On the Mutual Relation between Stratosphere and Troposphere during Periods of Stratospheric Warmings in Winter1

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ABSTRACT

An investigation of tropospheric conditions before and after pronounced stratospheric midwinter warmings indicates an interdependence of developments in the two atmospheric regions.

The eleven northern hemisphere winters which have been investigated show that every two years the behavior of the stratosphere is similar as regards the location of the initial warming, direction of movement of systems, and subsequent response of the troposphere.

Every second year the midwinter warmings begin in the stratosphere above the eastern United States and Canada, as illustrated in the published examples from 1957 and 1963.

During the alternate years of the cycle the warmings originate over central and eastern Europe. In this paper the emphasis has been placed on this type of warming. The tropospheric circulation patterns before each warming of this kind are analogous, and the warming is followed after about ten days by a blocking situation at sea level.

It is likely that there is a connection between the 26-month cycle in the stratospheric winds in the tropics and the cycle in the stratospheric warmings.

1. Introduction

Since 1958 the Stratospheric Research Group of the Free University of Berlin has analyzed and published daily synoptic maps of the 100-, 50-, 30-, (or 25-) and 10-mb levels for the northern hemisphere. (Free University, Berlin, 1960-1964).

By means of these maps it was possible to investigate the stratospheric circulation during the seven winters from 1957/58 to 1963/64. A result of this investigation was the discovery of similar behavior patterns of the stratospheric midwinter warmings in alternate years in the middle stratosphere.

These warmings begin in December, January, or February, either over the southeastern United States or over southeastern Europe. Some of them occasionally lead to a complete breakdown of the stratospheric polar vortex, but the vortex was reestablished in all the cases studied. One must be careful to distinguish between this type of stratospheric warmings and the final spring warmings, which, in the stratosphere, bring about the change from a winter to a summer circulation.

The first reported stratospheric midwinter warming occurred in 1952 (Scherlag, 1952). Today the midwinter warmings of the years 1956/57, 1957/58, and 1962/63, are well known through several publications (Teweles, 1958; Teweles and Finger, 1958; Craig and Hering, 1959; Scherlag, 1960, 1963; Reed, 1963a and b; Finger and Teweles, 1964).

There were, however, midwinter warmings in the middle and upper stratosphere every year, although not so strong that they led to a breakdown of the stratospheric polar vortex. Nevertheless, these minor warmings seem also to be interesting and worth studying. Perhaps one of the reasons why these warmings are not so well known is that they generally occurred at the 10-mb level. Over Europe they were often observed only by the radiosonde stations in Berlin and Vienna, because only these two stations regularly reach this height.

2. The two types of stratospheric midwinter warmings

If one compares the eight winters for which daily stratospheric maps are now available, with respect to the behavior of the stratospheric midwinter warmings, it appears that these warmings can be divided into two types, American and European:

1) Direction of movement enables primary classification;
2) Each type of warming starts after a particular tropospheric circulation pattern over a certain region;
3) The European type is followed by a pronounced blocking pattern in the troposphere.

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Fig. 1. The synoptic situation in the middle troposphere immediately before the stratospheric warmings. Units are geopotential dekameters. Contour interval 8 dekameters on the 500-mb and 16 dekameters on the 300-mb map.

Fig. 1 shows the synoptic situation in the middle troposphere immediately before the beginning of the well known stratospheric warmings in January 1957 and 1963, and also before the less known warmings of January 1959 and 1961. The maps are the three-day means for 500 and 300 mb immediately before the warmings began in the stratosphere.

After this synoptic situation in 1957 and 1963 very strong warmings followed, but also in 1959 and 1961 anticyclones with accompanying warm areas formed at the 10-mb level. It is remarkable how similar are the situations in Fig. 1, all showing a very strong jet stream in the region above which the warmings started, a fact mentioned by Tewes (1958) in his description of the warming in January 1957.

The map at the left in Fig. 2 shows the direction of movement, at the 10-mb level, of the highs which were connected with the warmings of the years 1957, 1959, 1961, and 1963. In all these four years the warmings originated over the same region, following the tropospheric conditions shown in Fig. 1. All of the paths have a net eastward movement, but the two major warmings later spread northward, causing a breakdown of the stratospheric polar vortex. But also in the intervening years stratospheric midwinter warmings were observed. The right hand side of Fig. 2 shows the tracks, at the 10-mb level, of the highs, which were connected with the warmings of the years 1958, 1960, 1962, and 1964.

It is striking that all of these highs originated between 30 and 70°E and that right from the beginning they all moved retrogressively. This is well known about the warming of 1958 (Scherhag, 1960). But also in 1960
highs at the 10-mb level moved westward (Labitzke, 1962), crossing Europe first on 25 January and again on 25 February. In 1962 and 1964 only a part of the warmings reached Europe, since the associated anticyclones stayed over Russia and Asia Minor, but from the radiosonde ascents there is no doubt that warmings took place.

From Table 1 it can be seen that over Berlin the stratosphere at 11 mb warmed from $-70$ to $-28^\circ$C in the middle of February 1962, and at 10 mb from $-72$ to $-34^\circ$C at the end of January 1964.

The tropospheric circulation at 500 and 300 mb, averaged over the three days immediately before the warmings started, is shown in Fig. 3. It is obvious that the preludes to the warmings are very similar. In each instance a strong northwesterly jet stream is situated over western Europe, obviously the strongest jet on the map, with a pronounced exit area.

The synoptic situation at sea level immediately before the warmings is shown in Fig. 4 as deviations of three-day means from normal, and the similarity of the patterns is again clearly to be seen. Shortly after these tropospheric circulation patterns the stratospheric warmings started, and this agrees with the ideas of Teweles (1958) and Boville (1960), who assumed that the vertical motions produced by strong cyclonic activity are the possible cause of the stratospheric warmings.

3. Tropospheric developments following the European type of stratospheric warmings

About ten days after the beginning of the stratospheric warmings, pressure rose over Europe, blocking patterns formed, and, as seen in Fig. 5, the large negative deviations of ten days before were replaced by large positive deviations from normal. The positive deviations persisted from one to three weeks in the blocking situations which followed the warmings. Furthermore, in 1958 and 1960 also the second warmings were followed by such positive deviations. This was
shown for the warmings of 1958 by Scherhag (1960) and for 1960 by Labitzke (1962). Fig. 6 shows the total pressure change from the prelude to the warmings to the period about ten days later.

Naturally, the stratospheric midwinter warmings are not a necessary condition for blocking action, but there was no stratospheric warming of the European type which was not followed by blocking within about ten days. In the years when the European warmings took place an examination of the months January, February, and March failed to show a similar chain of events at sea level over Europe which was not connected with a stratospheric warming.

The synoptic situations in the middle troposphere before the European type of warming, which are shown in Fig. 3, were all characterized by a strong northwesterly jet stream on the rear side of a trough whose axis generally tilted southeastwards. This is a situation favorable for transport of angular momentum to lower latitudes. According to Elliott and Smith (1949) and Namias and Clapp (1951) it is also a favorable situation for the initiation of blocking. The stratospheric warmings of the European type might therefore be taken as a second indicator and give additional support for a forecast of blocking.

4. A likely link with the 26-month cycle

When looking for an explanation of this apparent two-year cycle it seems obvious to link it with the fairly
recently discovered 26-month cycle of the winds in the tropical stratosphere.

Fig. 7 shows the direction of the winds at 10 and 30 mb over Canton Island in January, and the tendency of the direction, to indicate the phase within the 26-month cycle. During this period the European warmings always took place when the tendency of the cycle was towards easterly winds. This means that the European midwinter warmings always occurred in the same phase of the 26-month cycle.

This may be the first synoptic indication of the existence of the 26-month cycle in higher latitudes.

As mentioned above, the first winter in the continuous series of daily stratospheric analyses was that of 1958. A connection between the 26-month cycle and the European type of stratospheric midwinter warmings would mean that these warmings with the associated tropospheric circulation patterns should have taken place also in the winters 1954 and 1956. There is evidence (Table 1) that warmings occurred over Europe in 1954 and 1956 too. In Fig. 8 the tropospheric conditions, expressed as deviations from normal as in the previous figures, are similar to those in the winters of 1958, 1960, 1962, and 1964: large negative deviations immediately before the presumed warmings, followed about eight days later by large positive deviations; the total pressure change amounting to 60-70 mb.

5. Conclusions

1) The stratospheric midwinter warmings in the years investigated can be divided into two types
Fig. 5. The deviation of the three-day mean from normal pressure, at sea level, about ten days after the beginning of the stratospheric warmings. Units are millibars.

with respect to their origin and direction of movement: European and American.

2) The warmings started after similar synoptic conditions when extremely strong cyclonic activity presumably initiated the stratospheric warmings by strong vertical motions.

3) The occurrence of the European type of warming indicates a special state in the atmosphere which will lead, within about ten days, to a persistent blocking pattern.

4) The European type of warming occurs when the wind oscillation in the tropics tends to east in the middle and higher stratosphere. The American type occurs when the tendency of the oscillation is to west. This may be the first synoptic evidence of the existence of the 26-month cycle in higher latitudes.

Statistical investigations by Landsberg et al. (1963) fit into these results. They showed, "a tendency for the biennial pulse to become locked in phase with the season of the year," and, "that in the Northern Hemisphere there is some preference for the maxima to occur in winter, especially in January, February, and March."

Because the period of the oscillation is longer than two years, it must be expected that the cycle of the stratospheric warmings, as shown here, will get out of phase with respect to the winter season in the following years. There are indications that this was already beginning in the winter 1963/64. As Landsberg et al.
Fig. 6. The total pressure change at sea level from immediately before to about ten days after the beginning of the stratospheric warmings. Units are millibars.

<table>
<thead>
<tr>
<th>JAN/YEAR</th>
<th>10 MB</th>
<th>30 MB</th>
<th>MOVEMENT OF THE STRAT. WARMINGS</th>
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<tr>
<td>1954</td>
<td>E→E</td>
<td>E→E</td>
<td>P</td>
</tr>
<tr>
<td>1955</td>
<td>?</td>
<td>W→W</td>
<td>P</td>
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<tr>
<td>1956</td>
<td>E→E</td>
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<td>1957</td>
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<td>1963</td>
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<tr>
<td>1964</td>
<td>E→E</td>
<td>W→E</td>
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Fig. 7. Winds over Canton Island in January at 10 and 30 mb and their tendency within the 26-month cycle, compared with the movements of the stratospheric warmings. Heavy letters indicate wind maxima.
Fig. 8. a) Deviation of the three-day mean from normal immediately before; b) about eight days after the beginning of the stratospheric warmings; c) Total pressure change at sea level, from immediately before to about eight days after the beginning of the stratospheric warmings. Units are millibars.
pointed out, the cycle should be in phase again after 14 to 17 years. It is interesting to note that Elliott and Smith (1949) in their investigation of blocking, which covered the years from 1899 to 1938, found a long-term oscillation of occurrence of blocking with a period of about 14 years.

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REFERENCES


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