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FALL REVERSAL OF THE LOWER- AND MIDDLE-STRATOSPHERE CIRCULATIONS IN THE NORTHERN HEMISPHERE

By

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Abstract

Analysis of the zonal wind averaged longitudinally is made at 10 mb, 30 mb and 50 mb surfaces for July, August and September 1965, and the results show that the fall reversal of the stratospheric circulations starts at 50 mb near 60°N, and then progresses upwards and south- and northwards. This fact is also confirmed for 6 years from 1957 through 1962. Some discussions are given about the mechanism of this reversal.

1. Introduction

The easterly wind is a characteristic feature of the stratospheric circulation in summer season, and the westerly wind is that in winter, except in the equatorial region. The change in the stratospheric conditions from winter to summer or *spring reversal* is given a start by the so-called final warming, the description of which has been given by many meteorologists (e.g. Scherhag [1952] and Wilson and Godson [1963]).

Fall reversal of the stratospheric circulations or change from easterly to westerly wind has been studied by a few authors. Batten [1959] concludes that fall reversal starting at the polar region progresses upwards and southwards, studying the mean zonal component of wind over North America for 1957, above the height of 50,000 ft. Belmont [1962] analyzes 3-year data in the lower and middle stratosphere over North America, and describes that it is possible for wind first to become westerly at 60°N and later at higher latitudes. Hemispherical analyses of monthly mean circulations are also made by Belmont [1963]. His results show that fall reversal starts at the polar region in the lower stratosphere and progresses upwards and southwards. Miers [1963] presents an evidence showing that the fall reversal in the upper stratosphere begins above the height of 60 km and progresses downwards at about 1 to 4 km/day, analyzing 3-year data of the meteorological rocket soundings at White Sands and Point

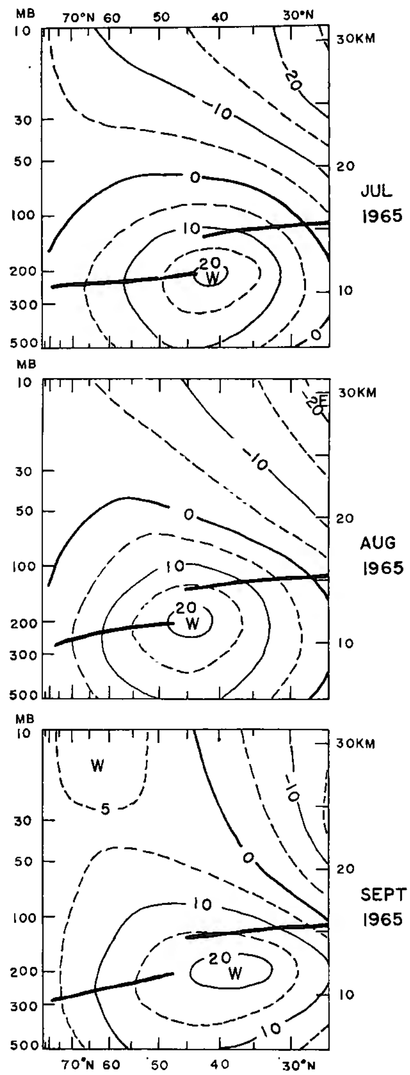


Fig. 1. Monthly-mean meridional cross-sections of the zonal winds averaged longitudinally. The westerly wind is positive and the unit is m/sec. Cosine-scale is used in the abscissa.

Mugu. These results require further study of the fall reversal in the stratospheric circulations. In this paper, analysis of hemispherical change of the zonal circulations in the lower and middle stratosphere are attempted, in relation to the fall reversal.

2. Change of monthly-mean stratospheric zonal circulations

Monthly-mean maps of 1965 issued by Scherhag, *et al.* [1966] make us possible to have distributions of the zonal wind in July, August and September 1965, under the geostrophic approximation. Fig. 1 shows meridional cross-sections of monthly-mean zonal wind averaged longitudinally in the lower and middle stratosphere and the upper troposphere. These are limited in layer between 500 mb and 10 mb, north of 25°N. In July 1965, the easterly wind prevails above 50 mb level at all the latitudes analyzed here. Speed of the easterly wind increases generally upwards and southwards, and the speed is higher than 25 m/sec at 10 mb, 25°N. The easterly wind becomes, in August, generally slower in the stratosphere, and the westerly wind appears at 50 mb level from 50°N to 65°N. In September, the westerly wind prevails in all the stratospheric layer north of 45°N.

The transition of the monthly-mean zonal circulations from July to August 1965 suggests that the fall reversal in 1965 may appear first in the lower stratosphere near 60°N on someday from middle July to mlddle August. More detailed analyses will be attempted in the following section, in order to depict the features of the reversal.

3. Fall reversal of 9-day mean stratospheric zonal circulations

9-day running-mean zonal wind averaged longitudinally is obtained for the period from middle July to middle September 1965, by use of daily series of hemispherical maps of 10 mb, 30 mb, 50 mb and 100 mb (Scherhag, *et al.* [1966]). Latitudinal distribution and time change of these winds are illustrated in time-meridional sections of the isotachs (Fig. 2). The zonal wind at 100 mb level is

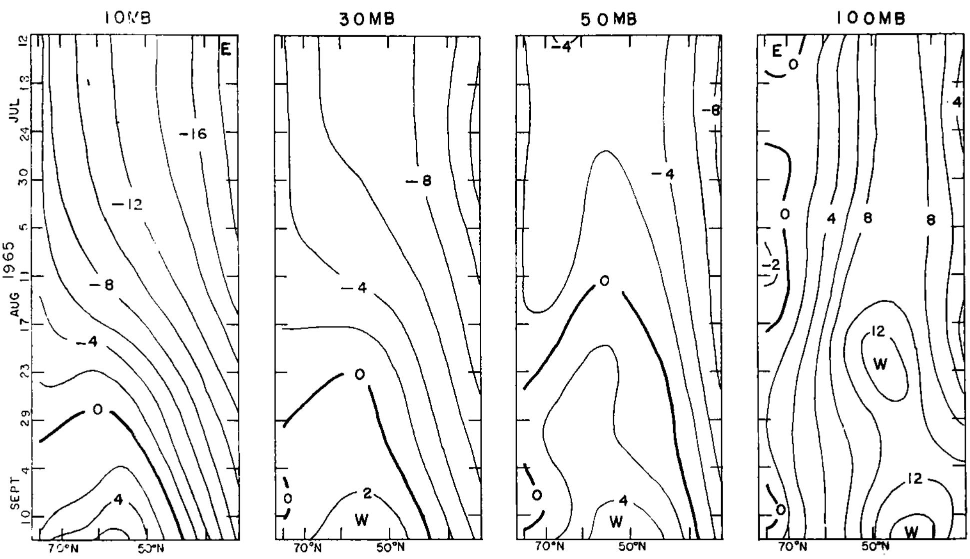


Fig. 2. Meridional and time sections of the zonal winds averaged longitudinally. The westerly winds is positive and the unit used is m/sec. Cosine-scale is used in the abscissa.

generally westerly, except at higher latitudes. The easterly wind prevails at 10 mb, 30 mb and 50 mb levels, north of 35°N before about August 10, 1965. About August 15, the westerly wind, first, appears at 50 mb level between 60°N and 50°N. At other latitudes, this reversal at 50 mb level is later and takes place at 45°N about August 20, and at 75°N about August 25, respectively. The speed of the zonal winds at 30 mb level almost vanishes at 55°N on August 23, and the westerly wind appears first on August 26 between 50°N and 65°N, becoming westerly later at other latitudes. The reversal at 10 mb level starts on August 29 between 55°N and 70°N, and it is delayed at the higher and lower latitudes.

Analysis for other years is required for confirming whether the features of the reversal found in the analysis for 1965 is normal or not. Dates of the fall reversal of zonal winds averaged longitudinally at 10 mb, 25 mb or 30 mb and 50 mb levels are determined for 6 years from 1957 through 1962 in a similar

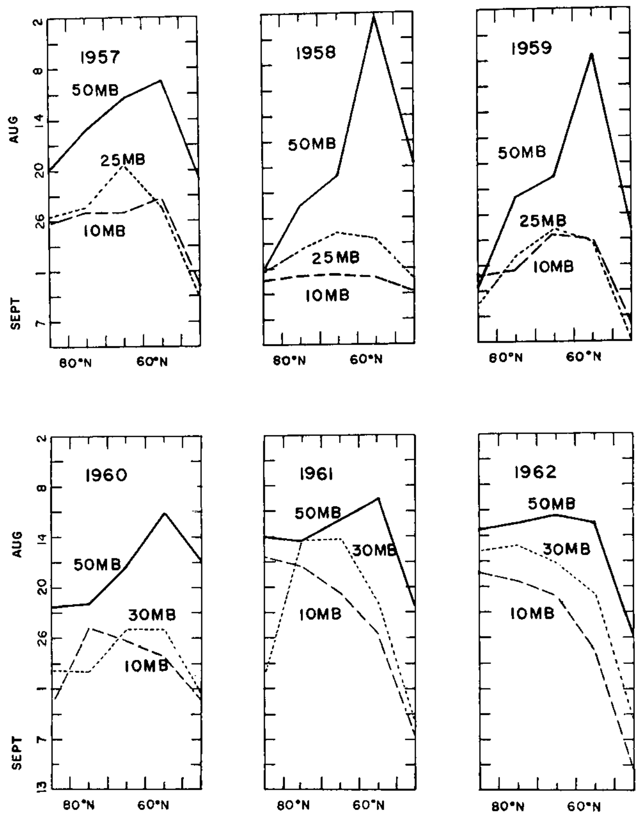


Fig. 3. The date of fall reversal of the stratospheric circulations averaged longitudinally for 6 years from 1957 through 1962.

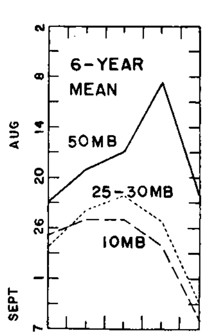


Fig. 4. The date of fall reversal of the stratospheric circulations averaged over 6 years from 1957 through 1962.

way to that for 1965 (Fig. 3). It is clear in every years that the reversal begins at 50 mb level, where it starts apparently near 55°N, except for 1962. The reversal at 25 mb or 30 mb level tends generally to appear earlier than that at 10 mb level, although an opposite order of appearance can be seen at some latitudes in some years. Mean date of the reversal obtained with the 6-year data from 1957 to 1962 is shown in Fig. 4, which illustrates clearly the characteristic features mentioned above, except the reversal at 85°N which is slightly earlier at 10 mb that that at 25 mb or 30 mb level. It may be noticed that the latitude where the reversal appears first at each level shifts somewhat northwards with increasing height.

4. Change of the circulation pattern associated with the fall reversal in 1965

9-day mean maps of 100 mb, 50 mb, 30 mb and 10 mb are shown in Fig. 5 for the days before and after the 1965 fall reversal of the stratospheric circulations. The circulation pattern at 100 mb level is such that the polar vortex of westerly wind occupies the majority of the northern hemisphere. Highs at 100 mb over Asia and western coast of the United States give predominancy of wave of angular wave number 2 at middle latitudes. The wave number of predominant waves at higher latitudes is 3 before August 16–24, and 2 after August 19–27 when the westerly wind averaged longitudinally at 50°N attains to a maximum higher than 12 m/sec.

Before the reversal, the contour pattern at 50 mb level shows an anticyclonic vortex centered near the Pole and a low ever Hudson Bay. Appearance of a high over western coast of the United States is associated with the reversal

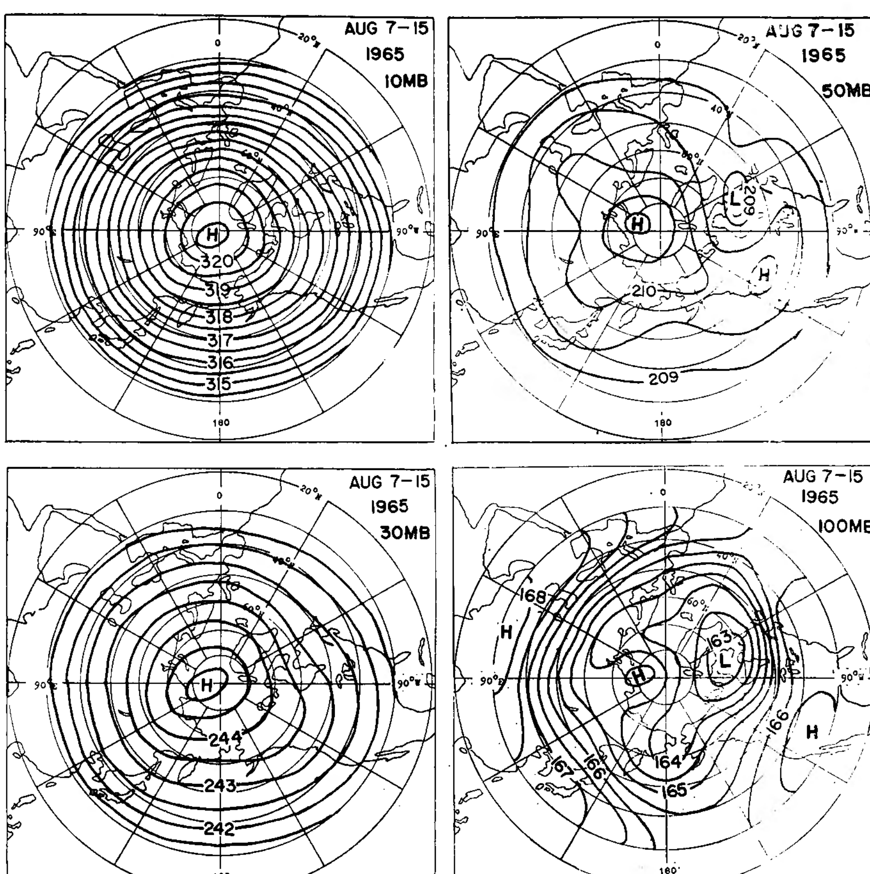


Fig. 5 (a). 9-day mean maps for Aug. 7–15, 1965. The unit is 100gpm.

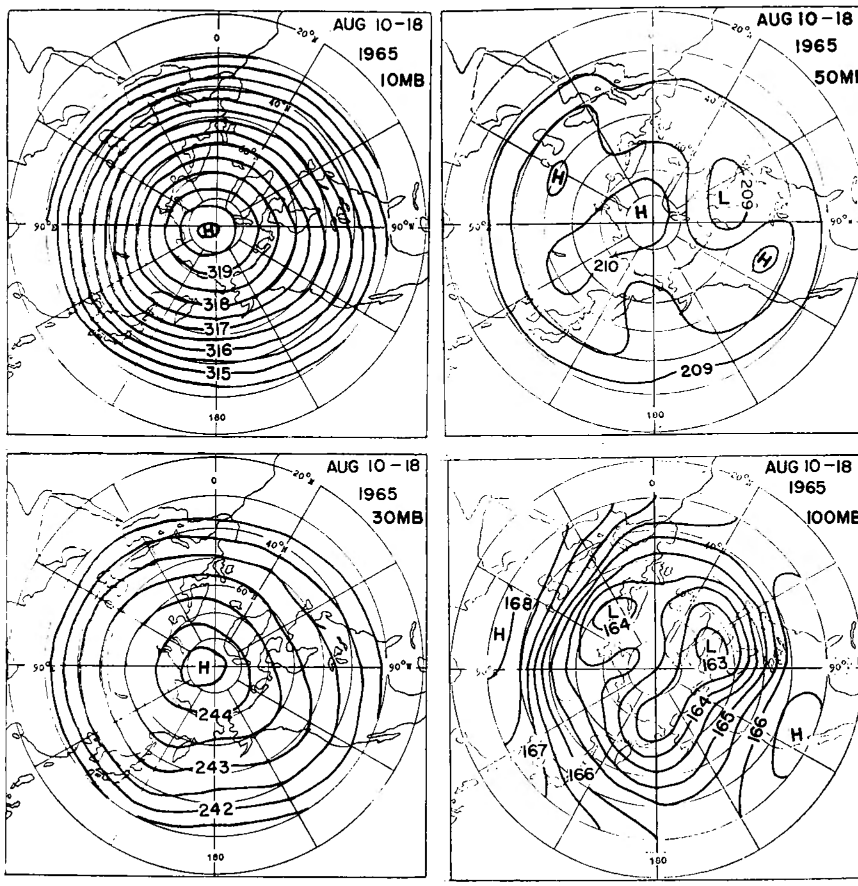
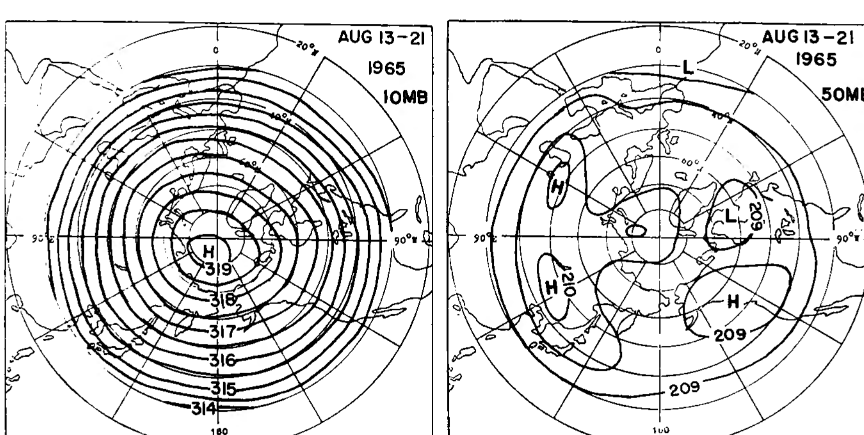


Fig. 5 (b). 9-day mean maps for Aug. 10-18, 1965.



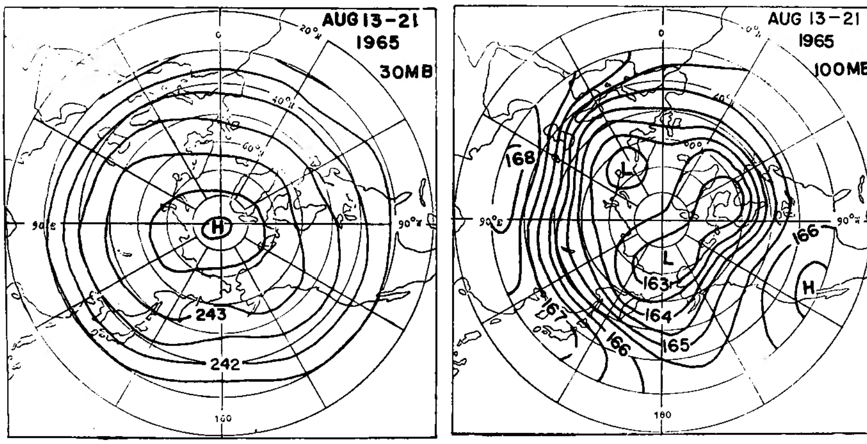


Fig. 5 (c). 9-day mean maps for Aug. 13–21, 1965.

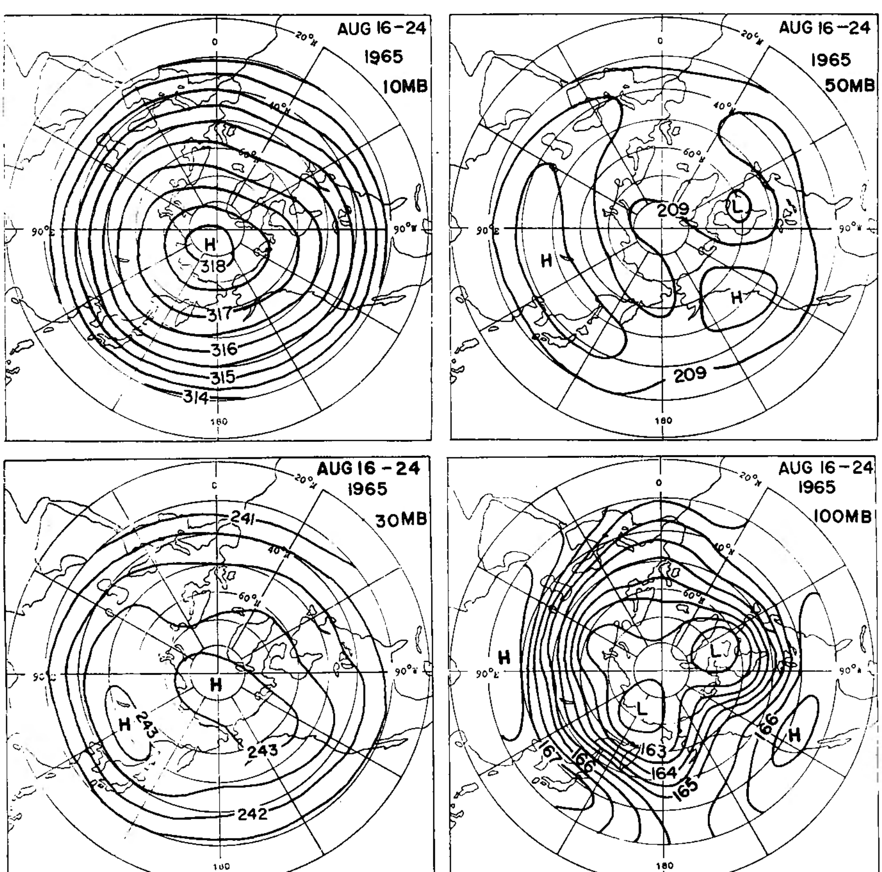


Fig. 5 (d). 9-day mean maps for Aug. 16–24, 1965.

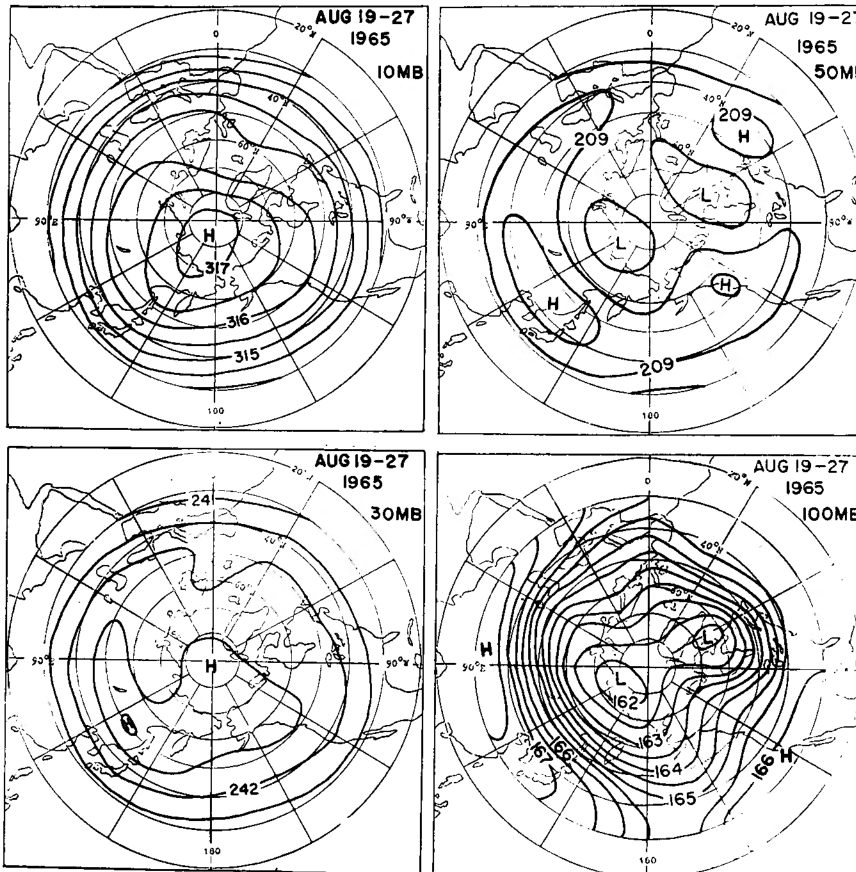
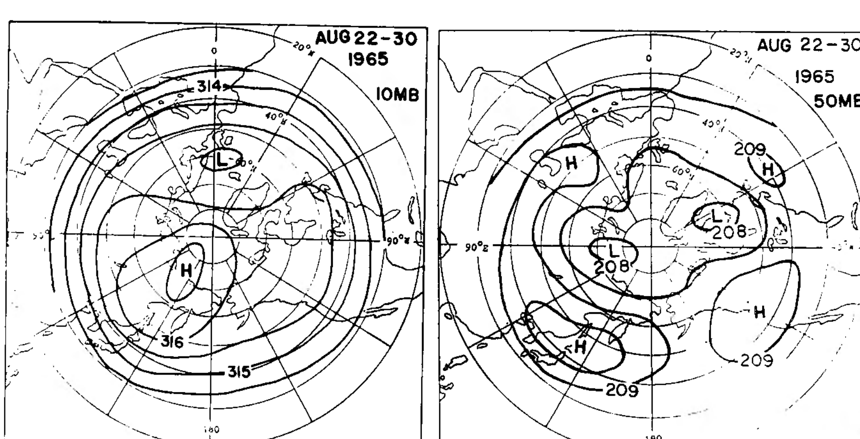


Fig. 5 (e). 9-day mean maps for Aug. 19-27, 1965.



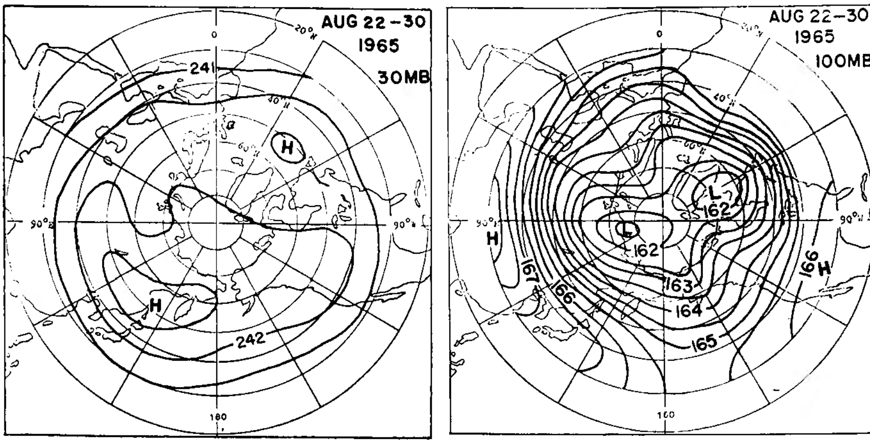


Fig. 5 (f). 9-day mean maps for Aug. 22-30, 1965.

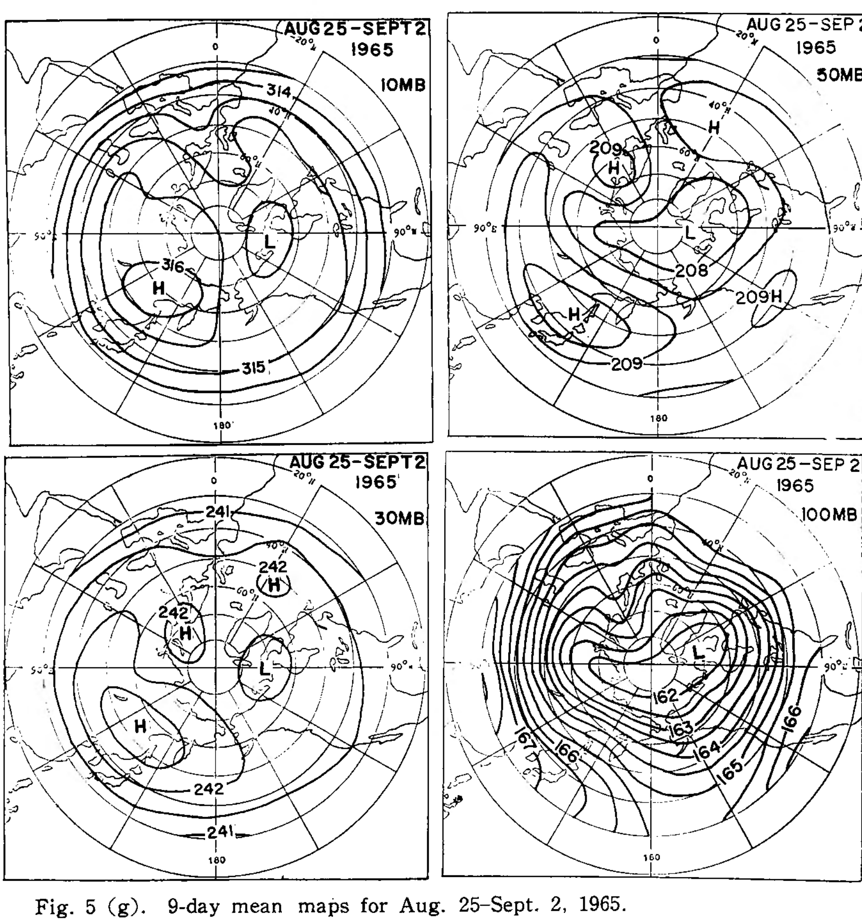


Fig. 5 (g). 9-day mean maps for Aug. 25-Sept. 2, 1965.

(August 7–15, 1965). Afterward, other highs can be found over Asia, the polar vortex becoming weak.

30 mb and 10 mb maps show, before the reversal, an anticyclonic vortex of approximate symmetry centered near North Pole. It is clear that appearance of high over Asia occurs at 30 mb and 10 mb level about time of the reversal or August 16–24 and August 25–September 2, respectively.

5. Discussions

Reversal of the meridional gradient of temperature is another characteristic of fall reversal in the stratosphere, except the region south of the so-called warm belt in the low stratosphere at middle latitudes. Time-meridional sections of 9-day running mean temperature of the layers of 10–30 mb, 30–50 mb, and 50–100 mb averaged longitudinally are shown in Fig. 6. In general, the reversal

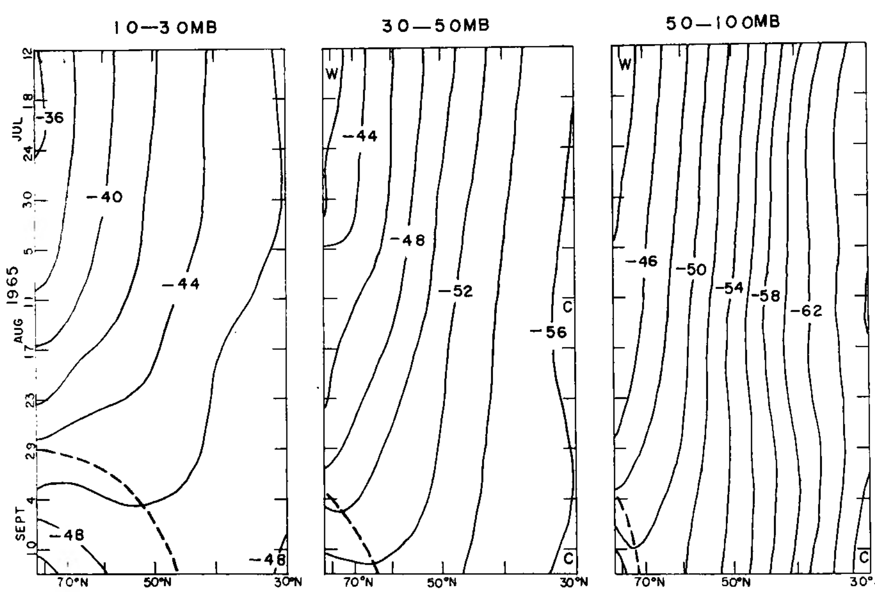


Fig. 6. Meridional and time sections of longitudinally, averaged temperature. The unit is °C. Cosine-scale is used in the abscissa.

of temperature gradient is much later than that of the circulation, and it starts at higher level and higher latitude and then progresses downwards and southwards. It is difficult, therefore, for the fall reversal in the circulations to attribute directly to that of temperature gradient.

The fact that appearance of the high over Asia is closely related with the reversal in the circulations at each level suggests that the cause should be sought for in phenomenon of upward propagation of wave disturbances at lower level. The condition of vertical propagation of planetary-scale wave given by Charney and Drazin [1961] is written as follows:

$$n^2 > 0 \tag{1}$$

where

$$n^2 = \left(\frac{\beta\sigma_B^2}{f^2} + \frac{dU}{dz}\frac{\sigma_i^2}{g}\right) \Big/ (U-c) - \frac{k^2\sigma_B^2}{f^2} - \frac{\sigma_i^4}{4g^2} \tag{2}$$

The formula (1) is derived under assumption that the lateral width of the wave is infinite and the vertical changes of wind shear, σ_B^2 and σ_i^2 are negligibly small. Here, β is the meridional change of Coriolis parameter f, and $\sigma_B^2 = g(\gamma_d - \gamma)/T$, $\sigma_i^2 = g(\gamma_h - \gamma)/T$, $\gamma_d = g/c_p$, $\gamma_h = g/R$. U, dU/dz, T, $\gamma(=-dT/dz)$, g, c_p, R, $L(=2\pi/k)$ and C are the undisturbed zonal wind, its vertical shear, the air temperature, its lapse rate, gravitational acceleration, isobaric specific heat of the air, wavelength and wave velocity, respectively.

Table 1. Calculation results of n^2 in the formula (2). Positive value of U and C is eastward.

Layer	Period	dU/dz (10^{-3}sec^{-1})	U (m/sec)	n^2 for $C=0$ (10^{-10}cm^{-2})	n^2 for $C=-2$ m/sec (10^{-10}cm^{-2})
50 mb–100 mb	Aug. 4–12	−1.6	1.3	0.14	0.032
	Aug. 7–15	−1.5	1.7	0.10	0.024
	Aug. 10–18	−1.5	2.2	0.066	0.052
	Aug. 13–21	−1.5	2.9	0.041	0.009
	Aug. 16–24	−1.5	3.3	0.032	0.005
	Aug. 19–27	−1.5	3.5	0.031	0.006
	Aug. 22–30	−1.4	3.5	0.033	0.009
	Aug. 25–Sept. 2	−1.3	3.5	0.036	0.009
30 mb–50 mb	Aug. 4–12	−0.87	−3.6	−0.13	−0.024
	Aug. 7–15	−0.93	−3.0	−0.15	−0.36
	Aug. 10–18	−0.96	−2.3	−0.18	−1.10
	Aug. 13–21	−1.1	−1.2	−0.28	0.32
	Aug. 16–24	−0.87	−0.5	−0.70	0.18
	Aug. 19–27	−0.81	0.3	1.1	0.11
	Aug. 22–30	−0.72	0.7	0.46	0.091
	Aug. 25–Sept. 2	−0.66	1.0	0.32	0.082
10 mb–30 mb	Aug. 4–12	−0.98	−11.3	−0.066	−0.072
	Aug. 7–15	−0.62	−6.9	−0.091	−0.11
	Aug. 10–18	−0.58	−6.1	−0.099	−0.13
	Aug. 13–21	−0.61	−5.0	−0.11	−0.16
	Aug. 16–24	−0.46	−3.6	−0.15	−0.28
	Aug. 19–27	−0.34	−2.4	−0.21	−1.1
	Aug. 22–30	−0.18	−1.3	−0.37	0.58
	Aug. 25–Sept. 2	−0.12	−0.7	−0.67	0.30

Predominancy of β-term in bracket of the right-hand side of the formula (2) shows that the positive value of $(U-C)$ is needed for vertical propagation. Possibility of upward propagation of the waves at the lower level is examined for the layers of 50-100 mb, 30-50 mb and 10-30 mb and for the zone between 40°N and 70°N. The values of n^2 in the formula (2) are calculated for stationary wave and westward-moving wave of $C=-2$ m/sec, using the 9-day mean values of U and dU/dz in August 1965, and taking $k=0.55\times10^{-8}\text{cm}^{-1}$ which corresponds to angular wave number of 2 at 55°N. The results are listed in Table 1.

In the layer of 50-100 mb, the both waves can propagate vertically over the period taken here. From 50 mb to 30 mb level, stationary wave can propagate after August 19-27, and westward-moving wave after August 13-21, respectively. Stationary wave at 30 mb level cannot propagate to 10 mb level, but westward-moving wave can do after August 22-30. Tendency of such change of n^2 sign agrees with that of appearance of disturbances at each level, particularly the high over Asia, appearance of which brings about the reversal of circulation at the middle latitudes. It may not be so difficult to find out wave velocity equal to -2 m/sec or about $-2°$ long./day at 55°N in the actual situation of August 1965.

Acknowledgements

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