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THE 1974/75 STRATOSPHERIC WINTER

NR WATSON

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SUMMARY

In August 1974, new stratospheric warming definitions were proposed. These were used for the first time during the northern winter of 1974/75 by the Stratospheric Research Group at the Free University of Berlin in issuing STRATWARM alert messages. This paper describes the features of the stratospheric circulation, in relation to the warmings of the winter. The examples of the circulation changes which occurred, mainly at 10 mb, were taken from the daily chart series prepared in the High Atmosphere Branch at Bracknell.

Examples of the kinetic energy changes and the vertical motion in the stratosphere during warming periods are also presented.

The Stratospheric Warming Alert System

In November 1973, the WMO Commission for Atmospheric Sciences (CAS) noted that adequate explanations for major stratospheric warmings were still not available and that the phenomena had not been observed in sufficient detail. Although the stratospheric warming alert system had first been introduced during the IQSY in 1964 and much information had subsequently been accumulated about the warmings, there remained many problems outstanding. It was considered that the studies of stratospheric problems would benefit from a concerted effort to gather as much information as possible during all stages of the winter warming period. A new improved alert system would allow investigators to schedule observations during the times of maximum scientific interest. Consequently a Rapporteur was appointed by the CAS working group on Stratospheric and Mesospheric problems to review the criteria for STRATWARM alert messages and the observational programme required on receipt of such messages. The Rapporteur in question, Dr Karin Labitzke, Free University of Berlin, met with a working party composed of interested workers at Wallops Station, Virginia in August 1974 and new criteria were proposed for use in the 1974/75 northern winter. It was agreed that the Stratospheric Research Group of the Free University of Berlin would initiate daily messages on the 10 mb circulation and issue the alerts when appropriate.

The new definitions for the warmings were formulated as follows:

a) A warming is called MINOR if there is a temperature increase, of 25°C in a week or less, observed by balloon or rocket sondes or radiances measured from satellites, at any stratospheric level in any area of the wintertime hemisphere. Warmings not meeting these criteria may be said to be local warmings.

b) A stratospheric warming is said to be MAJOR if at 10 mb or below the latitudinal mean temperature increases poleward from 60°N and an associated circulation reversal is observed (ie net mean easterly winds are established north of 60°N). A STRATALERT would therefore be issued when temperatures rose over an area by at least 25°C in a week or less.

A GEOALERT/STRATWARM Alert message would be initiated when the temperature rose at least 30°C in a week or less at 10 mb or below, or at least 40°C above 10 mb.

The 10 mb level was chosen as the key level because it was the highest level that could be analysed daily at Berlin with any degree of confidence. It was assumed that maximum use would be made of satellite radiance data eg from the Selective Chopper Radiometer (SCR) instrument on Nimbus 'E', and a link was established between Oxford and Berlin to pass this information. This data provided an 'early warning' of the subsequent warmings at 10 mb by detecting them at higher levels.

The daily alerts were issued by Berlin at 1400Z, received by the High Atmosphere Branch at Bracknell by about 1430Z and then redistributed to interested groups in the UK.

On receipt of a STRATALERT message concerning a MINOR or MAJOR warming, the various meteorological rocket stations throughout the northern hemisphere were prepared to fire rockets at an increased rate. Firing rates of up to 3 times per week were thought necessary depending on the location of the warm area in relation to the rocket station. The Metrocket group of the High Atmosphere Branch at Bracknell fired 22 skua rockets in all during two detatchments to West Geirinish, Hebrides in December 1974 and Jan/Feb 1975. The ROCOBS provided information up to about 65 km but only data below about 30km (10 mb) were used in the daily series of charts produced by the Stratospheric Analysis Group in Bracknell.

Stratospheric Analysis

Daily hemisphere charts at 50, 20 and 10 mb for 00Z have been drawn by the Stratospheric Analysis Group of the High Atmosphere Branch since April 1974. These charts are drawn from radio sonde data and, when available, rocket sonde observations (ROCOBS), but no satellite data are used. The ROCOBS are very valuable in determining the wind field at 10 mb especially over the polar cap, since few radiosondes reach that level during the winter. The paucity of observations at 10 mb means that an individual chart may take 10 or more days to finalise before the analyst is confident that continuity of flow pattern has been achieved. It is from this series of charts, mainly at 10 mb, that the major features of the 1974/75 winter stratospheric circulation will be discussed.

10 mb Circulation Changes

a) Summer to winter

The normal summertime circulation above about 20 mb is a general easterly flow around a warm anticyclone centred over the pole. The wind field near the Equator is dominated by the quasi-biennial oscillation which in the summer of 1974 was easterly about 60kt at 20 mb and was changing rapidly from easterly to westerly at 10 mb.

Figure 1 (taken from Murgatroyd[1]) shows the mean summer and winter zonal wind and temperature conditions to be expected.

The warmest air occurs at about 1 mb (47 km) over the summer pole, while at 10 mb the pole temperature is about -25°C decreasing steadily to about -50°C at the equator.

In mid July 1974 the 10 mb anticyclone was symmetrically placed over the pole with a central height of 3230 gdm and an easterly wind of 20-25 kt over the UK.

By late August the high had declined to 3150 dm and had moved to Alaska, as small cold pools began to appear in mid latitudes. The first sign of the polar vortex appeared in mid September near Novaya Zemlya and it deepened and moved eastwards around the pole. By the end of September it lay over the Canadian arctic 3048dm(-55°C) while the remains of the summer high were displaced across the Pacific and NW Atlantic (-45°C).

Cooling continued during October with further deepening of the polar vortex down to 2976 dm in early November over Greenland and with temperatures falling to -68°C. During November the main low split and then reamalgamated with troughs swinging eastwards across Siberia and Alaska. It was late in the month when the Aleutian anticyclone became finally established after the eastward passage of such a trough into the US. By early December the 10 mb circulation reached its "classical" winter state with a low 2856 dm near Novaya Zemlya and a high 3108 dm over the Aleutians Islands. The coldest air, -75°C, lay just to the west of the vortex, with the warmest air (-35°C) over China and Kamchatka (Figure 2)

b) Early Winter Warming

The first minor warming alert was issued on 14 December when temperatures over Southern Europe rose to about -25°C. Figure 3 shows the changes in the 30, 20 and 10 mb temperatures at Vienna during the period 10-19 December 1974. The 10 mb temperature rose 35°C in about 4 days and then fell to its original value again; the 20 mb temperature showed only small fluctuations while the 30 mb temperature change was in the opposite sense to that at 10 mb. The cause was a temperature wave that crossed the Atlantic from the Caribbean and then moved farther east into Asia. As this warm wave was moving east over the Atlantic, the 10 mb trough over Canada was intensifying so rapidly that from the 8 to 15 December it developed into the major low as it moved from the Canadian Arctic north eastwards to Spitzbergen. The original low which at the beginning of the month was near Novaya Zemlya degenerated into a trough which weakened rapidly as it rotated eastwards.

These rapid changes at 10 mb were probably indicative of much more violent changes in the middle and upper stratosphere. On the 13 December, the rocket sonde observation at West Geirinish showed an extremely strong wind belt at 55 km, the wind and temperatures profiles are shown in figure 4. The maximum wind speed of 173msec^{-1} (~340kt) at 55km, (the mean between 54 and 56km) is very near the highest ever recorded over Scotland.

From the 18 to 26 December, the 10 mb vortex (2830 dm) near Novaya Zemlya and the Aleutian High (3108dm) remained stationary and very strong northwesterly winds

(~ 150kt) blew across the Canadian Arctic.

c) Mid-Winter Warming

Just before Christmas the first signs of the warming appeared in the satellite data. Radiances in the B_{12} and B_{23} channels of the SCR showed maxima over Europe which moved eastwards with time. By 26 December, the temperature increases at 10 mb reached minor warming proportions over China and South Siberia, and by 1 January the warmest air (-8°C) was located over Central Siberia. The subsequent rise in contour heights over central and western Asia caused the vortex to weaken and move south west to northern Sweden by 7 January. Between 1 and 7 January the warm air had moved north eastwards to the Canadian Arctic, raising the 10 mb North Pole temperature to -28°C. The reversal of the meridional temperature gradient occurred by 3 January and the maximum temperature was located over the pole by 9 January.

Although the air over the Arctic then began to cool, warming still occurred over the Atlantic and Europe. Temperatures over Central Europe rose from -72°C on 9 January to -55°C on 18 January and a high cell (3072dm) appeared over the central Atlantic. This cell moved east across Europe and declined over Turkey by 24 January.

The pronounced wave number 2 pattern, which sometimes occurs shortly after warmings, showed up well on 20 January with the European and Aleutian highs and two lows, one over Canada the other over Siberia (figure 5). Later in January the Siberian low declined into a trough, leaving the main vortex (2880dm) over N Greenland. It is interesting to note that on 1 January, the highest and lowest temperature on the 10 mb chart were - 15°C and -82°C, a differential of 67°C. As a result of the warming, by the end of the month this differential had decreased to 20°C ie -45 to -65°C. These temperature changes can be plainly seen in figure 6 which shows cross sections over the pole and along the Greenwich Meridian.

The effect of the warm air to the north was to reduce the westerly flow at 10 mb due to the easterly thermal winds that were established. Although the 10 mb zonal wind at 60°N decreased by half in a week (29 Dec to 5 Jan) (figure 7), it did not turn easterly, so no "major warming" occurred. However, a major warming did occur at 1 mb (48km), where easterly winds were blowing to the north of 65°N by 2 January[3].

Early in February, further anticyclonic development over the UK and the Aleutians split the main vortex into two centres, over Hudson's Bay and Siberia. The UK high collapsed by the 11 February allowing a strong westerly flow to spread across Europe. The Hudson Bay centre degenerated into a trough by 15 February and swept eastwards across the north Atlantic so that by 22 February one main symmetrical vortex remained near Heiss Island (80°N 58°E) and the mean zonal wind at 60°N reached the highest level of the winter (see figure 7). By 25 February the temperature over Scandinavia had fallen to -70°C again but the satellite data showed warm air high over central Russia.

d) The Final Warming 27 February - 17 March

The first indication of the final warming was the development of a warm area (-40°C) over Manchuria at 10 mb on the 24 February. This area moved northwest across the wind flow and became steadily warmer over the next few days. A minor warming alert was issued on 27 February for the area near 58°N 110°E. For the next 2 to 3 weeks the warmest air at 10 mb moved little from this position reaching a maximum temperature of -5°C on 3 March. The warm air began to move northeastwards from Siberia on 26 February and the first warm pulse reached the pole on 10 March. The warm air, spreading to and over the pole, can be seen in figure 8, which shows the time variations of the 10 mb temperatures on a section from 50°N 90°W to 50°N 90°E. In the middle of the warming, the 10 mb temperatures over some areas of the Russian Arctic, rose by over 30°C in a week. The 10 mb zonal mean temperatures during the final warming are shown in figure 9. The meridional temperature gradient on 24 February was about -0.5°C/deg lat at 70°N, by 6 March the temperature gradient was about zero, and then it became positive (ie a normal summer situation). The Figure 10 shows two vertical temperature sections over the pole and through the Greenwich meridian during and after the warming. Comparisons between these and sections for the mid winter warming (figure 6) are interesting. Although the initial conditions on both occasions were similar the results were substantially different. The mid winter warming produced almost an isothermal temperature field at 10 mb (~ 30km) but a cold polar core was maintained at 50 mb (~ 20 km). The final warming, however, extended down throughout most of the polar stratosphere and produced a temperature section very similar to summer conditions. The extent of the warming in the upper stratosphere can be seen in the temperature profiles from the rocket sonde observations at Volgograd (49°N 44°E) (figure 4). Between 26 February and 5 March, the air below 55 km became warmer (at 35 km, by as much as 40°C) as the stratopause descended to 40 km and increased in temperature to 0°C.

The final warming was a simple wavenumber one type with the Aleutian High moving steadily northwards to the pole as the vortex filled and slipped southwards across Russia.

The effect on the geopotential heights between 28 February and 18 March is most striking. (See Figure 11(a) and (b)). The main vortex (2840dm) near 75°N 80°E, began to fill and move westwards immediately the warm air appeared over China. The Aleutian High intensified and began to edge north-eastwards as the warm air moved across Northern Alaska. By the 16 March both the vortex (2953dm), and high (3130dm), were equidistant from the pole at 70°N, northeasterly winds at 30 mb were flowing over Scotland and the zonal mean wind at 60°N had nearly turned to easterly (figure 7). All three criteria have been used independently by workers in the past to define the final warming, but at present no official definition of the final warming exists. 16 March occurs in the 15th pentad of the year and according to Ebdon[4] only once, in 1959, has the final warming occurred earlier.

By the end of March the high (3145dm) was centred at 80°N 120°W and the low had filled to 3030dm at 50°N 65°E. Air warmer than -45°C extended from Central Asia across the pole to Greenland and the Canadian Arctic, and a strong mean easterly flow was present north of 60°N. The strong winds eased in mid April when the air over the polar cap cooled a little and did not increase again until May.

Kinetic Energy Changes During the Winter

During the winter, measurements were made daily of the mean and eddy kinetic energies (KE) at 60°N. The definitions of these terms are:

$$\text{mean KE} = \tfrac{1}{2}\left([u]^2 + [v]^2\right)\frac{100}{g} \quad J\,m^{-2}\,mb^{-1}$$

$$\text{eddy KE} = \tfrac{1}{2}\left(\overline{u^{*2}} + \overline{v^{*2}}\right)\frac{100}{g} \quad J\,m^{-2}\,mb^{-1}$$

where the wind components at any point are given by $u = [u] + u^*$ and $v = [v] + v^*$. $[u]$ and $[v]$ are the zonal means, and u^* and v^* are the deviations from the means in $msec^{-1}$.

In general $[u] \gg [v]$ and for the average winter circulation at 10 mb, the mean KE is greater than the eddy KE.

However, during periods of stratospheric warmings, the increase in contour height over certain locations are substantial and they have the effect of increasing the local meridional wind speed and hence the eddy KE. Figure 7 also shows the mean and eddy KE at 10 mb at 60°N, plotted every day from mid December to late March. Assuming that the conditions at 60°N represent those over the winter polar cap, the features of the winter, already discussed, can be detected in the changes in the mean and eddy kinetic energies.

During late December the mean KE built up to a maximum and then rapidly decreased during the period of the mid winter warming. It then slowly increased to the highest of the winter, (21-22 February), in a series of increasing amplitude oscillations until finally there was a rapid loss of mean energy during the final warming.

The variation in the eddy KE is not as great as that of the mean, but it shows some marked periodicities and is generally out of phase with the mean KE.

This is most apparent during January and February when the mean KE is increasing. A fourier analysis of the eddy KE indicated a marked periodicity of about 15 days. This period has been noted before[5,6] with the suggestion that there was a lunar tidal effect influencing the stratospheric circulations.

Vertical Velocity Analyses

The fact that the day to day changes in the temperature pattern are generally not great considering the large horizontal wind speeds, implies that the air has a significant vertical motion over much of the winter hemisphere. In order to display the three dimensional nature of the flow, isentropic analyses were carried out during the winter for the 350°C potential temperature surface which lies between 20 and 30 mb. Figure 12 shows one such analysis for 28 February 1975, at the start of the final warming, on which streamlines and the height of the isentropic surface are drawn. The isentropic height field shows a high over the north western Atlantic and a low over north eastern Asia. The streamlines indicate that air passing near the centre of this low was displaced vertically by about 3 km, while ascending and moving over the pole to the North Atlantic. This ascent took about two days, while the descending air, moving more slowly over Europe and Central Asia took 3 days to return. During the descent into the Asian low, the air warmed up at the rate of about 15 degC per day and it cooled at about 25 degC per day as it ascended over the pole. This cooling rate is at least an order of magnitude greater than can be expected by radiational cooling alone.

An estimate was made of the vertical velocities involved assuming that the flow was adiabatic and the general pattern did not change significantly, from day to day. The main area of rising air on 28 February was located to the north of Alaska with a maximum vertical velocity of about $4 cmsec^{-1}$, while the core of the descending air was over central Asia with a vertical velocity of $-2\frac{1}{2} cmsec^{-1}$. It was found that the area north of 80°N was occupied entirely by ascending air. In fact when zonal means of vertical velocity are calculated with corrections for the slight height field changes with time, ascent it seen to have predominated north of about 65°N, with a maximum value of over $2 cmsec^{-1}$ at the pole (figure 13). This meridional profile during a warming is consistent with a two cell structure described by Perry[7] with ascent at low and high latitudes and descent in middle latitudes. Also shown in figure 13 is a similar profile for 17 March when the final warming was well advanced and the vertical velocities were decreasing.

Conclusions

The new alert system worked well in the 1974/75 northern winter. High level data were very useful to its application since without these data the analyst had no knowledge of any warming until it reached radiosonde levels or had been intercepted by a rocket sonde. Access to satellite data is therefore a prerequisite of any useful stratospheric alert system.

Even though no major warming occurred below 10 mb the 1974/75 winter contained many interested features. The very early final warming, together with the westerly phase of the quasibiennial oscillation have been shown by Ebdon to be important factors in determining the following summer's weather over south east England[8]. The hot, dry summer of 1975 certainly confirmed Ebdon's earlier suggestions.

Further study of the mid winter and final warmings, especially of the vertical motions present in the lower stratosphere, is continuing.

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