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1.2A OBSERVATIONS OF FRONTAL ZONE STRUCTURES WITH A VHF DOPPLER RADAR AND RADIOSONDES*

M. F. Larsen

Cornell University
Ithaca, NY 14853

J. Rottger**

EISCAT Scientific Association
Kiruna, Sweden

INTRODUCTION

The SOUSY-VHF-Radar is a pulsed coherent radar operating at 53.5 MHz and located near Bad Lauterberg, West Germany. Since 1977, the facility, operated by the Max-Planck-Institut fur Aeronomie, has been used to make a series of frontal passage observations in the spring and fall. Experiments in winter have been difficult because part of the transmitting and receiving array is usually covered by snow during that part of the year. Wavelengths around 6 m are known to be sensitive to the vertical temperature structure of the atmosphere (GREEN and GAGE, 1980; RASTOGI and ROTTGER, 1982). Thus, it has been possible to use radars operating at frequencies near 50 MHz to locate the tropopause. Comparisons between radar data and radiosonde data have shown that there is a large gradient in the radar reflectivity at the height where the radiosonde tropopause occurs.

An experiment carried out by ROTTGER (1979) on March 15-16, 1977, showed that the radar's sensitivity to the vertical temperature structure could also be used to locate the position of fronts. The SOUSY-VHF-Radar consists of a transmitting array, also used for receiving in some configurations, that can be scanned in the off-vertical direction but not at sufficiently low elevation angles to study the horizontal extent of structures as extended as fronts. GAGE and BALSLEY (1978), BALSLEY and GAGE (1980), ROTTGER (1980), and LARSEN and ROTTGER (1982) have reviewed UHF and VHF Doppler radar techniques and applications to atmospheric research. In the experiments described here, the radar was operated in the spaced antenna mode. ROTTGER and VINCENT (1978) and VINCENT and ROTTGER (1980) have described the method and its advantages. The transmitting array consists of 196 Yagi antennas, and the receivers are three separate arrays of 32 Yagis each. The effective antenna aperture was 2500 m^2, the applied average transmitter power was typically 20 kW, and the height resolution was 150 m. Vertical profiles of the reflectivity were obtained in each of the three receiver arrays, and it was found that besides the enhancement of the signal strength associated with the tropopause region, there was also a secondary band of enhanced reflectivities stretching downward from the upper to the lower troposphere. Comparisons between the radar data and data from a nearby radiosonde station show that the band is associated with the temperature gradients in a passing frontal zone. The vertical and horizontal velocities were also measured during the experiments, but they will not be discussed here.

The results of analyzing two events have been presented by ROTTGER (1979, 1981), ROTTGER and SCHMIDT (1981), and LARSEN and ROTTGER (1983). However, in

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**Presently at Arecibo Observatory, Arecibo, Puerto Rico, on leave from Max-Planck-Institut fur Aeronomie, Lindau, W. Germany.

this paper we would like to summarize a more complex data set consisting of a series of five observations of frontal structure made with the SOUSY-VHF-Radar in March 1977, March 1981, November 1981, February 1982, and April 1984. The extensive data set shows results essentially in agreement with the preliminary results. Comparison of time/height cross sections of reflectivity measured with the radar and potential refractivity gradients calculated from radiosonde data taken at a nearby location show good agreement. Therefore, we conclude that the radar is detecting the temperature structure associated with the front and that the enhancement in reflectivities is not due to precipitation or other very localized processes. Also, we have found that the radar can be used to locate the fronts consistently, even in some cases when the fronts are rather weak.

MARCH 15-16, 1977

At 0000 UTC on March 15, 1977, a low pressure center in the North Atlantic was propagating eastward toward the British Isles. The associated warm front and the trailing cold front extended southward from the center of the low. The warm front at the surface had traversed France and West Germany by 0000 UTC on March 17. Reflectivities measured with the SOUSY-VHF-Radar from 1200 UTC on March 15 to 0900 UTC on March 16 are shown in Figure 1. Cloud cover observations from two nearby meteorological observatories are shown below the reflectivities.

Of particular interest is the band of enhanced echoes stretching from 4 km altitude at 0000 UTC on March 16 to 2 km altitude at 0600 UTC. Extrapolating the slope of the band to the surface gave a time for the surface frontal passage in agreement with that derived from the weather charts. Comparison between the temperature cross section perpendicular to the front and the features seen in the radar reflectivity data showed good agreement.

MARCH 6-7, 1981

Figure 2 shows the reflectivities observed with the radar between 1200 UTC on March 6 and 0900 UTC on March 7, 1981. The contour interval is 2 dB, and the stippling indicates regions of higher reflectivity. The signal strength generally decreases with height in the troposphere but increases by 10-12 dB over a vertical distance of 0.5 km or so at the tropopause. The tropopause determinations from Hannover radiosonde data is shown by the heavy bars in the figure. The bar corresponding to 0900 UTC was actually obtained at 1200 UTC, the standard synoptic time.

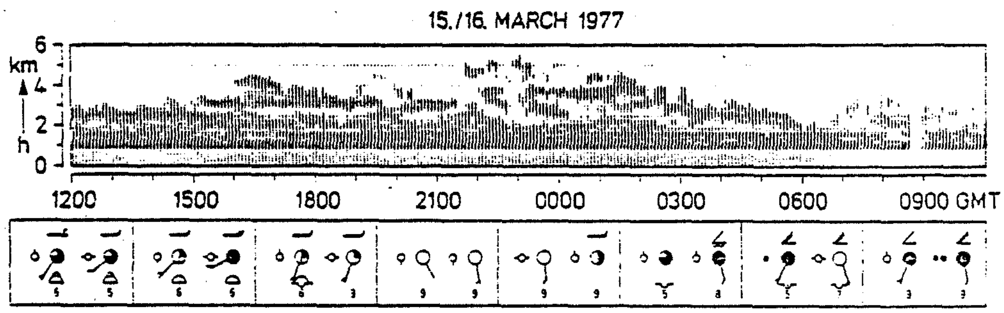

Figure 1. Radar reflectivities as a function of height and time measured by the SOUSY-VHF-Radar. Observations from the meteorological observatories at Kassel, 60 km southwest, and Hannover, 90 km north-northwest, are shown on the left and right sides of the boxes, respectively.

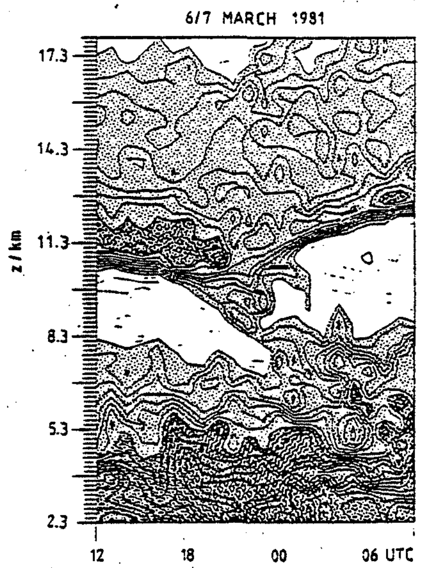

Figure 2. Radar reflectivities as a function of height and time. Contour interval is 2 dB. Stippled areas show higher reflectivities.

The feature of particular interest is the band of enhanced echo strength stretching downward from the tropopause beginning at approximately 1700 UTC. The feature is associated with a warm front that was essentially parallel to the NNW-SSE direction and propagated eastward across West Germany and past the radar. The radar reflectivity is proportional to M^2 with M given by

$$M = -77.6 \times 10^{-6} \frac{P}{T} \{\frac{\partial \ln \theta}{\partial z}\}$$

$$\cdot \{1 + \frac{15500}{T} (1 - \frac{1}{2} \frac{\partial \ln q/\partial z}{\partial \ln \theta/\partial z})\} \quad (1)$$

where P is in millibars, T is absolute temperature, θ is potential temperature, and q is the specific humidity. The contours of M^2 calculated from the Hannover radiosonde data are shown in Figure 3 with a contour interval of 4 dB. Once again, the stippled areas correspond to higher values. The agreement between the observations and the calculated values is quite good. The contours of M^2 show the increase in the height of the tropopause at 1200 UTC on March 7. Also, the enhancement of the echoes between 6.8 and 8.3 km after 0000 UTC on March 7 is apparent. There is an indication of the frontal echo band in the values of the potential refractivity at 0000 UTC as shown by the feature near 8.75 km altitude. However, the time resolution of the radiosonde data is not sufficient to show the details of the frontal zone structure.

NOVEMBER 4-10, 1981

In the first half the November 1981 observations were made over a period of more than a week. The reflectivities for the period from November 4 (Day 308) to November 10 (Day 314) are shown in Figure 4. On Day 308, the reflectivities decrease with altitude in the troposphere and then begin to increase just below the tropopause. A cold frontal band is observed after 1600 UTC and stretches upward in altitude with time as would be expected. Two warm frontal bands are evident as enhanced reflectivity regions moving downward with time. The first is observed near the tropopause at 0000 UTC on Day 309. The second is first seen at 0600 UTC on Day 310.

Potential temperatures were calculated from the Hannover radiosonde data

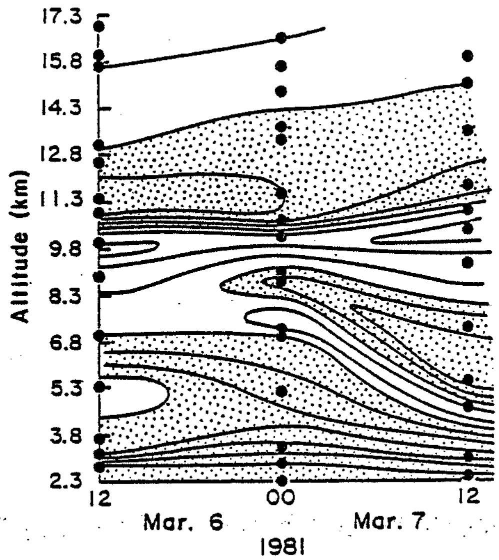

Figure 3. Gradient of potential refractive index calculated from Hannover radiosonde data for the time period corresponding to the reflectivities shown in Figure 2. Stippled areas correspond to larger values.

and have been plotted and contoured on a scale similar to that used for the reflectivities. The results are shown in Figure 5. The same general features are evident in both figures. The packing of the potential temperature contours is characteristic of the tropopause and stratosphere. The lower boundary of the packing is located at the same height as the increase in the radar reflectivities associated with the tropopause. The cold front and the second warm front show up clearly in the potential temperature data, but the first warm frontal band is not as clearly evident. However, satellite photos for this time show two distinct cloud bands.

During the time from Nov. 4 to 10, the radar site was in a region of northerly flow on the eastern side of a stationary high pressure system centered over the British Isles. The fronts that traversed the radar site were confined to the upper troposphere, as the potential temperature cross section shows.

FEBRUARY 7-9, 1982

The reflectivities measured by the radar during the period from February 7 to 9, 1982, are shown in Figure 6. Once again the stippled areas represent

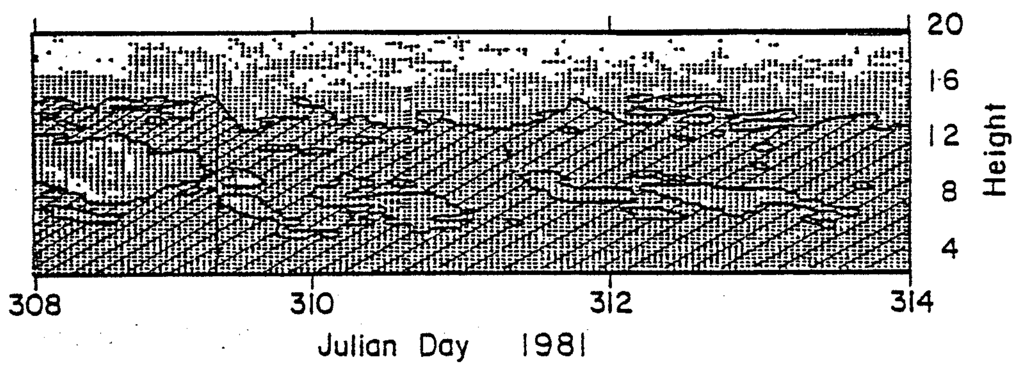

Figure 4. Reflectivities measured by the SOUSY-VHF-Radar during the period from Nov. 4 to 10, 1981.

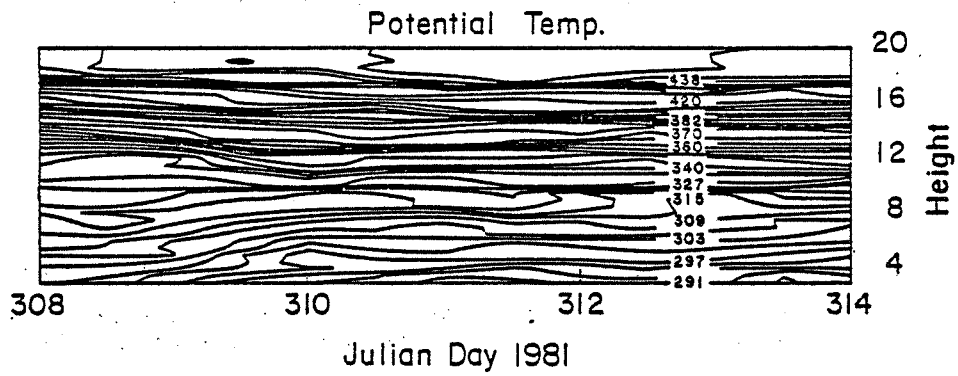

Figure 5. Potential temperatures calculated from the Hannover radiosonde data for the period corresponding to the radar reflectivities shown in Figure 4.

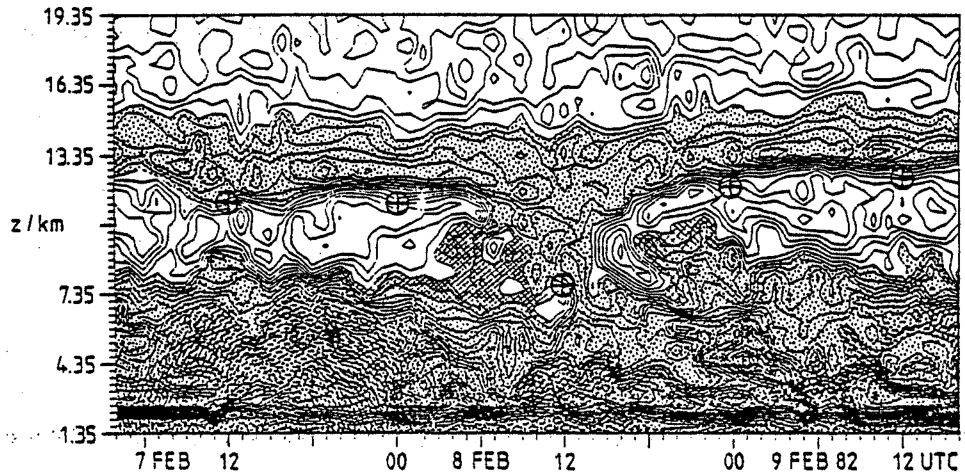

Figure 6. Same as Figure 2 but for February 7-9, 1982.

larger reflectivities. However, this time the intermediate values have been cross hatched, as well. The typical features already noted in the previous examples are present. The echo strength decreases with altitude in the troposphere, but there is an enhancement in the reflectivities in the upper troposphere associated with the temperature discontinuity that defines the location of the tropopause. The heavy circles show the tropopause height determined from the Hannover radiosonde.

Near 1200 UTC on February 8, a band of enhanced reflectivities associated with a warm front stretches downward from the tropopause. Beginning at approximately 0200 UTC on February 8, a band of intermediate reflectivities stretches upward in connection with a cold front associated with the low pressure system. The cold front for this particular event was much weaker than the warm front, and the difference in strength accounts for the difference in the magnitude of the reflectivities.

We have also calculated the potential refractive index gradient M^2 based on Hannover radiosonde data. The vertical time section is shown in Figure 7. The same features are evident in both the reflectivity and M^2 cross sections. More detailed analysis of the event is given by LARSEN and ROTTGER (1983).

APRIL 9-13, 1984

Observations were made with the SOUSY-VHF-Radar over a five day period in April 1984. From 1200 UTC on April 9 until 1200 UTC on April 11, the radar was located in a region of northerly flow on the eastern side of a stationary high pressure system. During this time a number of mesoscale disturbances with horizontal scales of 50 to 100 km developed in the region. Most did not pass the radar, but one such system was observed near 0000 UTC on April 11. The radar reflectivities are shown in Figure 8.

The signal strength showed an enchancement in the upper troposphere during the passage of the mesoscale system, but the feature is not as narrow and does not show the tilt characteristic of the other frontal passage observations that we have presented. Late in the day on April 12 a surface frontal passage took place, as shown by the weather charts and satellite photographs. The features typical of a frontal passage are clearly present in the reflectivity data beginning at about 1600 UTC on April 11. A band of enhanced echoes begins to descend from the height of the tropopause and stretches downward toward the surface. The air mass following the frontal passage then has a higher tropo-

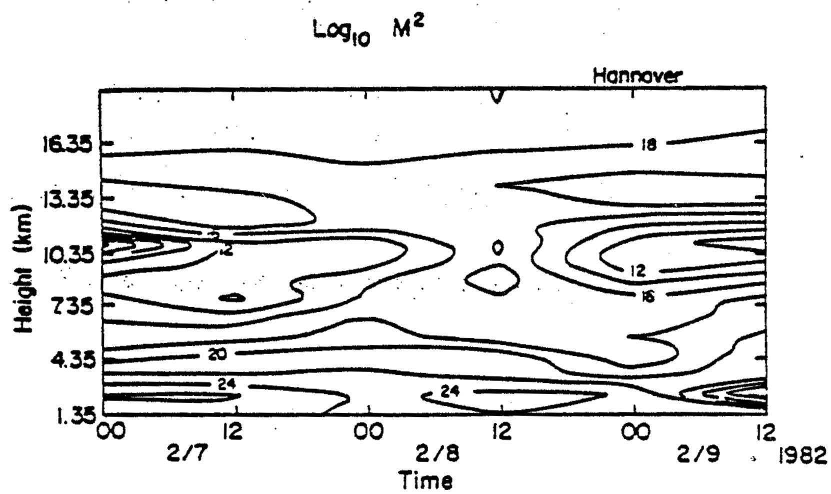

Figure 7. Same as Figure 3 but corresponding to the data shown in Figure 6.

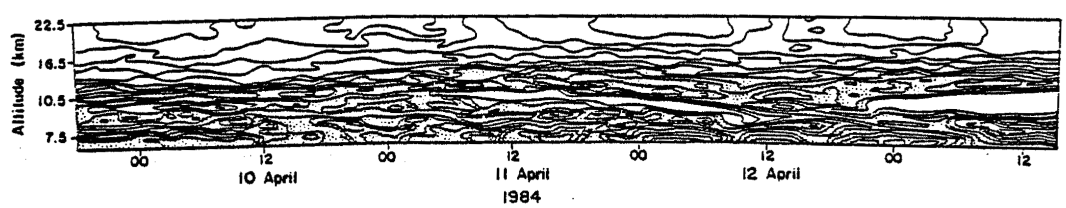

Figure 8. Same as in Figure 2 but for the period April 9-13, 1984.

pause height than the air mass prior to the frontal passage. The morphology in this event is very similar to the morphology in the other four events presented here.

CONCLUSION

Observations of five separate frontal passage events made with the SOUSY-VHF-Radar have shown that a radar operating at a frequency near 50 MHz can be used to detect the location of fronts on a routine basis. The SOUSY-VHF-Radar does not operate on a continuous basis. While the observation periods were chosen on the basis that it would be likely that a frontal passage would take place at the location of the radar, no attempt was made to choose only the strongest or most developed fronts. In fact, the front observed in April 1984 and the cold front observed in February 1982 did not have particularly strong temperature gradients.

The comparisonsbetween radar and radiosonde data have shown good agreement, indicating that the features seen in the radar reflectivity data are characteristic of the frontal temperature structure and are not associated with precipitation or local convection. That is particularly true since the separation between the radar site and the nearest radiosonde station is approximately 90 km.

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