A Weather Situation with Strong Convection in the Middle Stratosphere

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Abstract

Two examples of convective cells in the middle stratosphere are demonstrated. They have been measured during two routine aerological soundings in Östersund, Central Sweden. The accuracy of the measurements of the vertical wind velocities (in one case amounting to some ten meters per second) is discussed. The phenomenon is explained from the weather situation, which is characterized by two cold-pools, one in the troposphere moving southwest from Russia and one in the upper stratosphere moving southsoutheast over Scandinavia from the North Pole region.

In early February 1953 two routine radiosondes launched at Östersund in Central Sweden (63° N, 15° E) indicated the existence of strong convective vertical currents in the middle stratosphere, 7 km above the tropopause and about 15 km above sea level.

The sounding result of the first radiosonde, sent up at 1500 GCT 4 February 1953, is illustrated in Fig. 1. The well defined tropopause is at the 8 km level, and in the stratosphere there are two separate temperature regions. The lower one extends up to 14.5 km with temperatures above — 59° C, and the upper region above 15.5 km has temperatures below — 64° C slowly decreasing with height to — 70° C at 20 km.

Between these layers there is an intermediate region with temperature gradients as high as 0.7° C per 100 m, and in the upper part of this region the radiosonde experienced highly variable vertical winds. At first the radiosonde entered a strong downward current, enough strong to force the whole sounding system down. The record suddenly showed an increase of pressure, and the operator assumed the sond to fall due to a bursted balloon. However, half a minute later the sonde left the strong downward current and began to rise again, at first rapidly and then in quite a normal manner. The winddriven commutator increased the angular velocity at time, indicating acceleration of the balloon or wind-shear between the sonde and the balloon. The details of this part of the sounding are examined with extremely care, and the result is shown in Fig. 2 with temperature plotted against pressure. Assuming the buoyancy force of the balloon to vary only slowly during the ascent and the ascending velocity of the balloon to be equal to 5 m/s when passing the convective cell, we obtain from the variations in calculated heights, the vertical velocities in the cell as measured by our sonde. The flight values are tabulated in Table 1 and from these values we obtain the downward wind velocity = 25 m/s and the upward wind velocity = 10 m/s with an error discussed later being about 50 per cent.

The second radiosonde was sent up at 1500

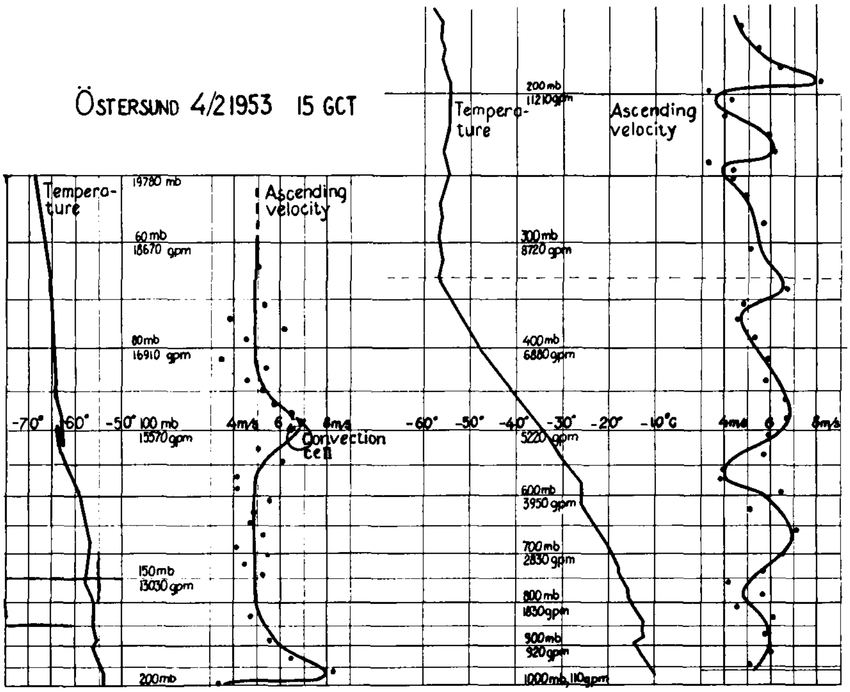


Fig. 1. The sounding made at Östersund (63°N, 15°E). Both temperature curves and curves of ascending velocity of the sonde are shown. The circular arrow indicates the location of the measured conventive cell.

GCT 6 February 1953, and the stratospheric part of the sounding is illustrated in Fig. 3. The temperature curve of the middle stratosphere is similar to that of 4 February, and in the upper part of the most unstable layer now situated between 13.5 and 14.2 km the sonde experienced a motion similar to the first sonde. The downward wind velocity of the cell was here not strong enough to force the sonde down, but the recorded pressure stopped falling and stayed at the same value for some ten seconds. The downward velocity measured here was 5 m/s and the upward velocity 3 m/s with an error of about 50 per cent.

The sounding equipment. The sounding system used at the Swedish aerological stations is the wellknown Finnish system. The reader not familiar with it is referred to a paper of TOMMILA and VÄISÄLÄ (1947). However, a short description of the functioning is necessary here, when discussing the errors in the above measurements.

The radiosonde is a variable radio-frequency oscillator, the variation of the radio-frequency by means of a variable condensor corresponding to the variation of the meteorological element. The receiver is a superheterodyne with variable beat-frequency discrimination. The recording pen is mechanically coupled to the condensor of the beat-oscillator, and by proper manual tuning the variation in the frequency of the radiosonde can be followed on the recording paper. Five intermittent signals of different frequencies are sent by the radiosonde, pressure, temperature, humidity, and two reference frequencies, and the operator has to follow all these signals one by one. Hence there is a limitation in the number o consecutive points in the record of one single element, the limitation depending upon the ability of the operator. It is also customary to devote more care to the record of temperature than to the other elements because of the more rapid random fluctuations in temperature than in e.g. pressure. The reference frequencies vary very slowly, hence it is not common to record them in more than 3—4 points per minute. Nearly the same holds for pressure and humidity, say 4—6 points, and the temperature records generally consist of 10 points per minute. Thus the record of pressure from which height calculations are made will not completely show the details in pressure variations with the sonde passing the convective cell.

The variations are smoothed out due to the sparsely recorded points. Important is, however, that we could state that the pressure variations recorded in this manner are not exaggerated. Another important smoothing influence is the hysterese in the pressure bulb.

The measurement of the vertical wind velocity by means of radiosonde height calculations. The ascending velocity of the radiosonde can be calculated from the consecutive height values of the sounding. This is made for the first entire sounding, and the values are demonstrated in Fig. 1. The sounding is divided into layers of about 300 m thickness, and the ascending velocity is calculated in every layer. The dots around the right curves in Fig. 1 indicate these values. The dispersion error is about 15 per cent at 1,000 mb and 50 per cent at 100 mb in these determinations. The curve drawn is smoothed with regard to this fact.

Some main features in the vertical velocity-height curve can be detected. The mean value of a layer of say 5 km thickness is estimated from the figure to be about 5.5 m/s in the lower troposphere and decreases slowly to 5 m/s or somewhat less in the stratosphere. This slow variation may be due to the variations in the buoyancy and frictional forces of the balloon. In the troposphere and the lower stratosphere there are wave-like patterns indicating gravitational waves in these layers. Above 13 km there is no indication of variations in the velocity up to the end of the sounding in the 19 km level, except in the 15—16 km layer where the convective cell is situated. This fact shows that the buoyancy force is practically constant in this region and that the ascending velocity of the balloon relative to the air is 4.9 m/s ± 0.3 m/s. In the 15—16 km layer there is a general upward motion, which may result of the compensation for the strong downward motions which seem to drive the convection in this layer.

The error in a measurement of the ascending velocity in such a small layer as about 300 m is rather large. It consists of an error in pressure measurement and an error in time interval measurement. The pressure error consists of two distinct parts, the first is an instrumental error which is practically constant throughout the sounding but varies from sonde to sonde. The dispersion of this instrumental error is

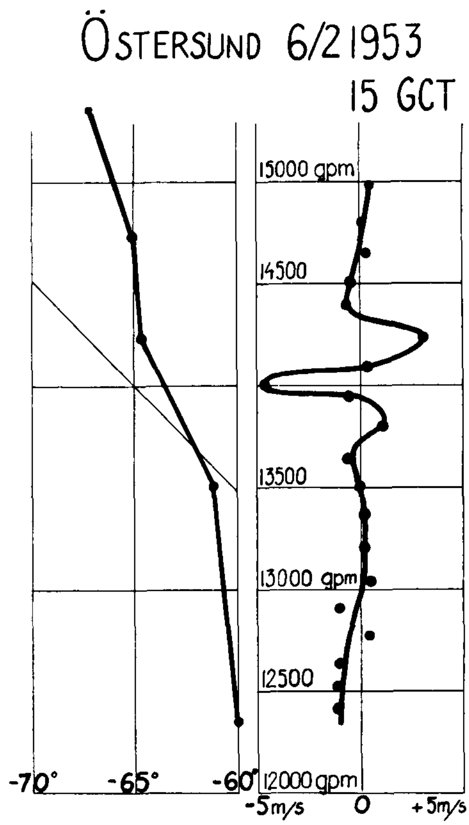


Fig. 3. The stratospherical part of the second sounding in Östersund showing the persistance of the convective layer. Both temperature and vertical wind velocity are shown.

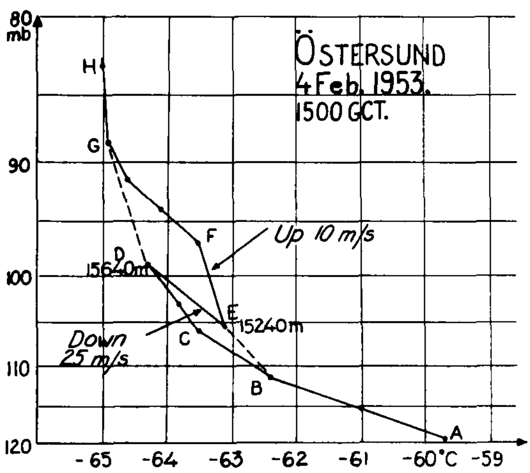
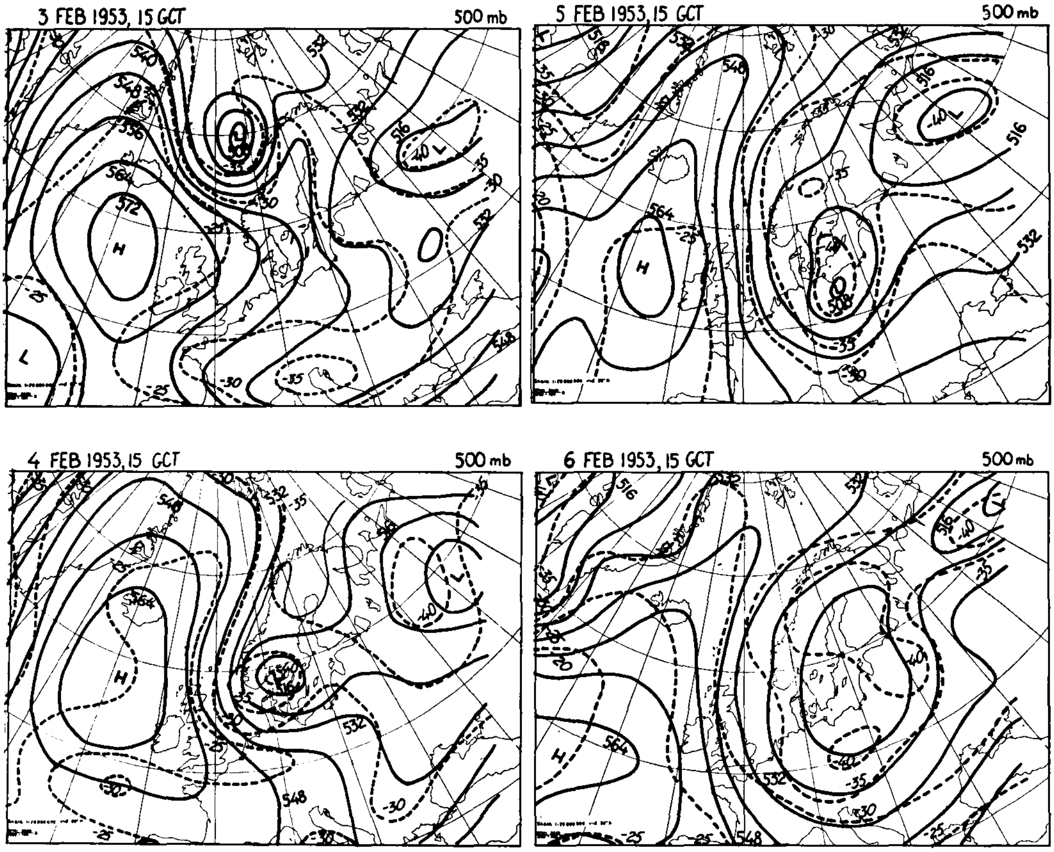


Fig. 2. The details of the sounding in Fig. 1 when the radiosonde passed the convective layer. Full line indicates the real path of the sonde, dashed lines indicate interpolated temperatures in different horizontal regions.



Eig. 4, 5, 6 and 7. Upper air maps showing the development and motion of the intence low mowing from northeast Greenland southeast over Europe.

rather great = 7—10 mb. The second part is due to inaccurate recording and evaluation and will be about 1.5 mb at a pressure of 100 mb if extremely great care is taken in the evaluation. The error in pressure difference will be only 2 mb, because of the elimination of the instrumental error. (See RAAB and RODSKJER, 1950.) In our case the pressure difference when the sonde descended was 6 mb and the relative error is then 33 per cent. The error in time interval measurement is $^1/_{10}$ minute which in $^1/_2$ minute makes an error of 20 per cent. These errors add so that the error in vertical wind velocity will be as large as 53, say 50 per cent. There will also be an error in the pressure measurement as described above due to the sparse number of recorded points and due to the hysterese in the pressure bulb. This error is approximately estimated to 1 mb, that is 15 per cent, which adds to the upper error limit. We may then state that the error is between + 65 per cent and — 50 per cent.

The values of the downward wind velocity will then be between 41 m/s and 12 m/s and the upward wind velocity will be between 17 m/s and 5 m/s.

In the second sounding the corresponding values are 8 and 2.5 m/s (the downward wind velocity) and 5 and 1.5 m/s (the upward wind velocity).

The dynamics of the convective cell. The movement up and down illustrated in Fig. 2 will probably have been accompanied by a horizontal motion of the sonde. At first the sonde seems to have entered a horizontally limited region with a temperature curve ABCDGH. At D the sonde entered the downdraft and followed it to the point E where the sonde reached another horizontally limited region with the corresponding temperature curve ABEFGH and then followed this upwards. In the colder region the air will begin to sink due to the warmer surroundings.

Is it now possible for an air parcel which starts at G and follows the curve GDE to obtain a final velocity of 25 m/s if the surroundings do not change? The fact that the air parcel falling along the curve GDE does not warm dry-adiabatically may be explained by assuming sufficient entrainment to keep the temperature of the air parcel low enough. The buoyancy force is in our case negative and equal to

$$\frac{\varrho_{\text{surr.}} - \varrho_{\text{parcel}}}{\varrho_{\text{surr.}}} g$$

per unit mass. That is according to the gas law

$$\frac{T_{\text{parcel}} - T_{\text{surr.}}}{T_{\text{parcel}}} g.$$

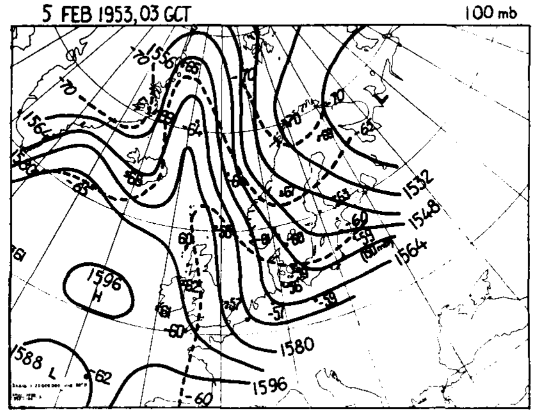
The energy gained is

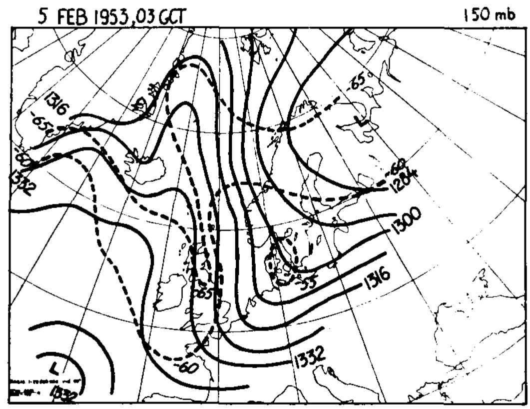
$$\int_{\text{GDE}} \frac{T_{\text{parcel}} - T_{\text{surr.}}}{T_{\text{parcel}}} g dz = w^2/2.$$

An integration of the area GDEFG = S gives the value 530 m · °C, and we obtain $w^2 =$ $= 2 \cdot 9.81 \cdot S/210 = 50$ (m/s)^2.

$w = 7$ m/s which is somewhat lower but of the right order of the lower error limit of the value w described above. The surface S may be assumed to be twice as large if we assume the starting point a little more to the left of point G. The value of w will then be 10 m/s which is practically in agreement with the lower limit of the measured value of w.

The persistence of the stratosphere with double temperature regions. As the phenomenon with the convective cells repeated on the 6th of February and the temperature soundings still show the double temperature region in the stratosphere there must be some mechanism which sustains the regions, because convection and turbulence would cause an elimination of the sharp border with the great temperature gradient. This mechanism is to be found in the general circulation pattern. The main features of the weather development as seen from the 500 mb upper air maps (Fig.





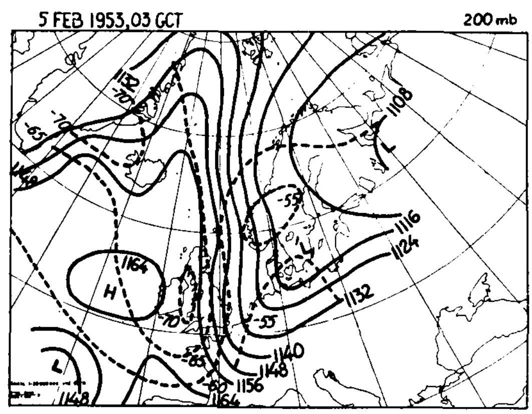


Fig. 8, 9 and 10. Upper air maps showing the distribution of wind and temperature in different levels of the stratosphere.

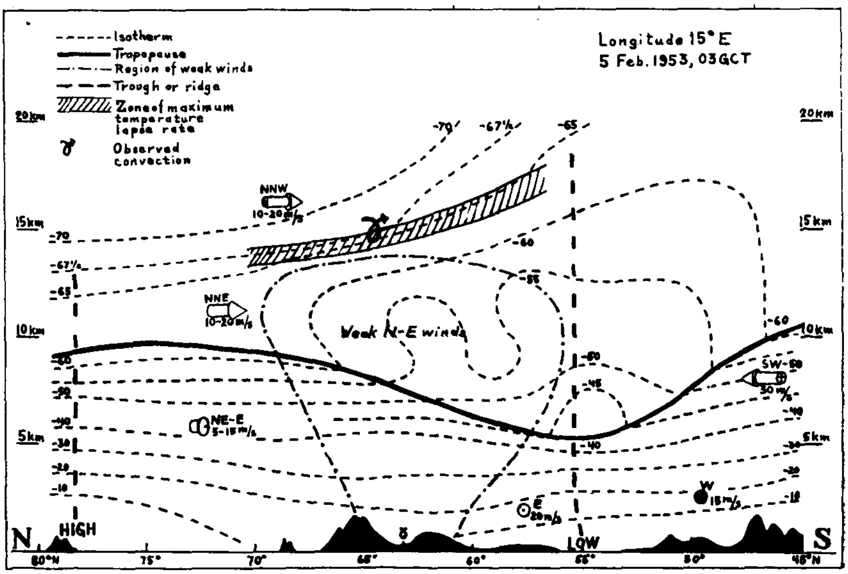


Fig. 11 The vertical section through latitude 15° E showing the mechanism of instabilisation in the middle stratosphere.

4—7) during the days in question are the following:

1. Together with warm air advection over Greenland a strong high pressure ridge is building up from the south over Iceland and eastern Greenland and reaches maximum intensity on the 4th of February.

2. The warm air advection over Greenland forces a relatively small cold-pool to move from Jan Mayen southeast over Scandinavia and form a deepening low.

3. In the morning of the 4th of February the deepening low passes the Scandinavian mountain range and makes contact with a wide cold-pool situated west of the Ural mountains.

4. The 4th of February the cold air from the Russian cold-pool entered the rear side of the Scandinavian low and began to fill it with cold air.

5. The Scandinavian low then retards and spreads out and at 1500 GCT the 6th of February there is a wide cold-pool over central and northern Europe and only a smaller rest west of the Ural mountains.

The variations of the circulation pattern with height is demonstrated in Fig. 8—11 and shows the situation at 0300 GCT the 5th of February instead of 1500 GCT the 4th of February. This because of the satisfactory number of soundings made in the Scandinavian region in the morning of the 5th of February. The network consists of all the ordinary stations in the analysed region of the 100 mb map and can be seen from the temperature values plotted on the 100 mb map (Fig. 8).

6. In the cold-pools and the lower stratosphere above there is a general downward motion causing the specific warm stratosphere, the downward motion being a part of the tropopause circulation. The contrasts between the "warm" and "cold" air masses are expressively shown on the 200 mb map (Fig. 10).

7. Up to the 200 mb level above Östersund there is advection between east and north of this warmed stratospherical air.

8. Arriving to the 100 mb level we can see the weather situation change and a general cold advection taking place over total Scandinavia, especially in the northern and eastern parts. The cold air arrives from northnortheast from Spitzbergen and originates from a cold-pool of the upper stratosphere with its centre north of Spitzbergen. As an example of a stratospherical cold-pool combined with a surrounding stratospherical "jet stream" see for instance HUBERT (1953).

9. With the high pressure ridge over the Atlantic still reaching up in the 100 mb level this ridge forces the cold air from northnorthwest over central Sweden and Östersund and further to the south.

Hence the advection is still there above 100 mb and in the layers below there is the warming effect above the cold-pool of the troposphere.

Hence the contrasts between lower and higher stratosphere are sustained with the described convective phenomenon as a result.

Fig. 11 shows schematically the variation in the vertical of the described circulation pattern together with the equiniveaus of temperature.

Final remarks. Radiosondes entering convective cells have been observed in the tropospheric region, but in the middle of the stratosphere such an event seems a little surprising. At the first glance an instrumental error seems to be the most natural explanation of the behavior of the radiosonde, but the radiosonde worked with both reference frequencies in good conditions and both the temperature and pressure gradient changed the direction at the same time. An instrumental error which enters both in the temperature and pressure sensing elements but not in the reference elements does not seem probable. The repetition of the phenomenon both the 4th and 6th of February makes an explanation due to real effects in the circulation more probable.

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Table 1.

Time of recorded pressure point Minutes	Temperature °C	Pressure mb	Height gpm	Ascend. vel. m/s	Vertical wind vel. m/s
44.25	—59.7	119.5	14,460		
				+ 4.1	—0.7
45.15	—61.0	115.5	680		
				+ 4.1	—0.7
46.00	—62.4	111.5	890		
				+ 6.0	+ 1.2
46.90	—63.5	106.0	15 210		
				+ 5.0	+ 0.2
47.50	—63.8	103.0	390		
				+ 7.0	+ 2.2
48.10	—64.3	99.0	640		
				—22.3	—27.1
48.40	—63.1	105.5	240		
				+ 14.2	+ 9.4
49.00	—63.5	97.0	750		
				+ 6.4	+ 1.6
49.50	—64.1	94.0	940		
				+ 5.7	+ 0.9
50.00	—64.6	91.5	16,110		
				+ 5.2	+ 0.4
50.65	—64.9	88.5	310		
				+ 4.8	0.0
52.00	—65.0	83.0	16,700		

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