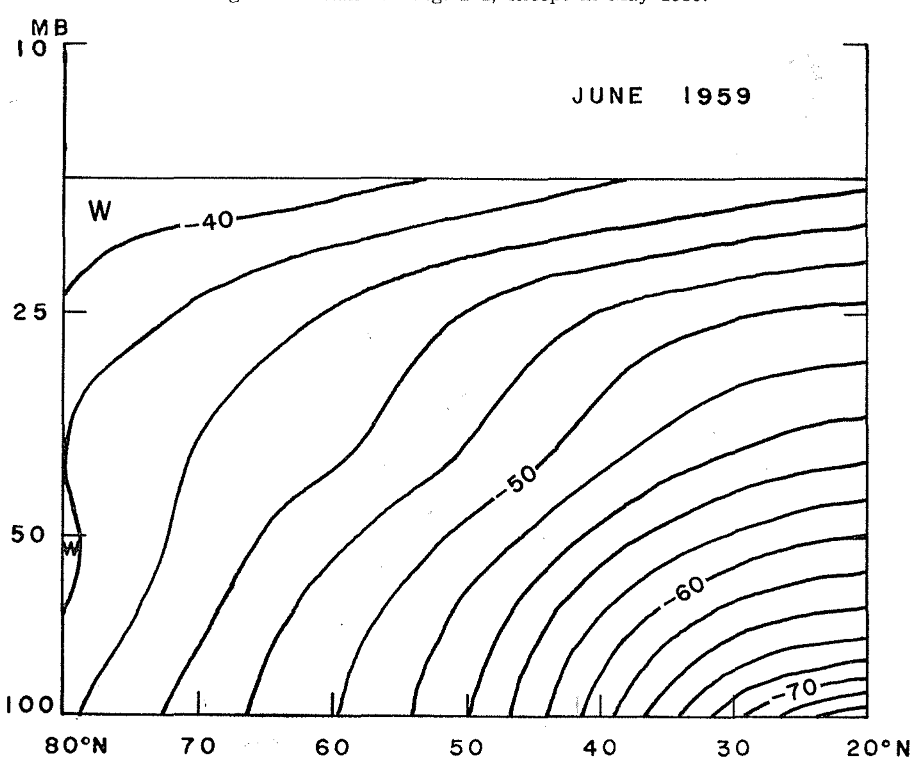

Fig. 2-15 Same as Fig. 2-1, except in June 1959.

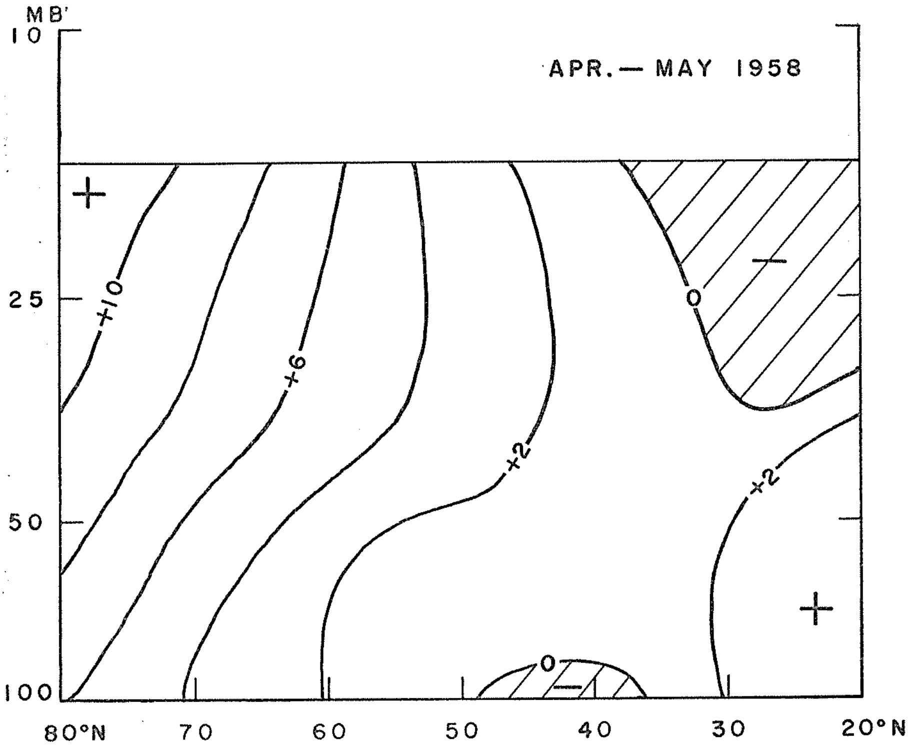

Fig. 3-1 Meridional cross-section of month-to-month change of zonal mean temperature (°C/month) from April to May 1958. Region of cooling is shaded.

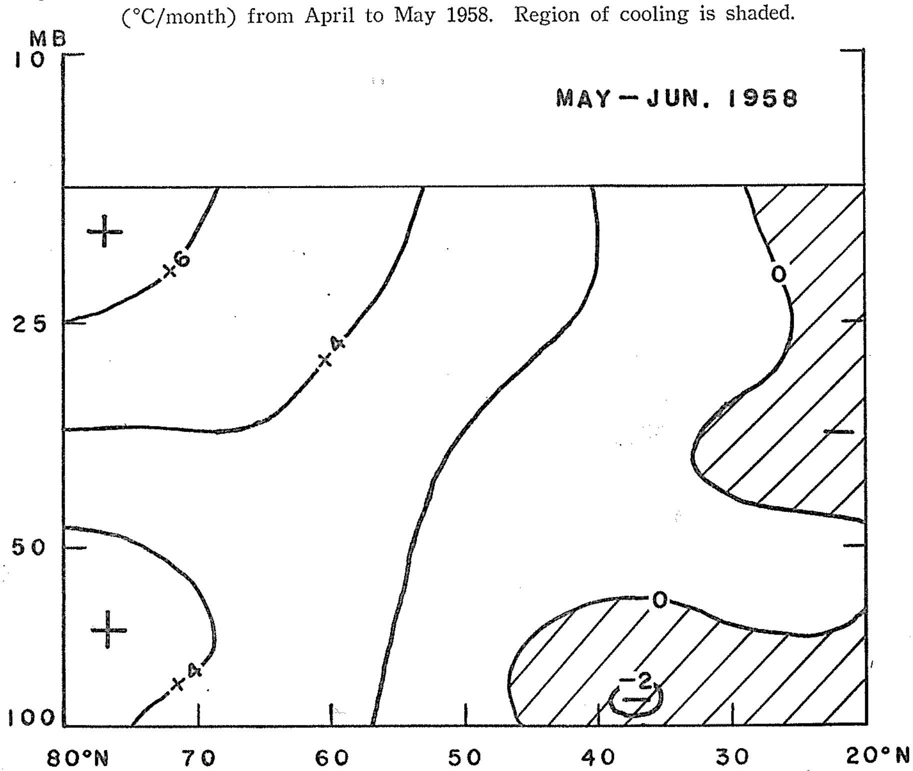

Fig. 3-2 Same as Fig. 3-1, except from May to June 1958.

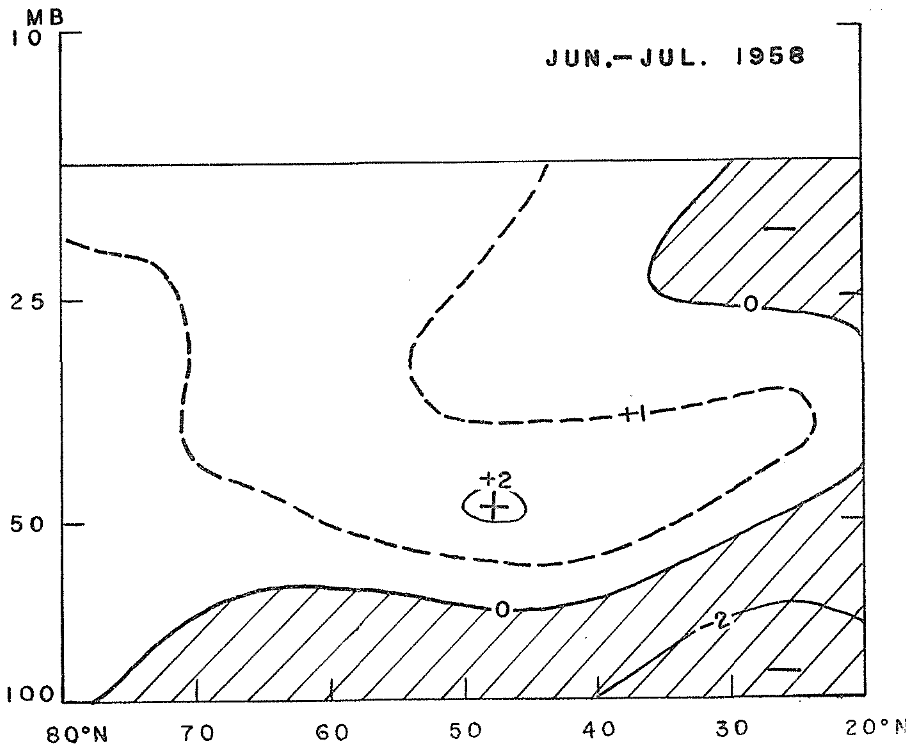

Fig. 3–3 Same as Fig. 3–1, except from June to July 1958.

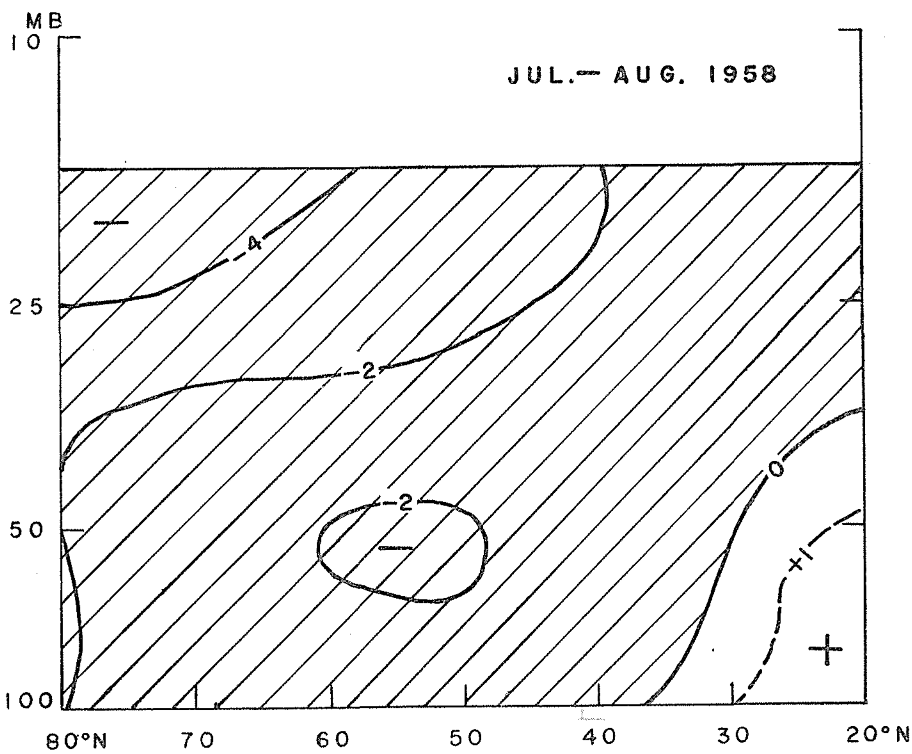

Fig. 3–4 Same as Fig. 3–1, except from July to August 1958.

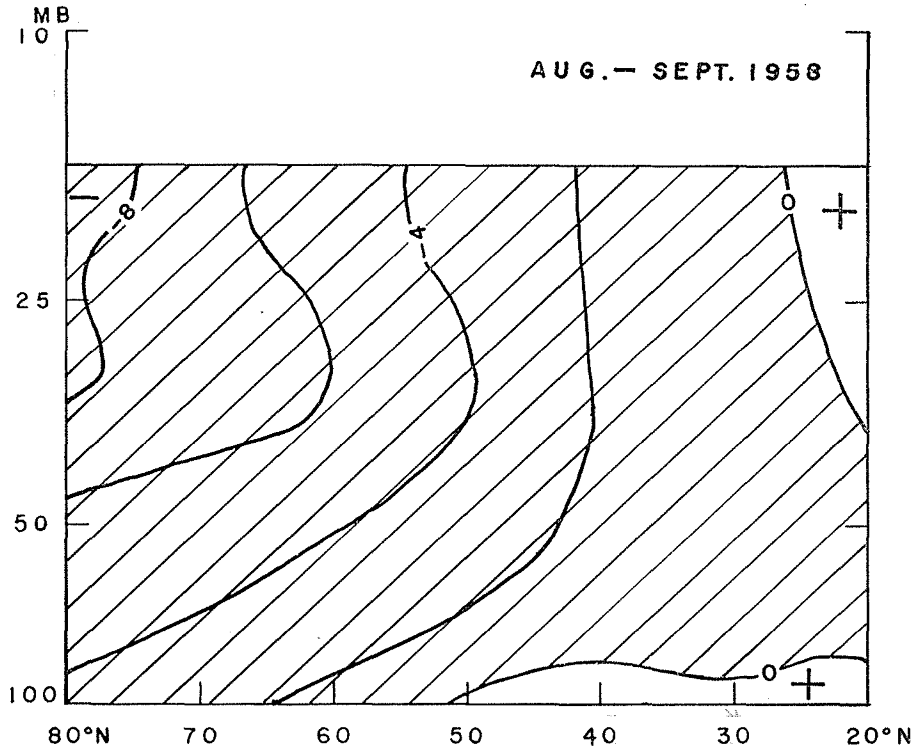

Fig. 3-5 Same as Fig. 3-1, except from August to September 1958

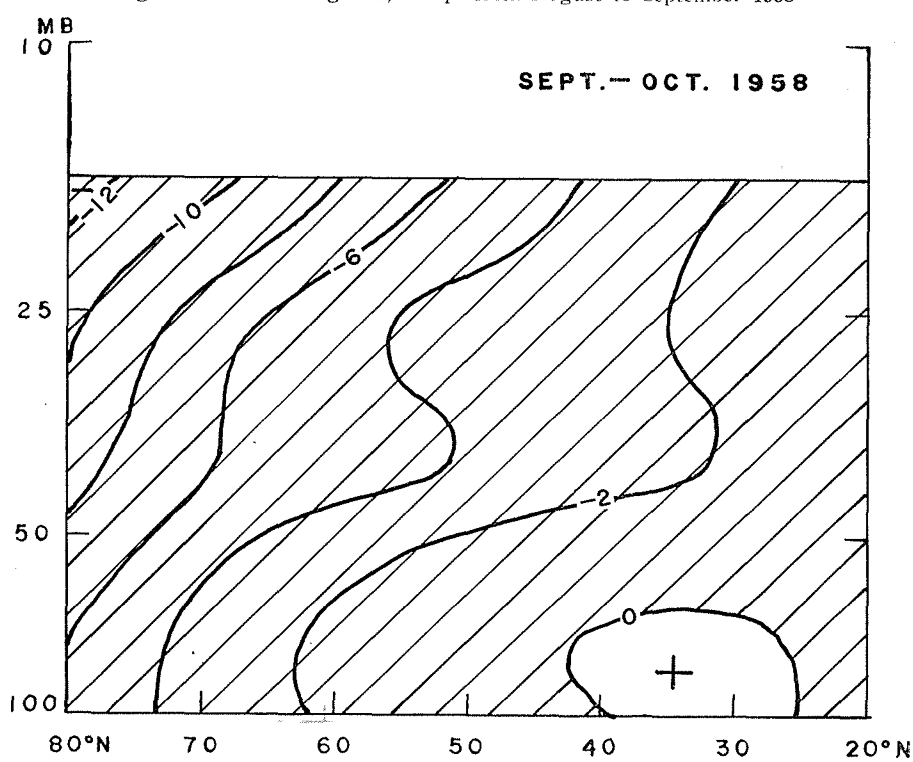

Fig. 3-6 Same as Fig. 3-1, except from September to October 1958.

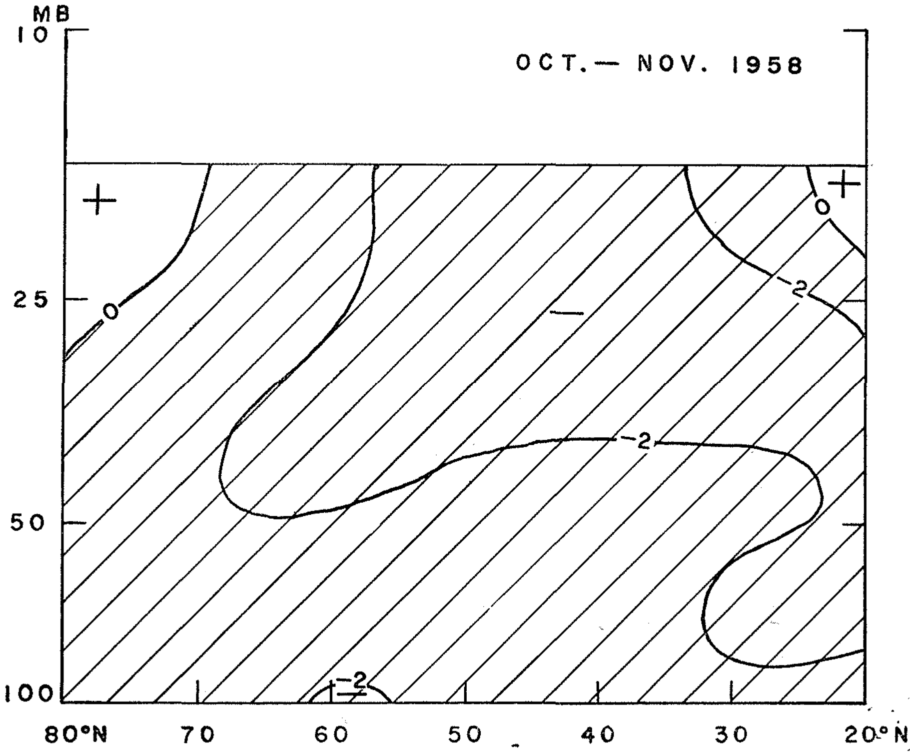

Fig. 3-7 Same as Fig. 3-1, except from October to November 1958.

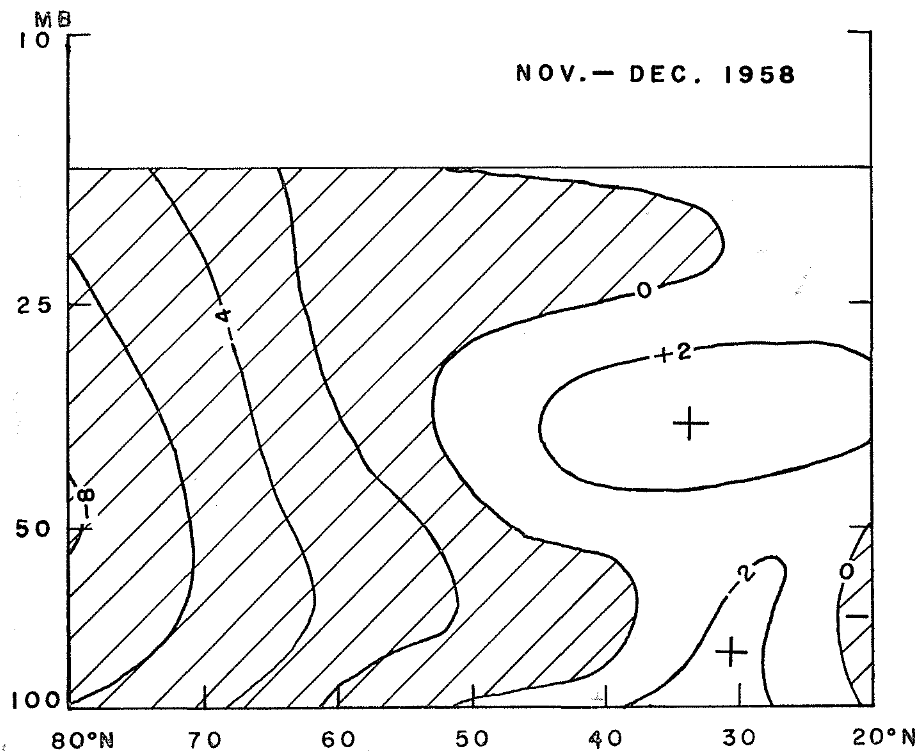

Fig. 3-8 Same as Fig. 3-1, except from November to December 1958.

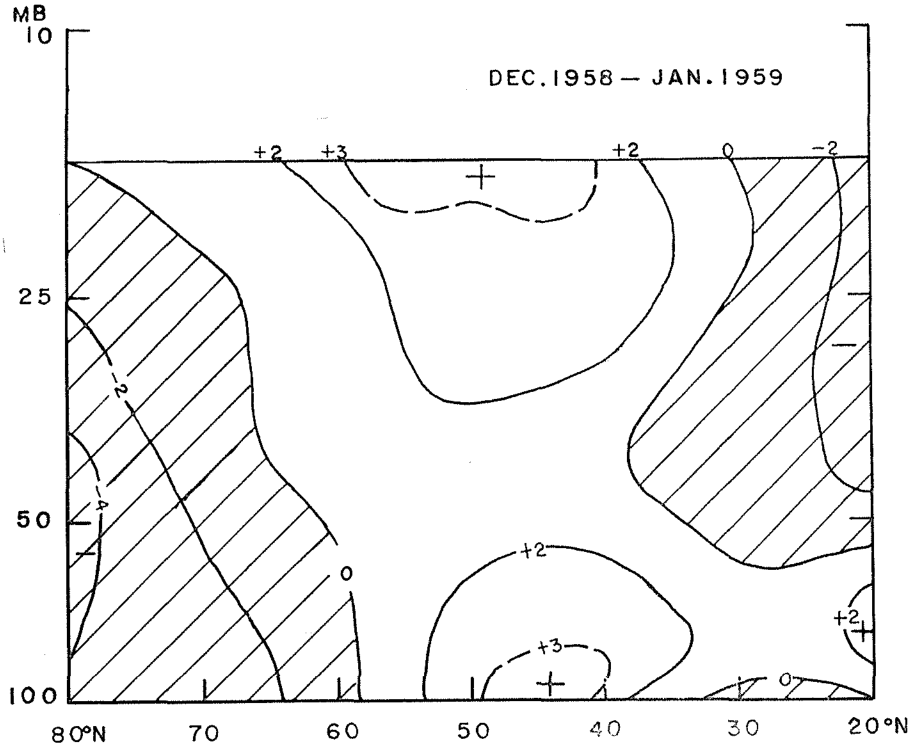

Fig. 3-9 Same as Fig. 3-1, except from December 1958 to January 1959.

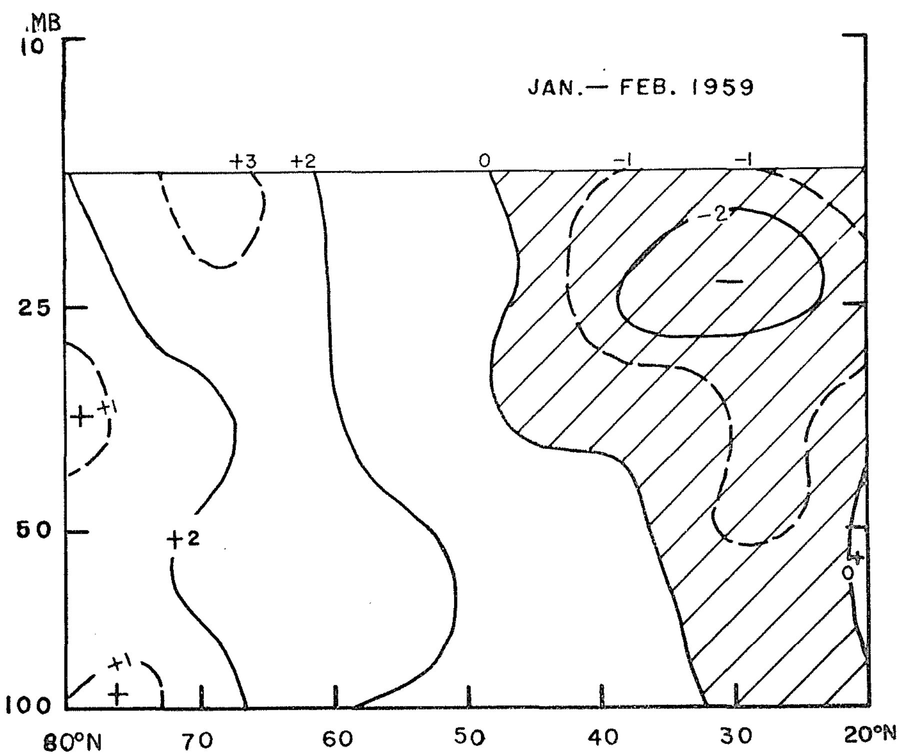

Fig. 3-10 Same as Fig. 3-1, except from January to February 1959.

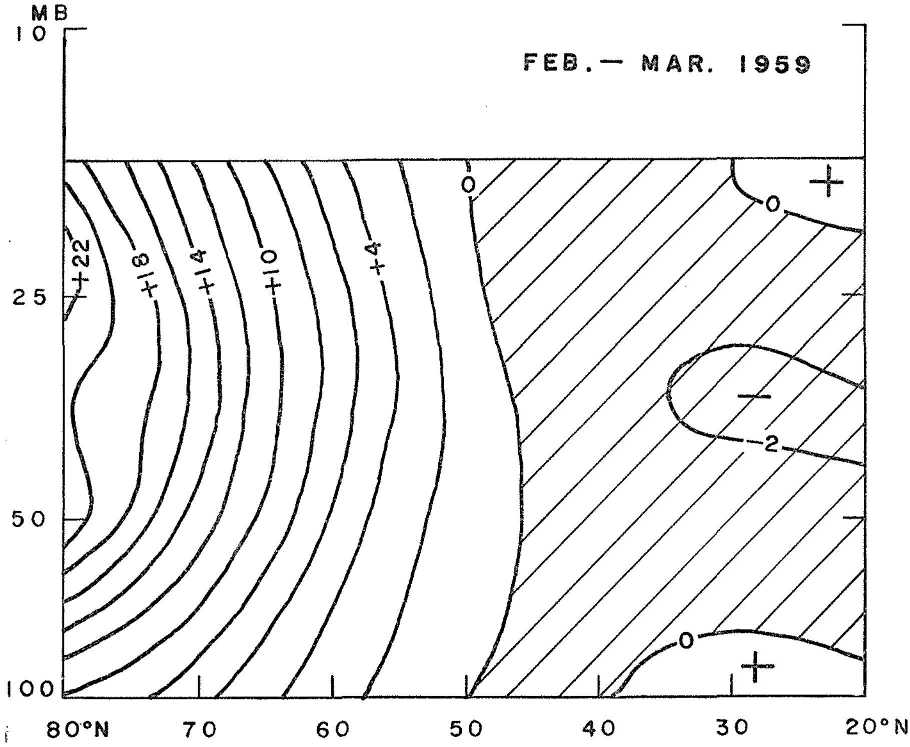

Fig. 3–11 Same as Fig. 3–1, except from February to March 1959.

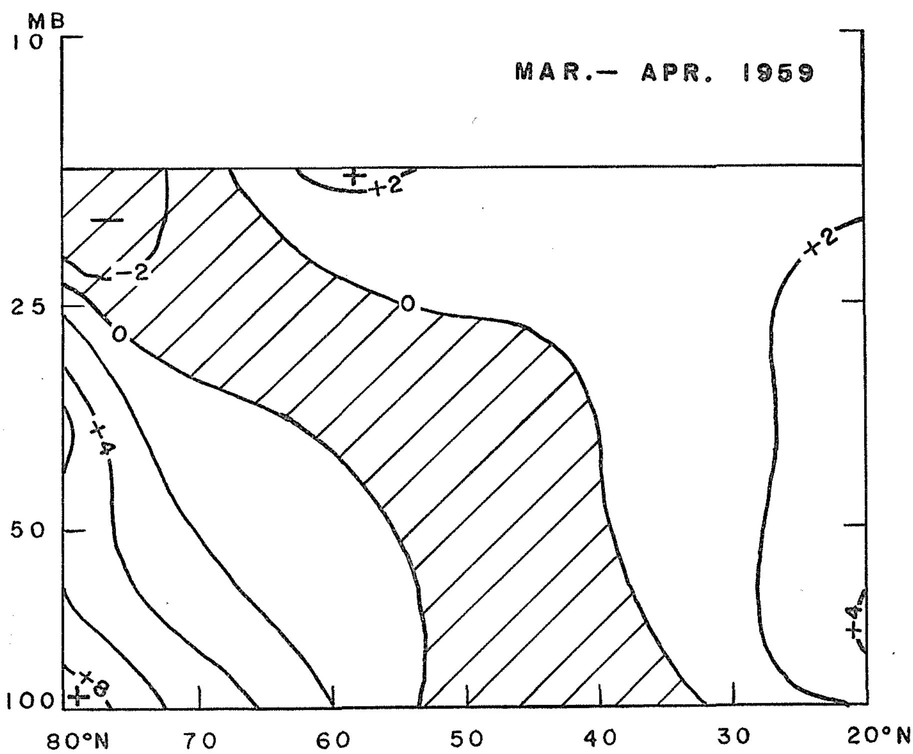

Fig. 3–12 Same as Fig. 3–1, except from March to April 1959.

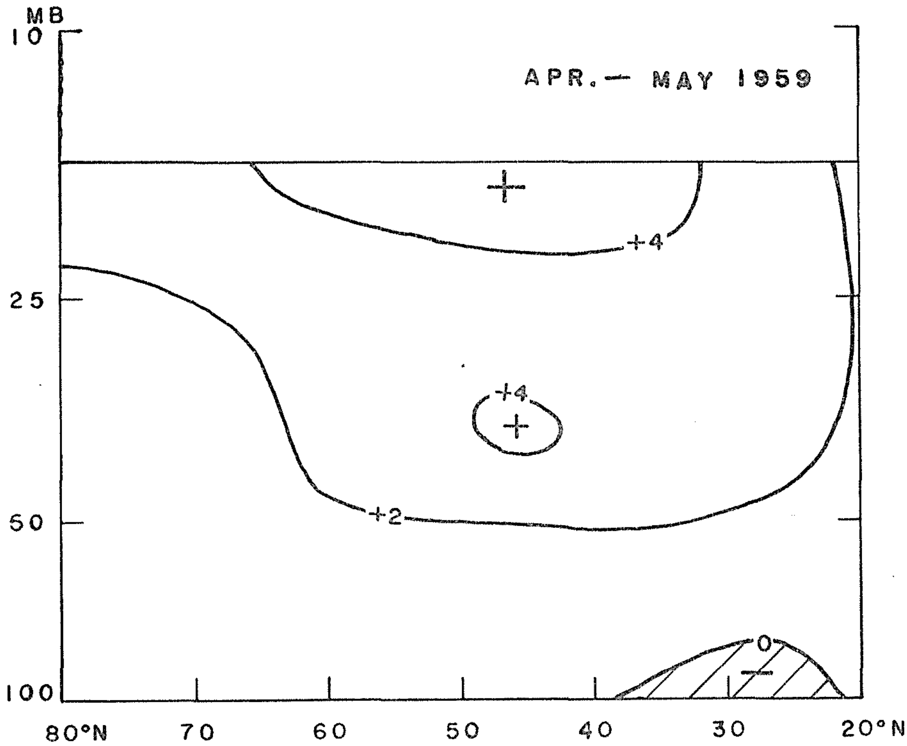

Fig. 3-13 Same as Fig. 3-1, except from April to May 1959.

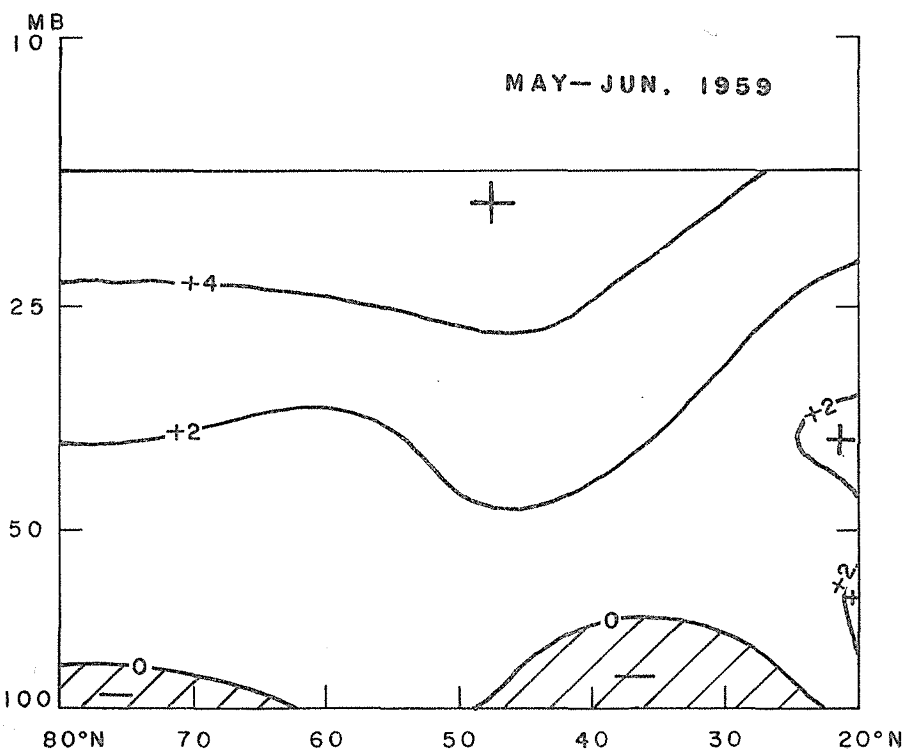

Fig. 3-14 Same as Fig. 3-1, except from May to June 1959.

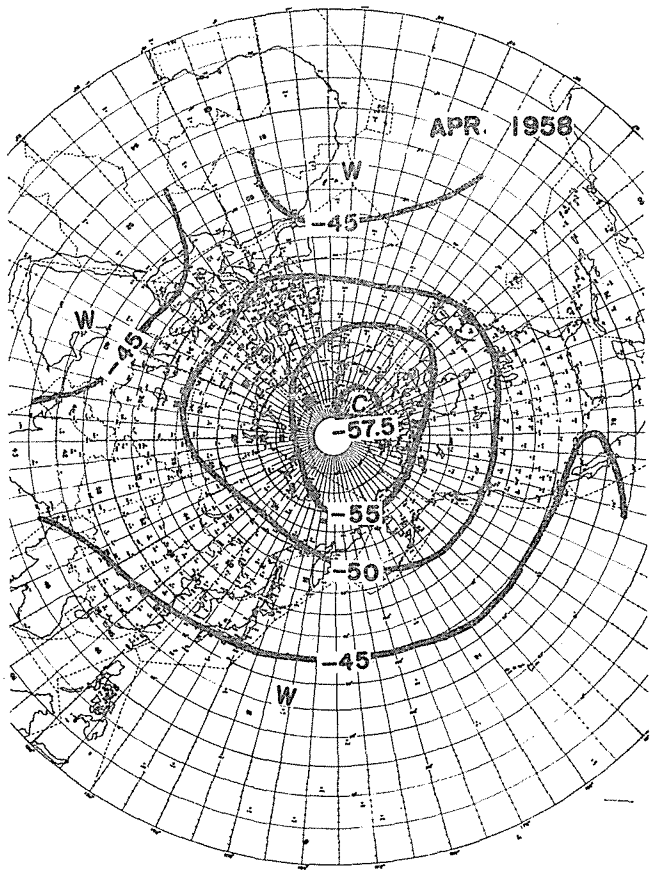

Fig. 4–1 Hemispherical distribution of monthly mean temperature of 10–25 mb layer at the latitudes higher than 20°N in April 1958 (°C).

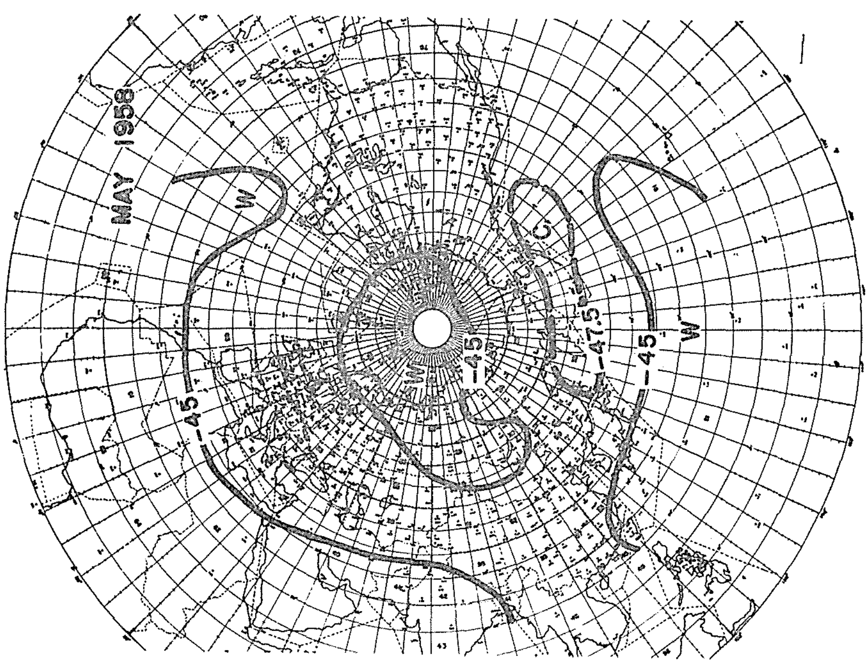

Fig. 4-2 Same as Fig. 4-1, except in May 1958.

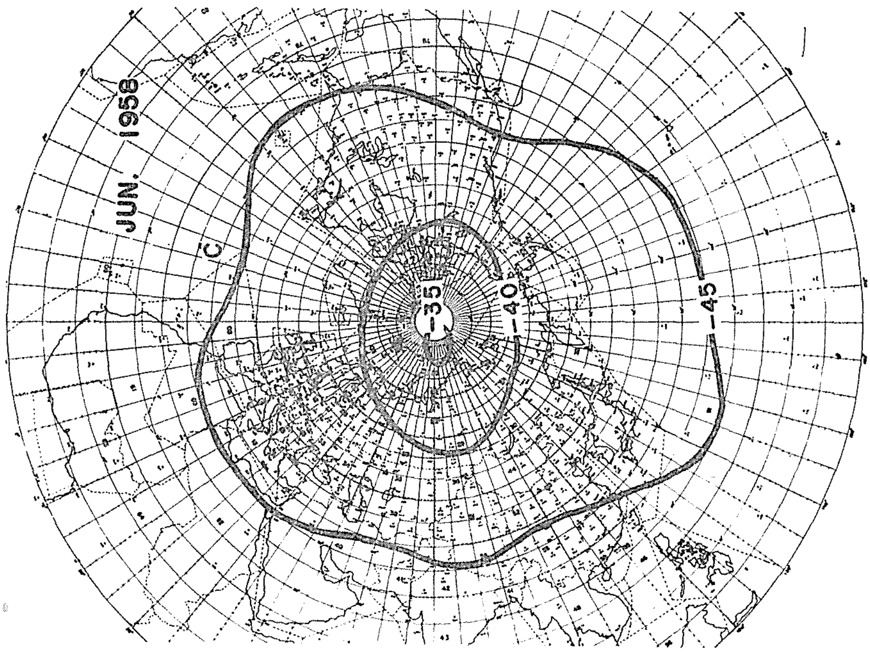

Fig. 4-3 Same as Fig. 4-1, except in June 1958.

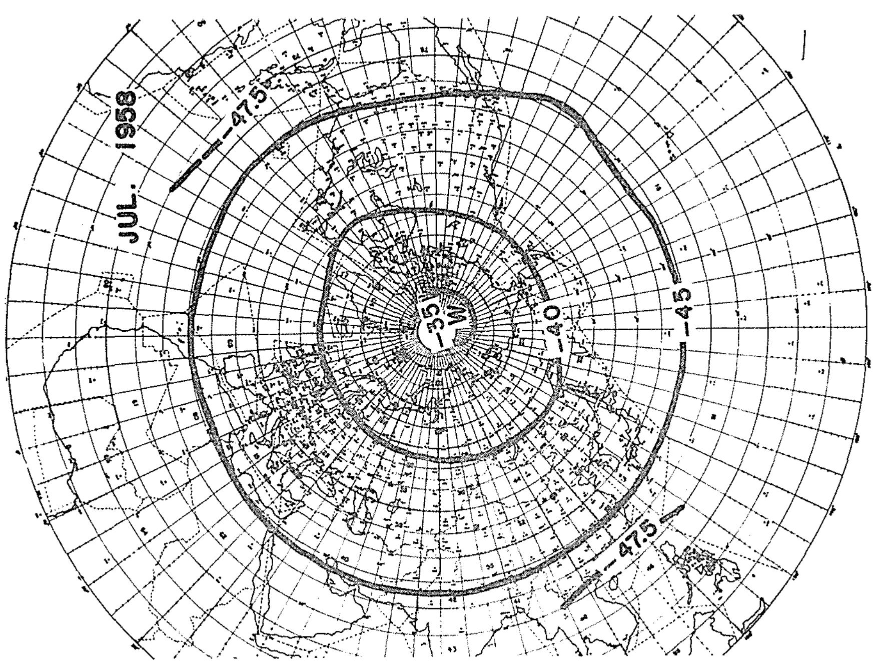

Fig. 4-4 Same as Fig. 4-1, except in July 1958.

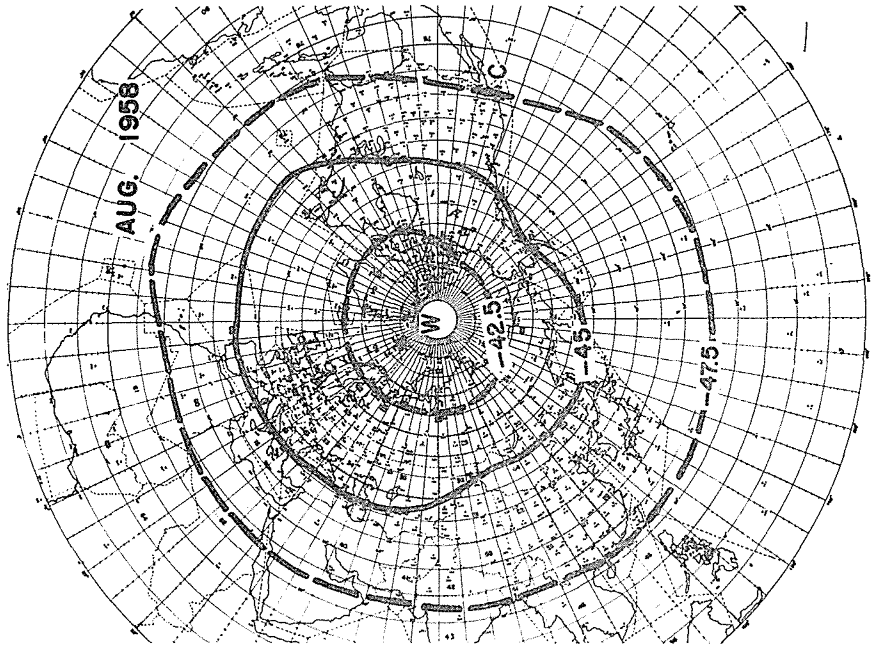

Fig. 4-5 Same as Fig. 4-1, except in August 1958.

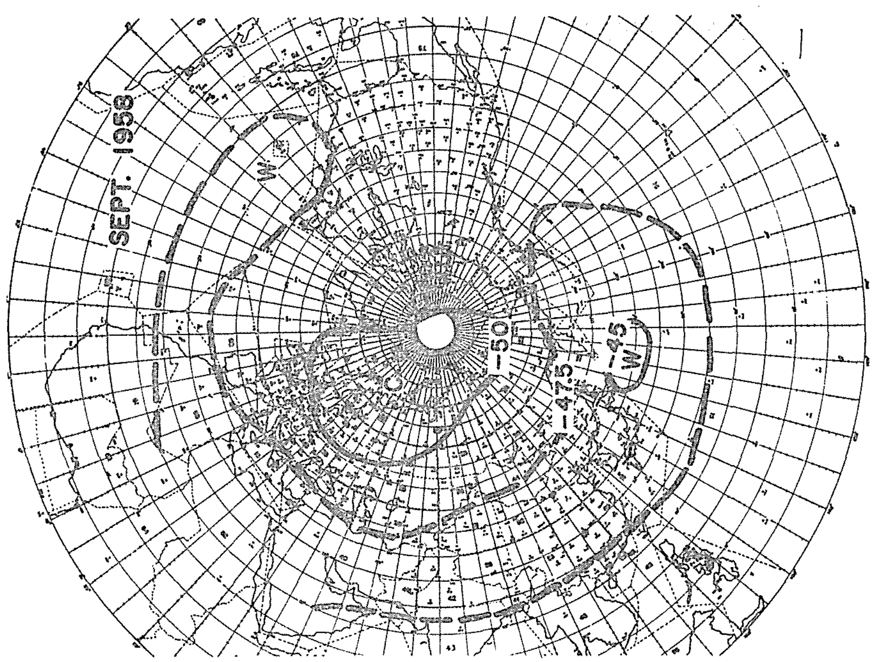

Fig. 4-6 Same as Fig. 4-1, except in September 1958.

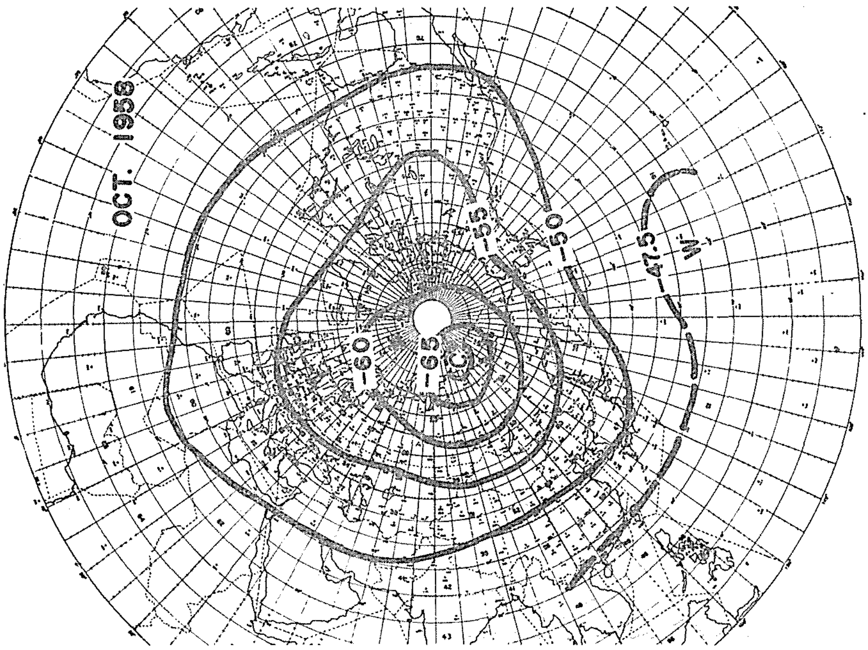

Fig. 4-7 Same as Fig. 4-1, except in October 1958.

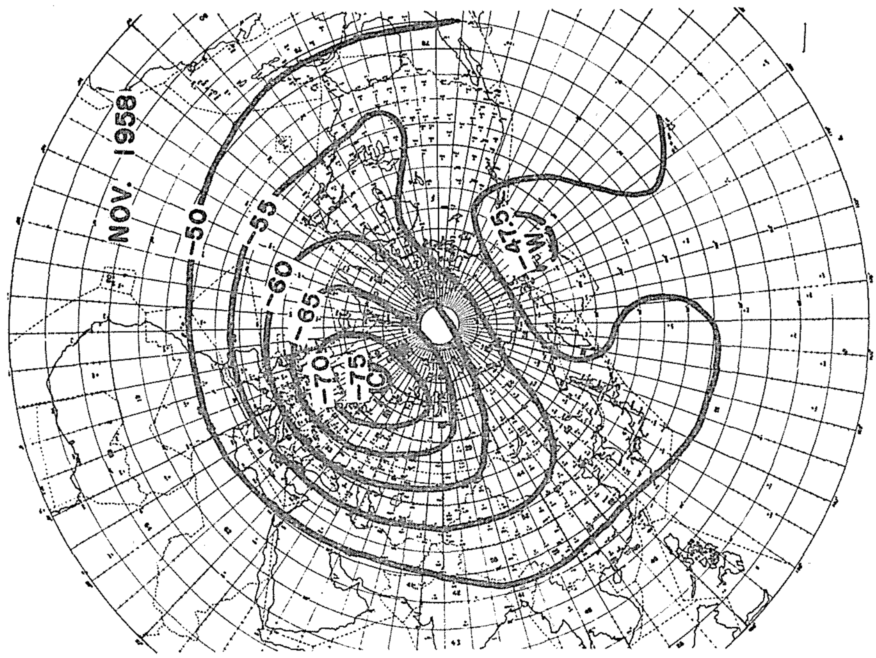

Fig. 4-8 Same as Fig. 4-1, except in November 1958.

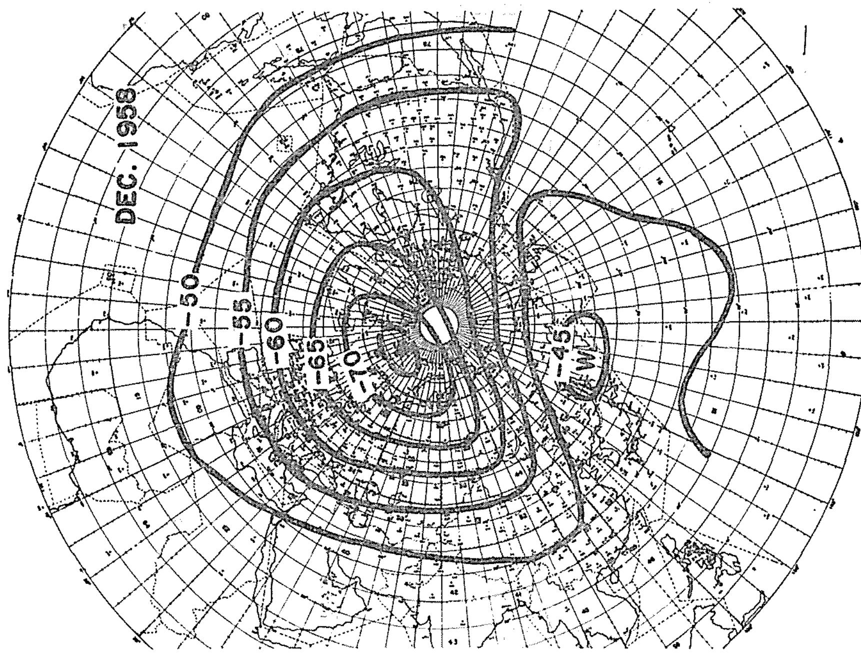

Fig. 4-9 Same as Fig. 4-1, except in December 1958.

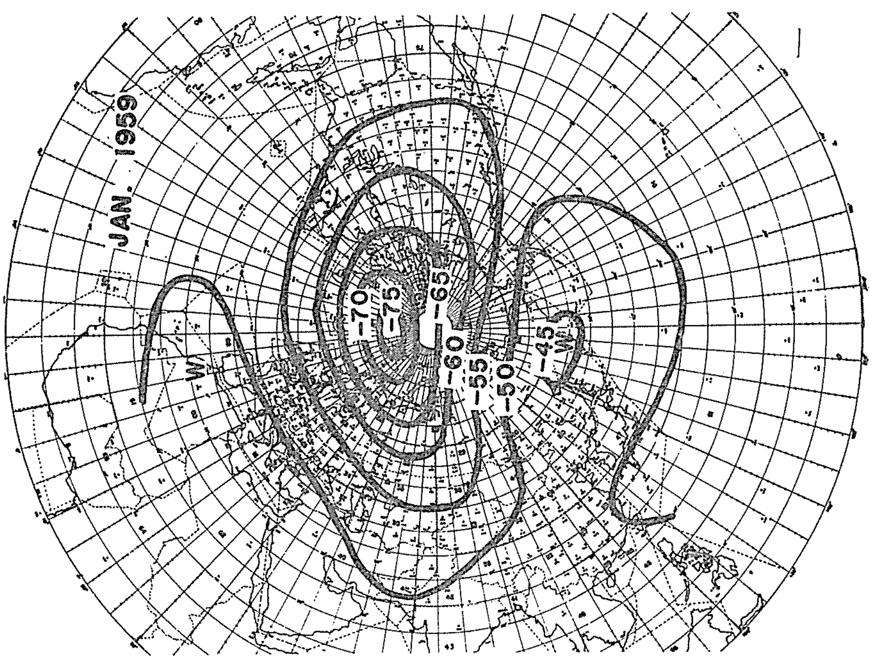

Fig. 4–10 Same as Fig. 4–1, except in January 1959.

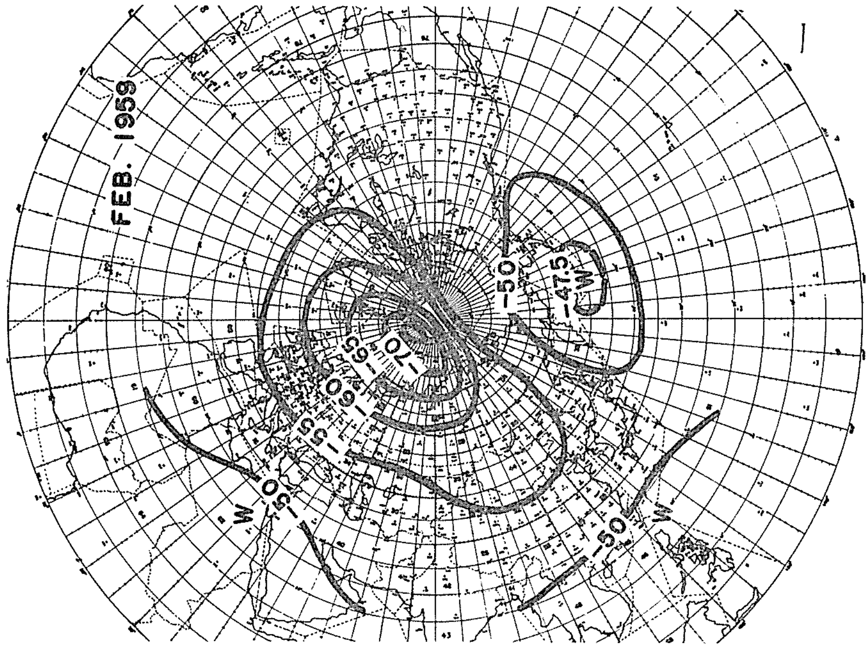

Fig. 4–11 Same as Fig. 4–1, except in February 1959.

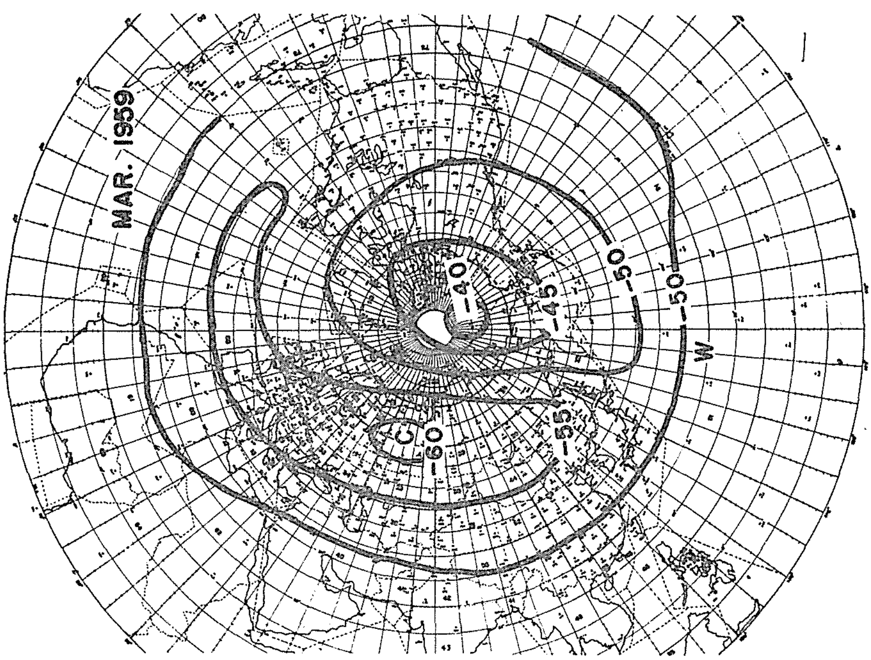

Fig. 4-12 Same as Fig. 4-1, except in March 1959.

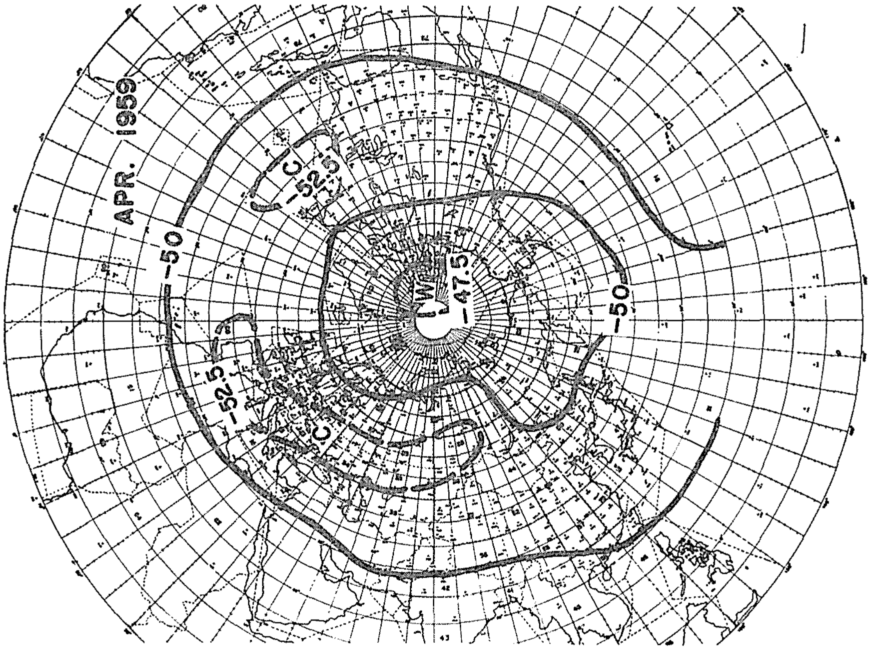

Fig. 4-13 Same as Fig. 4-1, except in April 1959.

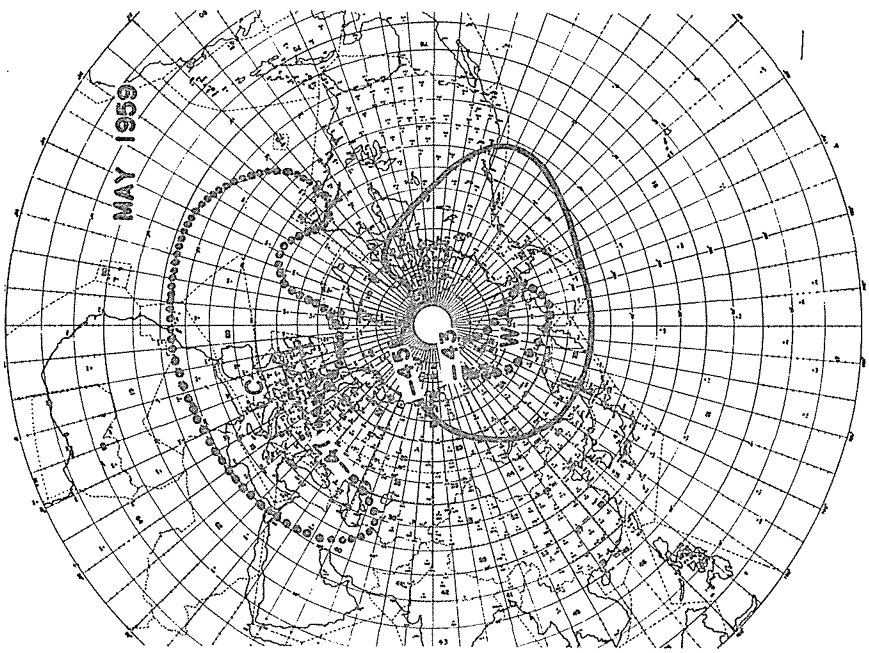

Fig. 4-14 Same as Fig. 4-1, except in May 1959.

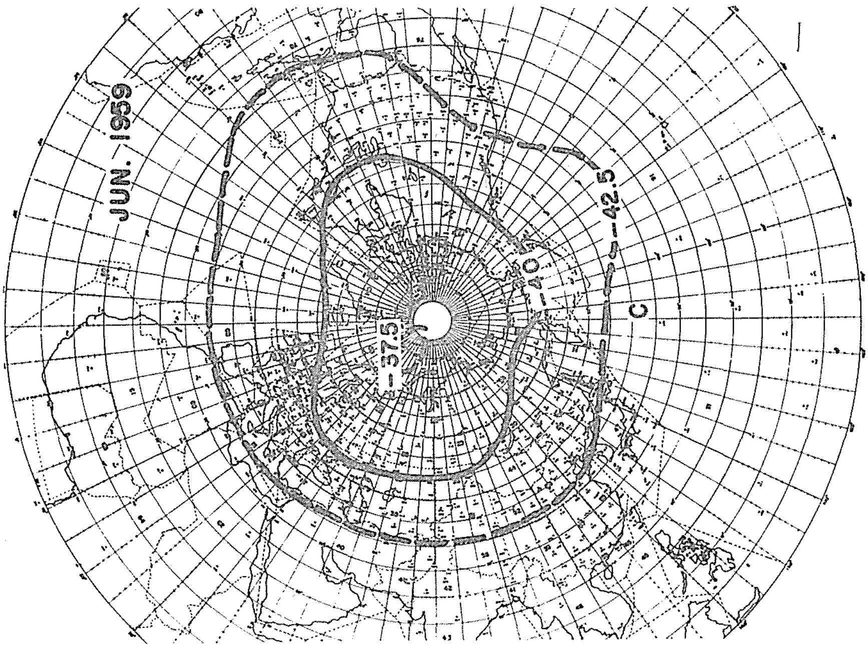

Fig. 4-15 Same as Fig. 4-1, except in June 1959.

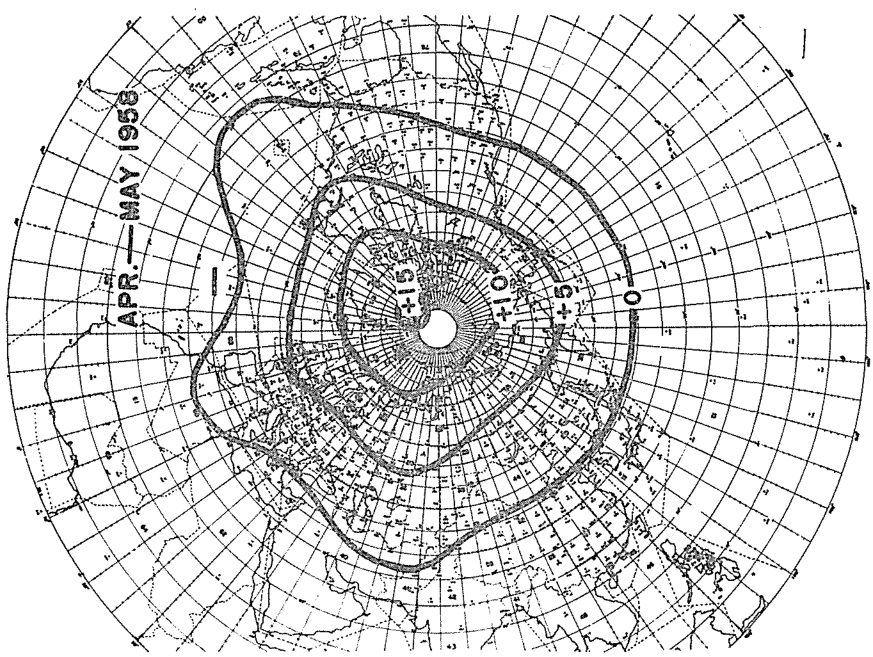

Fig. 5-1 Hemispherical distribution of change of monthly mean temperatuer of 10−25 mb layer at the latitudes higher than 20°N from April to May 1958 (°C/month).

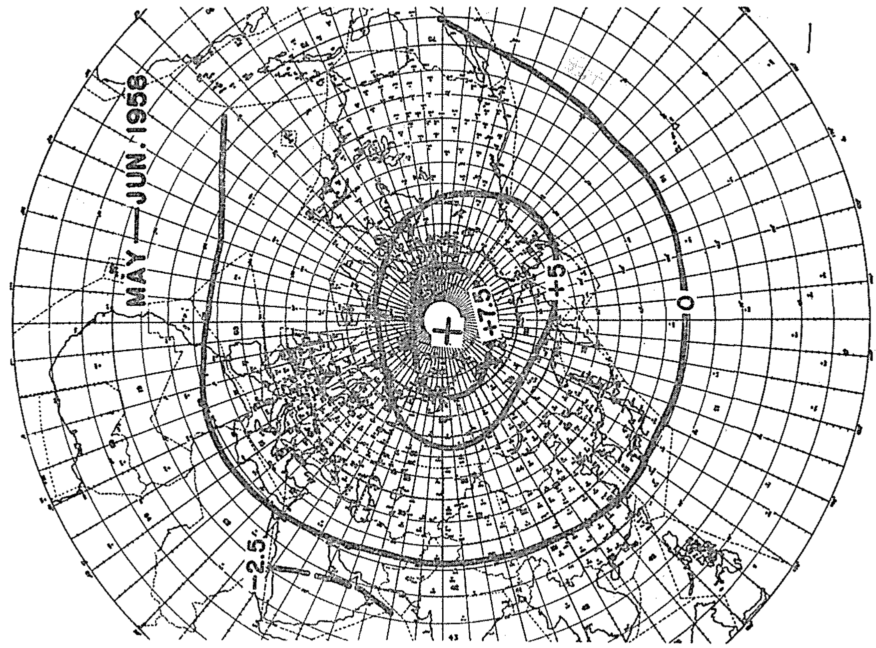

Fig. 5-2 Same as Fig. 5-1, except from May to June 1958.

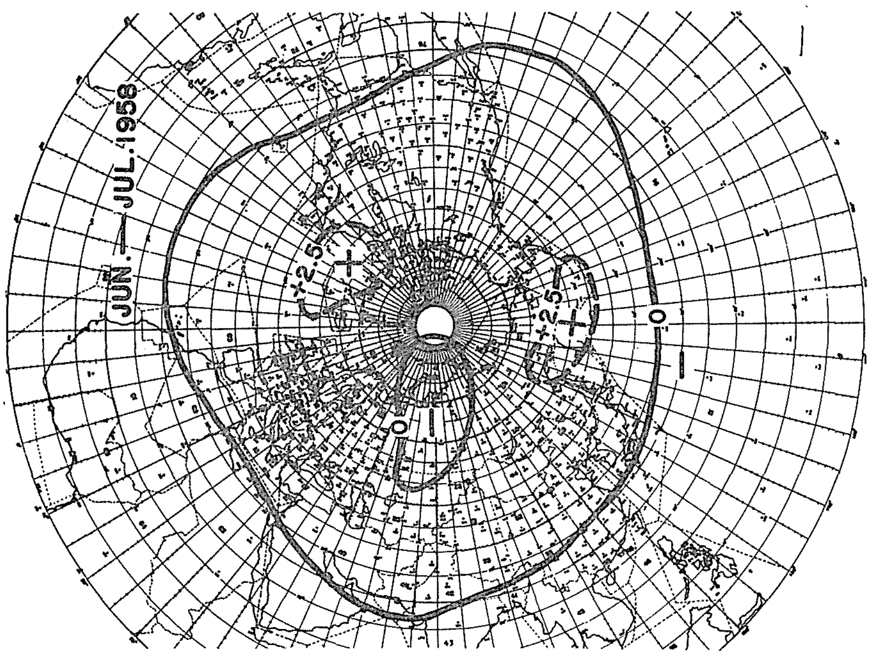

Fig. 5-3 Same as Fig. 5-1, except from June to July 1958.

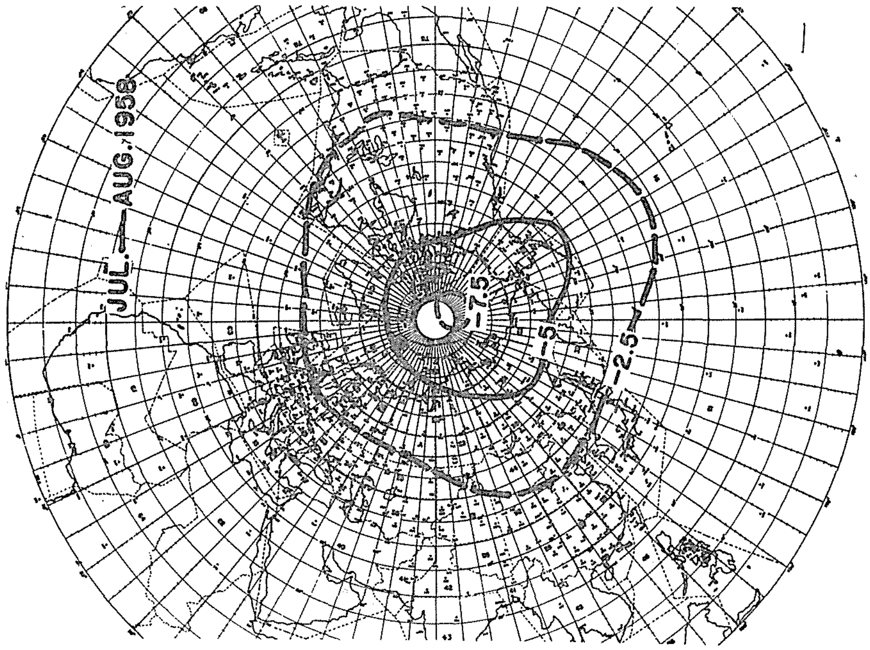

Fig. 5-4 Same as Fig. 5-1, except from July to August 1958.

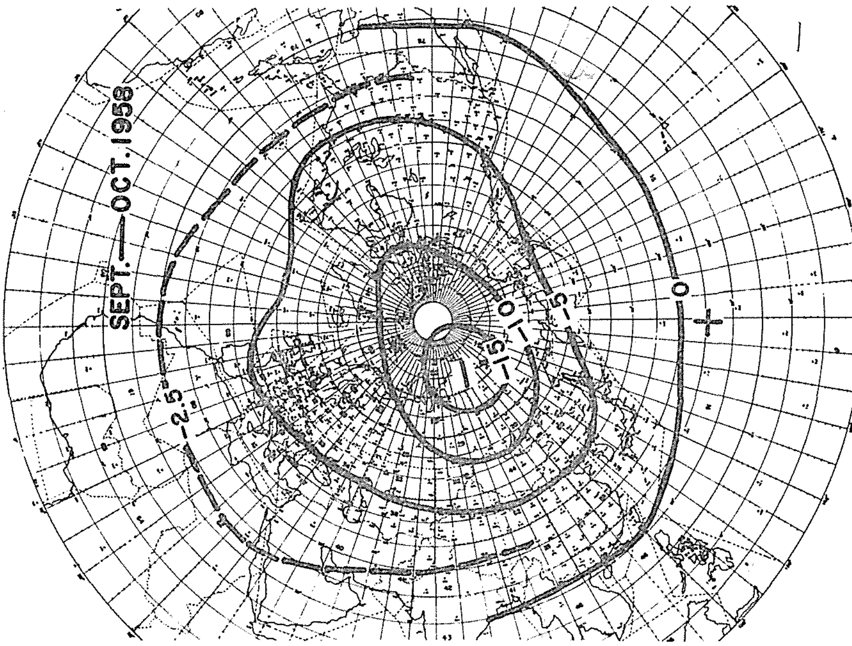

Fig. 5-6 Same as Fig. 5-1, except from September to October 1958.

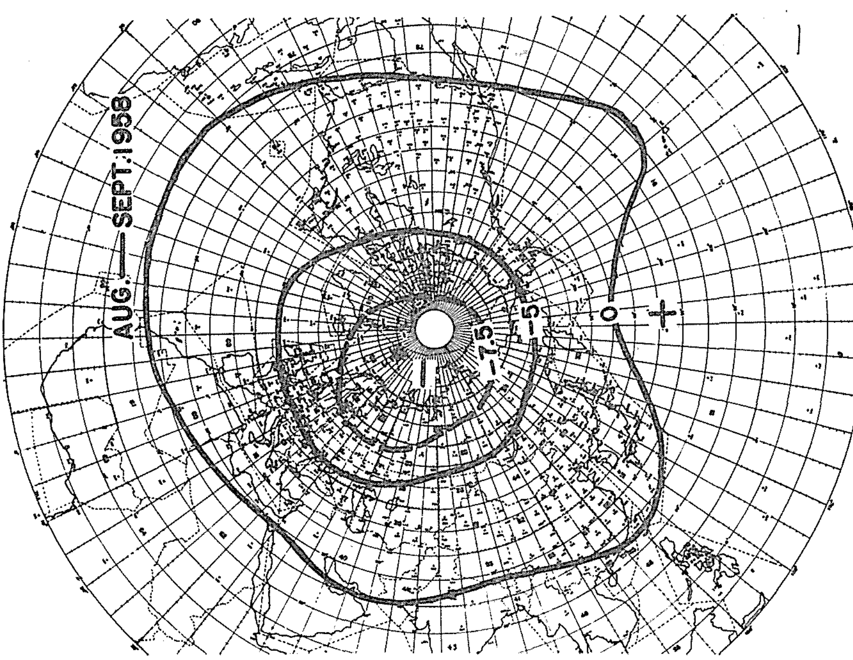

Fig. 5-5 Same as Fig. 5-1, except from August to September 1958.

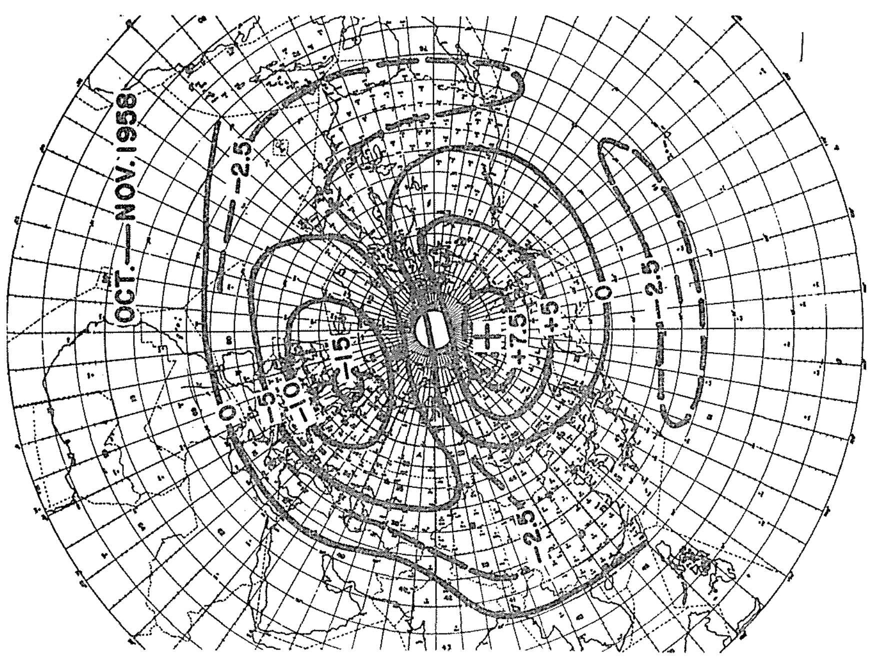

Fig. 5-7 Same as Fig. 5-1, except from October to November 1958.

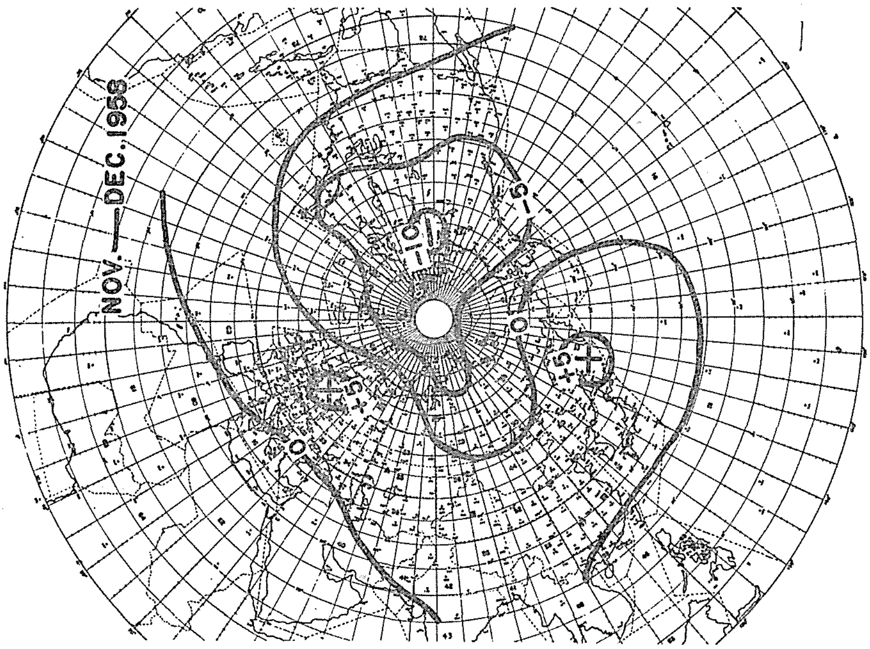

Fig. 5-8 Same as Fig. 5-1, except from November to December 1958.

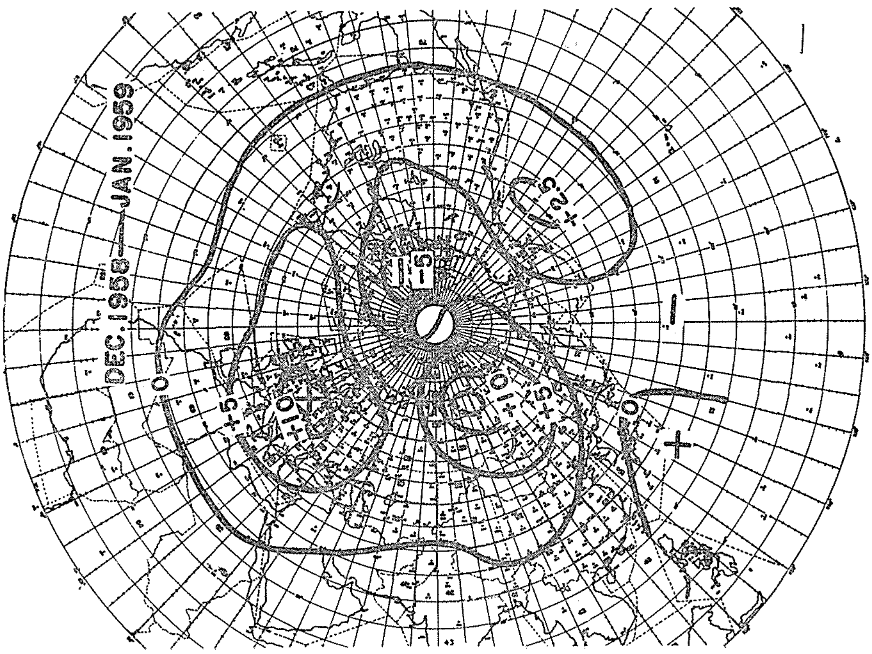

Fig. 5-9 Same as Fig. 5-1, except from December 1958 to January 1959.

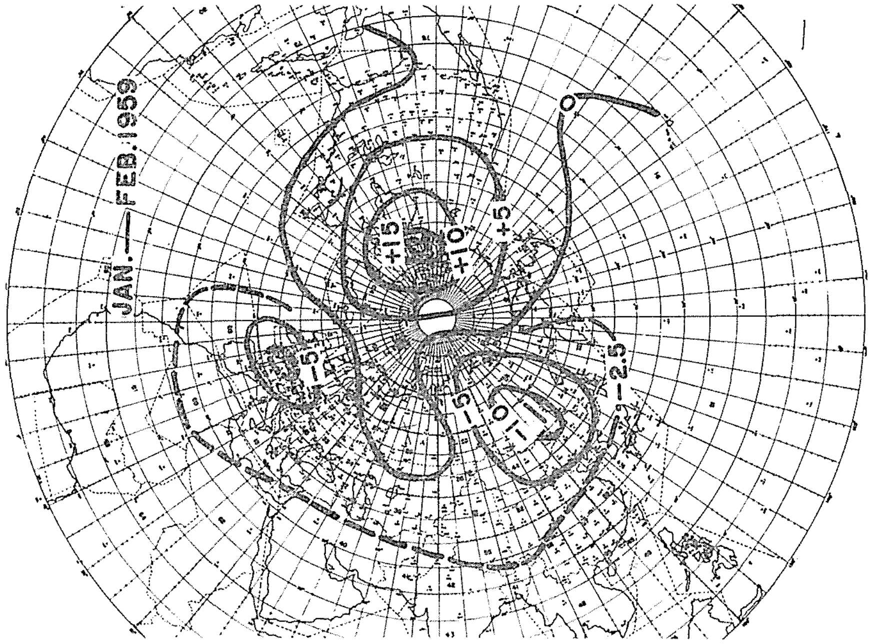

Fig. 5-10 Same as Fig. 5-1, except from January to February 1959.

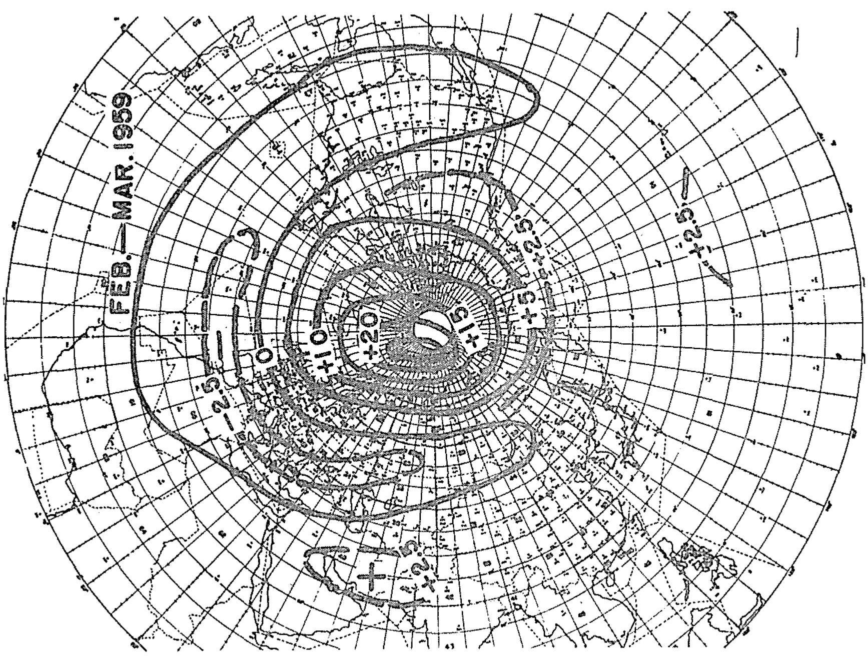

Fig. 5-11 Same as Fig. 5-1, except from February to March 1959.

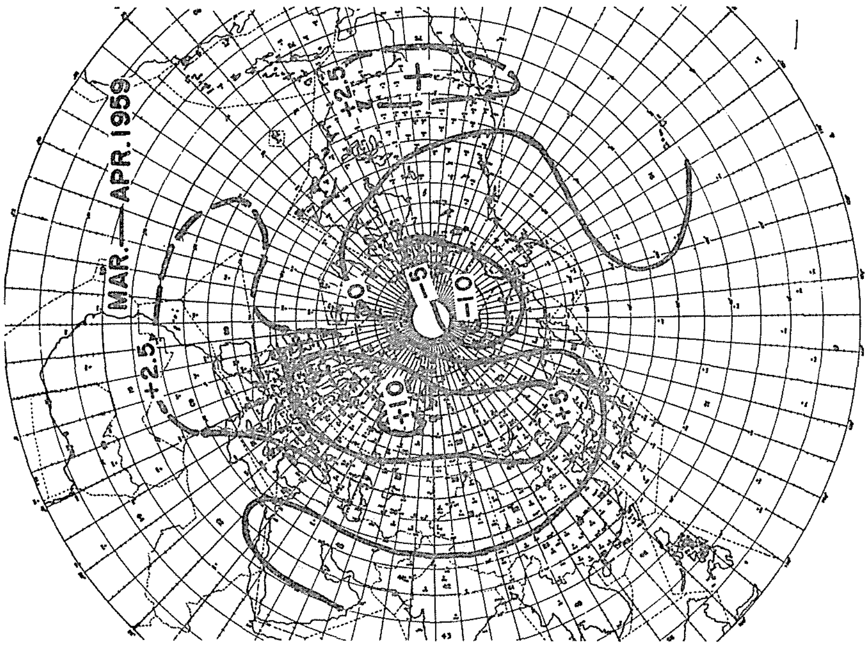

Fig. 5-12 Same as Fig. 5-1, except from March to April 1959.

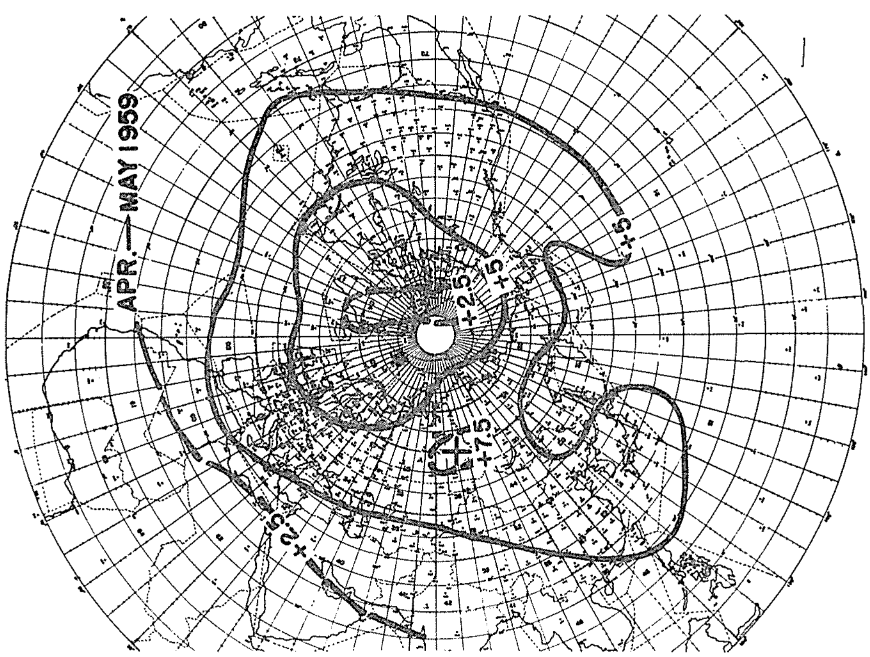

Fig. 5–13 Same as Fig. 5–1, except from April to May 1959.

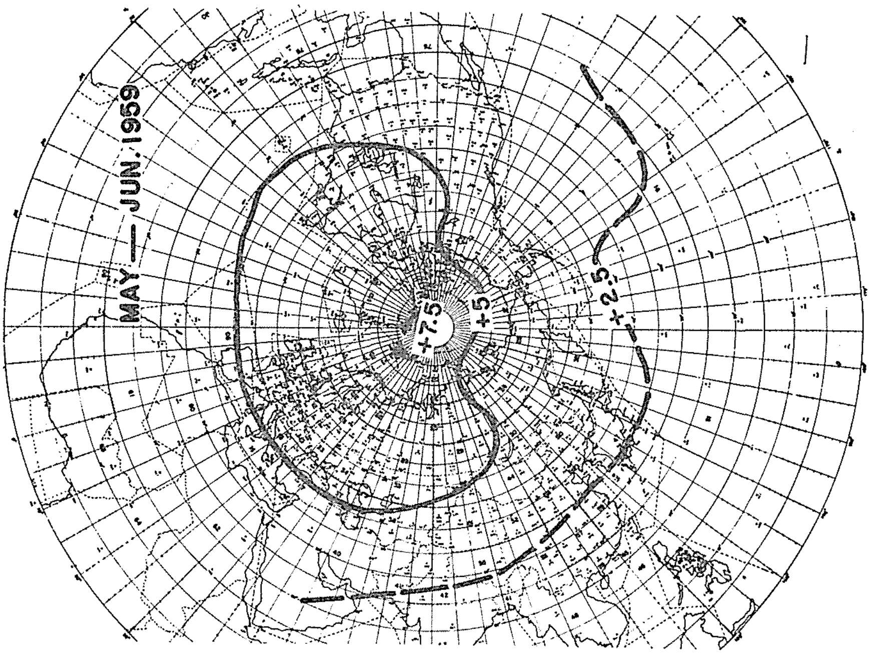

Fig. 5–14 Same as Fig. 5–1, except from May to June 1959.