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THE WINTER ANOMALY OF RADIO WAVE ABSORPTION IN THE D-REGION AND THE PLANETARY WAVE IN THE STRATOSPHERE

By

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Abstract

Interrelations between stratospheric conditions and the strong absorption of radio waves in the D-region are investigated by using the daily data of the northern hemispheric maps of 10- and 30-mb, and of the ionospheric f_{min} from December 1965 to March 1966.

Analyses are based upon the time-longitudinal sections along 60°N circle of temperature and planetary wave in the stratosphere, and of the Δf_{min} which is the deviation from the monthly median value, and the positive value of which represents stronger absorption than the normal, on every day at each station.

Both the warmer region in the middle stratosphere and the stronger absorptive region in the D-region have a similar horizontal scale of the order of 1000 to 10000 km. It may be mentioned that the occurrence of unusual warming in the middle stratosphere is a sufficient condition for that of an absorption anomaly in the D-region, but not a necessary condition.

On the relation between the transient part of the planetary wave at 10-mb surface and stronger absorption, both amplitudes reach nearly simultaneously a maximum in mid-winter for wave number one. Also, the movements of both phases are similar, in speed and direction, during Dec. 1965~middle Feb. 1966 for wave numbers one and two.

These results suggest the important role of planetary waves in contributing to the absorption anomaly in the D-region.

1. Introduction

It has been known for many years that in winter, at temperate latitudes, there are many days with exceedingly strong absorption of radio waves in the ionosphere, not related to any influences from solar activity (Dieminger [1952], Beynon and Davies [1955], Appleton and Piggott [1954], Dieminger *et al.* [1967]). This phenomenon is called the "winter anomaly of the ionospheric absorption". Recent rocket observations have revealed that the direct cause of the winter anomaly is the sudden increase of electron density centered at a height of 75 km (Sechrist [1967], Sechrist *et al.* [1969]). Some authors

(Sechrist [1967], Gregory and Mason [1969]) suggested that the winter anomaly might probably be caused by internal gravity waves. According to a statistical study by Thomas [1961], however, the winter anomaly is observed over an area of at least 10^6 km^2. To confirm their suggestions, comprehensive explanation is required of the differences between the horizontal scale of the anomaly and the internal gravity wave.

Bossolasco and Elena [1963] produced evidence for a correlation between the winter anomaly of ionospheric absorption and the temperature in the middle stratosphere (about 10-mb surface). Shapley and Beynon [1965] carried out a superposed epoch-analysis of the 10-mb temperature and the daily values of the ionospheric absorption, and reported that, on the average, the absorption and the temperature reach a maximum about the same day. Sinno and Higashimura [1969] investigated the daily hemispherical distribution of the absorption anomaly at the times of the sudden stratospheric warmings in the winter of 1958 and 1963, and found that the warmings and the absorption anomaly have similar areal size. However, the winter anomaly is generally observed more frequently than the stratospheric warmings. According to the analysis by Sechrist [1967], five cases of the anomaly could be found in the two months of Nov. and Dec. 1963, but no remarkable warmings in the middle stratosphere could be found.

These results suggest the existence of intimate relationships between the large scale stratospheric phenomena and the winter anomaly. In the present paper, the relationships between the stratospheric temperature and the absorption are investigated by time-longitudinal sections along a 60°N circle, and those between the stratospheric planetary waves and the absorption are studied by comparing the time changes of their amplitudes and phases.

2. Analysis of the data

Interrelationships between the time changes of hemispherical conditions in the stratosphere and of the absorption in the D-region will be investigated for the four months from Dec. 1965 to Mar. 1966.

(1) *The absorption*

The observational network of the radio wave absorption in the D-region is too sparse to describe its detailed distribution over the whole hemisphere. However, it is shown that the data of f_{min} which are observed in relatively dense network, give an indication of the absorption in the D-region. Sinno and Higashimura [1969] used the following relation for daily distribution of the absorption ;

$$\Delta L\,(\mathrm{dB}) \sim \Delta f_{min}\,(\mathrm{MHz}), \tag{1}$$

where L is the absorption of radio waves obtained by A1 method (2.2 MHz). Δ signifies the deviation from the monthly median value. f_{min} is the minimum frequency of reflected radio wave from the ionosphere. This relation was already verified by analyzing the data obtained over a long period by many stations (Higashimura, Sinno and Hirukawa [1969]). The present analysis of the absorption along 60°N circle is based upon the data at sixteen stations located between 70°N and 50°N (Fig. 1). The distribution of these stations is neither uniform nor dense, so that it is not easy to describe the detailed pattern of f_{min}. However, the large scale pattern can be depicted by using such data. Figs. 2(a), (b), (c) and (d) are the time sections of Δf_{min} along 60°N circle from

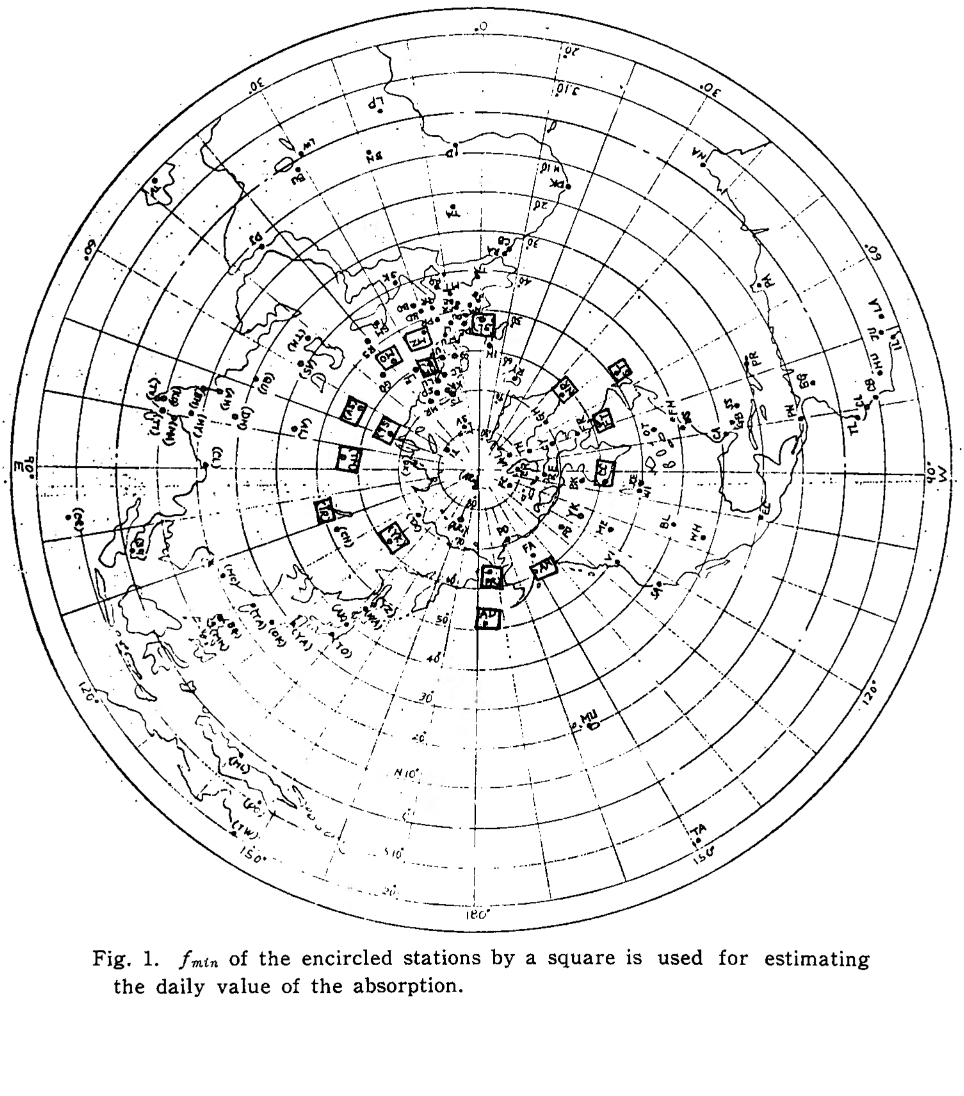

Fig. 1. f_{min} of the encircled stations by a square is used for estimating the daily value of the absorption.

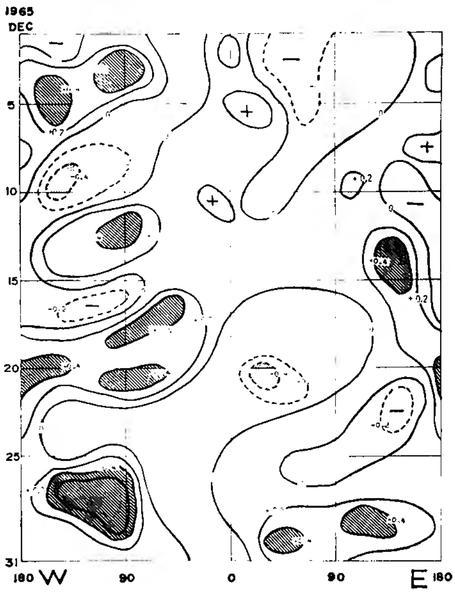

Fig. 2(a). Time section of Δf_{min} along 60°N circle in Dec. 1965. Positive values and the region shaded by oblique lines signify a stronger absorptive region than the normal. Negative values and the region shaded by dot signify a less absorptive region than the normal.

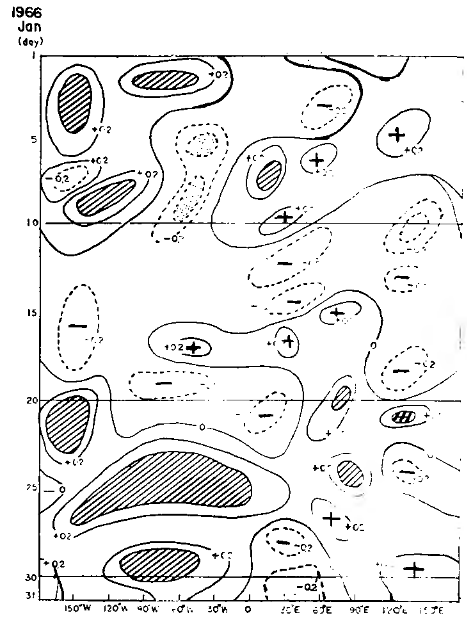

Fig. 2(b). Time section of Δf_{min} along 60°N circle in Jan. 1966. Others are same as in Fig. 2(a).

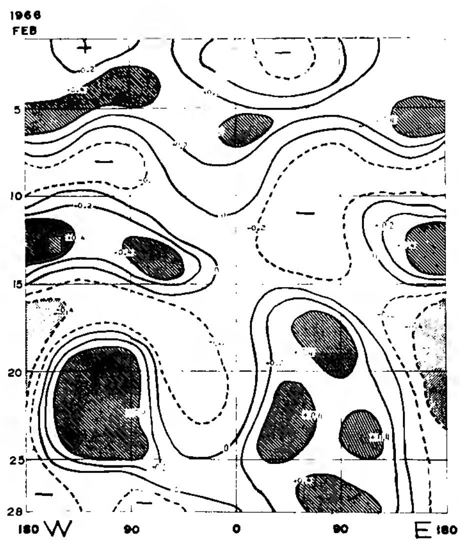

Fig. 2(c). Time section of Δf_{min} along 60°N circle in Feb. 1966. Others are same as in Fig. 2(a).

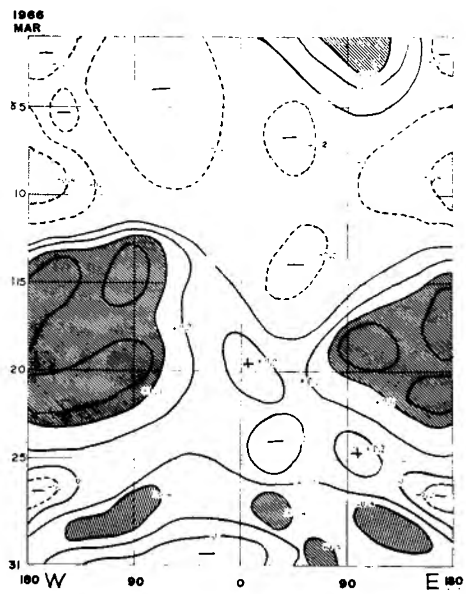

Fig. 2(d). Time section of Δf_{min} along 60°N circle in Mar. 1966. Others are same as in Fig. 2(a).

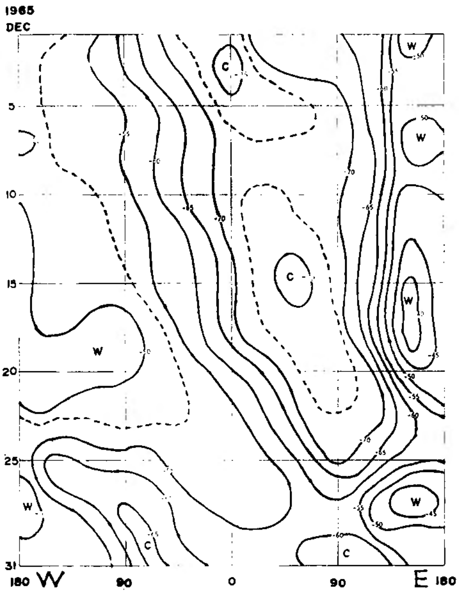

Fig. 3(a). Time section of temperature obtained by thickness between 10–30 mb along 60°N circle in Dec. 1965.

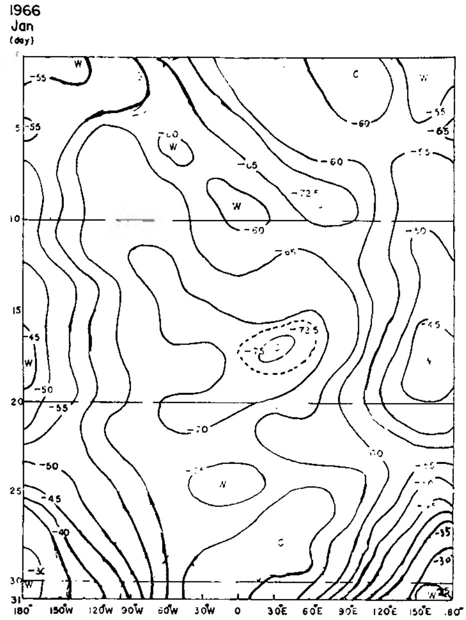

Fig. 3(b). Time section of temperature in Jan. 1966. Others are same as in Fig. 3(a).

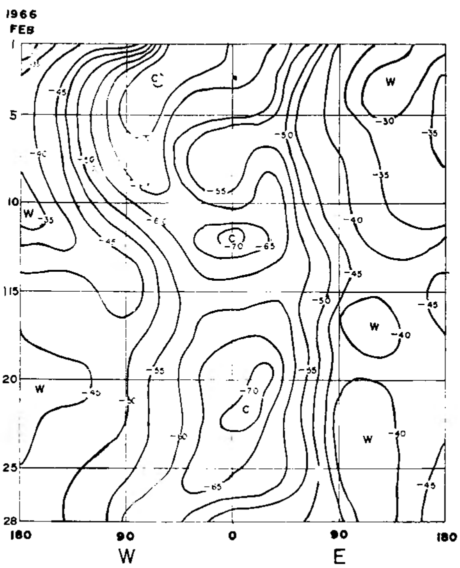

Fig. 3(c). Time section of temperature in Feb. 1966. Others are same as in Fig. 3(a).

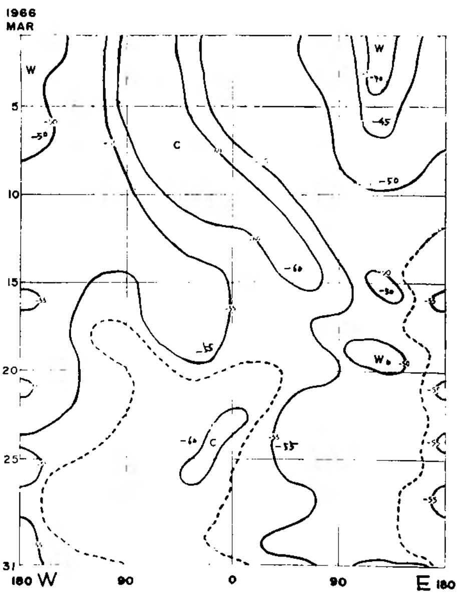

Fig. 3(d). Time section of temperature in Feb. 1966. Others are same as in Fig. 3(a).

Dec. 1965 to Mar. 1966, respectively. Positive values of Δf_{min} signify the relatively stronger absorptive region than the normal, and the region shaded by the oblique lines is the appreciably strong one. In the region shaded by dots where the values of Δf_{min} are negative, absorption is appreciably less than the normal. These show that unusual absorption has a large horizontal scale (1000 to 10000 km order) as pointed out by Thomas [1961], and a life time of a few days.

(2) *The temperature field in the middle stratosphere*

In order to describe the large scale pattern of temperature, the thickness is more appropriate rather than radio-sonde data themselves, since the latter data have, sometimes, irregular fluctations of 7-8°C at a level of 10-mb (Yamamoto [1967]). With the aid of the Northern Hemispherical Maps issued from Berlin Free University (Scherhag *et al.* [1966, 1967]), the distribution of temperature is determined from the thickness between 10- (~30 km) and 30-mb (~24 km). Figs. 3(a), (b), (c) and (d) are the time section along a 60°N circle of the temperature thus obtained. According to the analysis by Williams [1968], the sudden warming was observed during 1-10 Feb. 1966, near 50°N. In Fig. 3(c), also, unusual warming over −25°C can be found about 3 Feb. near 150°E.

(3) *Planetary waves in the stratosphere*

Many meteorologists (e.g., Deland [1964], Eliasen and Machenhauer [1965], Deland and Johnson [1968]) have shown that the planetary wave consists of a transient part and a stationary part by analyzing the hemispherical data below 10-mb level. In the present paper, the following method is adopted to separate the two parts of the planetary wave.

Fourier analysis is applied to the daily geopotential field, Z, along 60°N circle, and the amplitude of cosine term, $Z_c(n)$, and that of sine term, $Z_s(n)$, for each wave number, n, are obtained. The monthly mean value of $Z_c(n)$ and $Z_s(n)$ are assumed to be those of the stationary part, $\overline{Z_c(n)}$ and $\overline{Z_s(n)}$, and the daily deviation from the monthly mean to be those of the transient part, $Z_c'(n)$ and $Z_s'(n)$. Thus the geopotential field, Z, is analyzed as follows;

$$Z=\sum_{n=0}^{\infty}[(Z_c'(n)\cos(n\phi)+Z_s'(n)\sin(n\phi))+(\overline{Z_c(n)}\cos(n\phi)+\overline{Z_s(n)}\sin(n\phi))], \qquad (2)$$

where ϕ represents the longitude.

3. Discussion

On the basis of Figs. 2 and 3, the interrelationships between the stratospheric temperature change and the absorption anomaly in each month will be discussed.

(1) The stratospheric temperature and the absorption

Our attention is given to whether the appearance of a relatively stronger absorptive region might coincide or not, in time and location, with that of the stratospheric warm region. In Dec. 1965 (Figs. 2(a) and 3(a)), the warmer region and the strong absorptive region which appeared on 12–20th near 150°E–90°W are similar, in horizontal- and time-scale. On the other hand, another strong absorptive region during 26–31st near 90°E–150°E appears over a rather cooler region centered on 25th at 90°W. In other cases, we can not find clear correspondence between the strong absorptive region and the warmer region. In Jan. 1966 (Figs. 2(b) and 3(b)), there is a clear time and geographical correspondence between both these regions, on 2nd near 100°W. Other cases do not show clear correspondence, in particular, the strong absorption on 25th at 90°W does not correspond to any warmer regions. In Feb. 1966 (Figs. 2(c) and 3(c)), four strong absorptions appear on 5th at 150°E, on 13th at 150°E, on 23rd at 120°W and on 24th at 100°E, and clearly correspond to warmer regions, respectively. In this month, nearly all cases show clear correspondence. In Mar. 1966 (Figs. 2(d) and 3(d)), the strong absorption on 3rd at 90°E corresponds to the remarkable warm region. Except in this case, no other

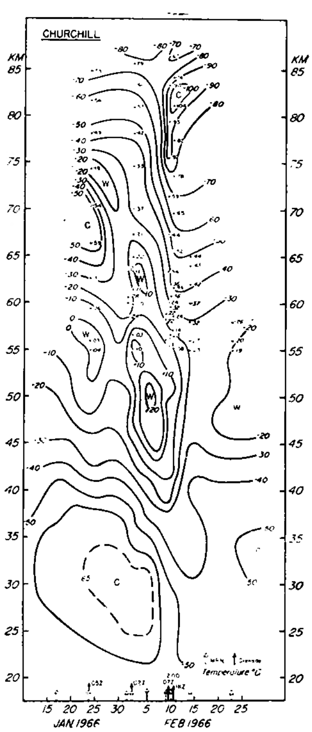

Fig. 4. Time section of temperature for Fort Churchill, Canada, based upon four rocket observations and nine small meteorological rocket soundings during Jan.~Feb. 1966. (after Quiroz [1969]).

correspondences are found; in particular, there is no warm region in the case of the strong absorption centered on 17th at 180°E.

In conclusion, it may be mentioned as a result of this analysis that the occurrence of unusual stratospheric warmings near 30 km height is a sufficient condition for that of the absorption anomaly in the D-region near 75 km height but not a necessary condition. It shoud be noted that this observation is not made for temperature changes in the upper stratosphere and the mesosphere, but for that in the layer of the middle stratosphere. In fact, when a remarkable absorption was found about 25th Jan. 1966, at 90°W (Fig. 2(b)), a noticeable inversion of temperature is found in the mesosphere (Quiroz [1969], Fig. 4), although no unusual warming appears in the middle stratosphere.

(2) *The planetary wave and the absorption*

Taking account of the fact that the life time of the absorption anomaly is generally a few days, the transient part of the planetary wave is taken for comparison. For this purpose, the daily values of Δf_{min} along the 60°N circle are analyzed into zonal harmonics for wave numbers one, two and three.

The daily values of amplitude of Δf_{min} and the planetary wave at 10-mb surface are shown in Figs. 5(a), (b) and (c) for each wave number, respectively.

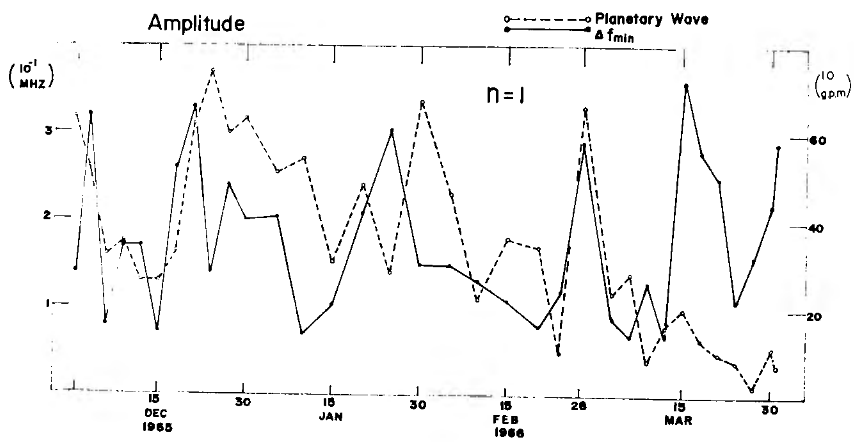

Fig. 5(a). Daily changes of both amplitudes of Δf_{min} (full line) and the transient part of the planetary wave at 10-mb surface (dotted line) at 60°N during Dec. 1965～Mar. 1966 for wave number one.

For wave number one, the remarkable peaks of amplitude of the absorption appear five times in the period considered here, on 6th Dec., 21st Dec., 26th Jan., 1st Mar. and 15th Mar. These peaks are quite significant and have values nearly equal to, or greater than 3×10^{-1} (MHz), and those of the planetary wave appear four times on 1st Dec., 24th Dec., 30th Jan. and 1st Mar. Among the five peaks of Δf_{min}, the first four appear nearly simultaneously with those of planetary waves. When the last peak of Δf_{min} appears in Mar., no remarkable peak of the amplitude of planetary wave can be found. Concerning wave number two shown in Fig. 5(b), relatively unusual peaks appear four

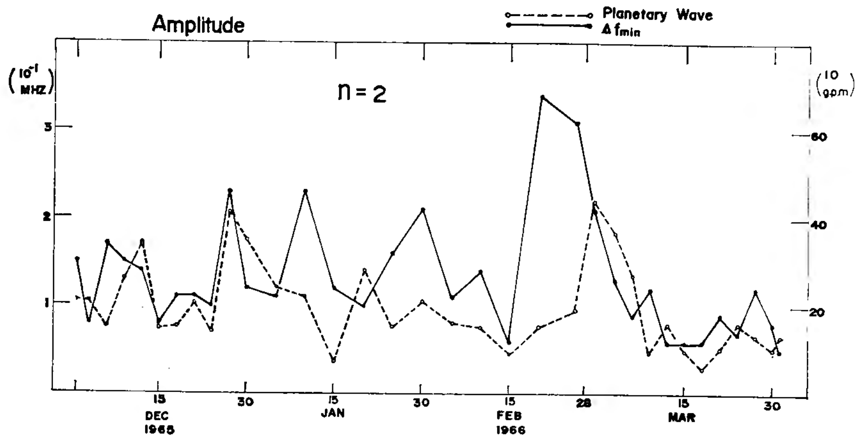

Fig. 5(b). Daily changes of both amplitudes for wave number two. Others are same as in Fig. 5(a).

times in Jan. and Feb. 1966, with the value of Δf_{min} greater than 2×10^{-1} (MHz). There are, however, no remarkable peaks of the planetary wave corresponding to that of Δf_{min}. In Dec. 1965 and Mar. 1965, their daily changes of the amplitude have some similarity. And in Jan. and Feb. 1966, there are no remarkable peaks of the planetary wave corresponding to the three signifi-

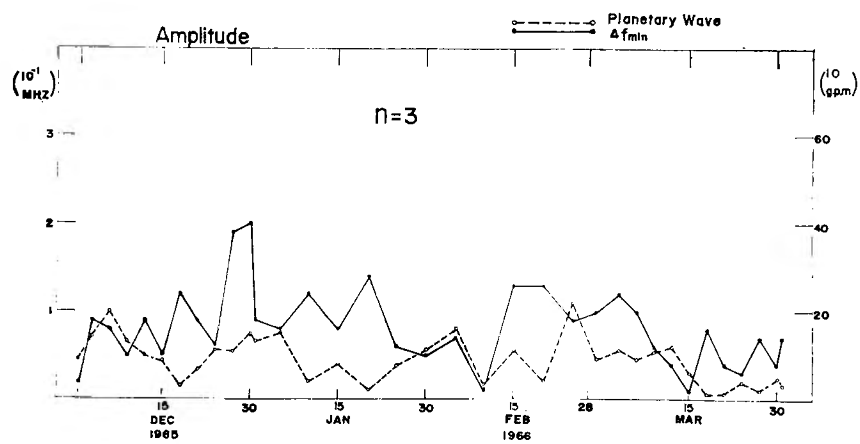

Fig. 5(c). Daily changes of both amplitudes for wave number three. Others are same as in Fig. 5(a).

cant peaks of Δf_{min}. For wave number three given in Fig. 5(c), although several peaks of Δf_{min} appear, most of them have values less than 1.5×10^{-1} (MHz), and these are less than the values of wave numbers one and two. Therefore, the disturbance of wave number three may play no important role in the absorption anomaly.

In conclusion, the simultaneous time changes of the two amplitudes of the absorption and the planetary wave are shown for wave number one in Dec. 1965, Jan. and Feb. 1966.

Daily values of the phases of Δf_{min} and the transient part of the planetary wave at 10-mb surface are shown in Figs. 6(a), (b) and (c), respectively. Full lines and dotted lines in these figures represent the phases of both Δf_{min} and the planetary wave.

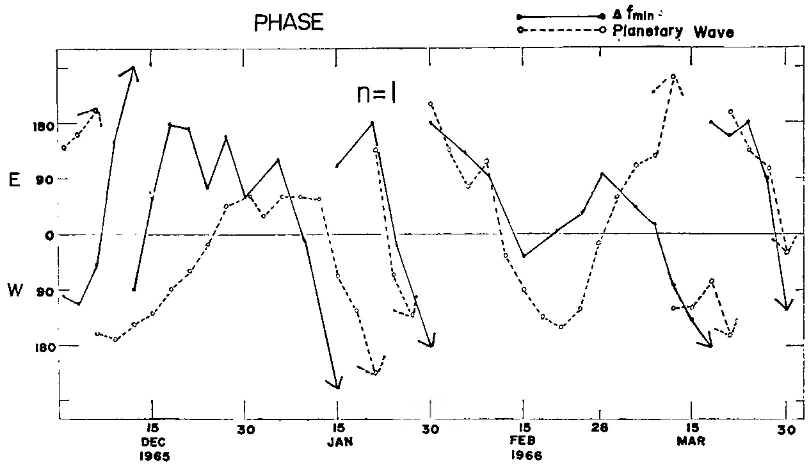

Fig. 6(a). Daily changes of both phases of Δf_{min} (full line) and the transient part of the planetary wave at 10-mb surface (dotted line) at 60°N during Dec. 1965~Mar. 1966 for wave number one.

The daily change of the phase of Δf_{min} for wave number one given in Fig. 6(a) shows that the point of the strongest absorption moves eastwards till 18th Dec. with a speed of about 40° longitude/day. Following westward movement ceases about 15th Feb. and is replaced by a slow eastward movement. Westward displacement again begins about 1st Mar. with a speed of about 20° longitude/day. On the other hand, the planetary wave moves eastwards from 1st Dec. to 1st Jan. 1966 with a speed of about 10° longitude/day, in average, and from 1st to 15th Jan., is stationary near 60°E. After this, the westward movement of the wave continues with a speed of about 15° longitude/day until 21st Feb., and then, the movement changes to an eastward one with a speed of about 20° longitude/day.

Concerning daily changes of both phases of wave number one, the direction of both movements are opposite after the middle of February and, except for this period, their general movements may be said to be similar, in speed and direction. For the two phases of wave number two given in Fig. 6(b), it may

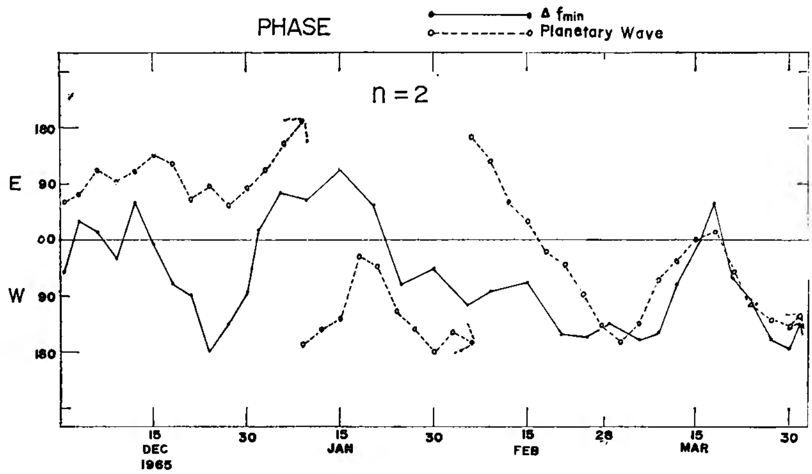

Fig. 6(b). Daily changes of both phases for wave number two. Others are same as in Fig. 6(a).

be said that their modes correspond well in speed (about 30° longitude/day) and direction during nearly all the period, except the difference of speed from 15th to 30th Dec. 1965.

Concerning both phases of wave number three given in Fig. 6(c), the sys-

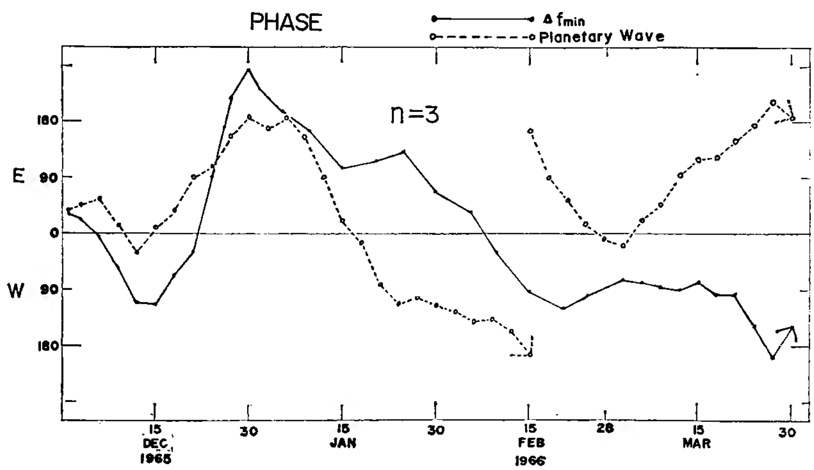

Fig. 6(c). Daily changes of both phases for wave number three. Others are same as in Fig. 6(a).

tematic similarity in speed and direction of both waves is apparent until 18th Feb. 1966. However, after that time, their movements become opposite in direction. Bearing in mind that the amplitude of this wave number is considerably smaller than that of wave numbers one and two, there is no necessity to discuss in detail the relation of these two phases.

In conclusion, for the relation of the daily values of those two phases, it may be said that in this case study, both movements have a similar daily change during the three months of Dec. 1965, Jan., Feb., 1966, for wave numbers one and two.

4. Concluding remarks

Daily analysis of large scale patterns of middle stratospheric conditions and the absorption anomaly in the D-region give the following aspects;

(1) Appearances of sudden warmings in the middle stratosphere are always associated with the absorption anomaly, but, occurrences of the latter do not always correspond with the warming.

(2) Both amplitudes of the strong absorption and the transient part of the planetary wave show a similar daily change in the mid-winter season for wave number one, i.e., they reach a maximum nearly simultaneously.

(3) The phase change of absorption represents similar movement to that of the transient part of the planetary wave at 10-mb surface, in speed and direction, for wave numbers one, two and three, except for both movements of wave number two after the middle of Feb. 1966.

From the point of view of the results mentioned above and the spatial- and time-scales of the absorption anomaly, it should be noted that the dynamical effects of the planetary wave may be one of the important factors in the occurrence of the absorption anomaly in the D-region.

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