THE MIDDLE ATMOSPHERE ABOVE ANDOYA, NORWAY DURING THE WINTER 1983/84 AS DERIVED FROM METROCKETS AND OH NIGHTGLOW OBSERVATIONS

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ABSTRACT

A total of 110 wind measurements have been performed in the middle atmosphere above Andøya (69°N, 16°E) during the MAP/WINE Campaign from December 2, 1983 to February 23, 1984 using 57 inflatable passive falling spheres, 33 datasondes, 18 foil clouds and 2 instrumented active spheres. Temperature profiles could be derived from 42 falling spheres, 26 datasondes and 2 active spheres. In addition, near-mesopause temperatures were determined from OH nightglow observations. The results are presented in terms of synthesized charts of the temperatures as well as the zonal and meridional wind components between 0 and 90 km altitude. The temperature measurements indicate the occurrence of several minor and one major stratospheric warming, the latter being observed over Andøya just at the end of the launch series.

Keywords: Middle Atmosphere, Winds, Temperatures, Sudden Stratospheric Warmings, Meteorological Rockets, Hydroxyl Nightglow, MAP/WINE

1. INTRODUCTION

In the course of the project MAP/WINE (Ref. 1) more than 100 metrockets were launched at the Andøya Rocket Range (Northern Norway). The combination of these launches should give background information of dynamic and thermodynamic parameters in the altitude range between 20 and 90 km as well as information about the short time variability with time scales down to a few hours.

The purpose of this paper is to give a brief overview about the temperature and wind data covering the period from December 2, 1983 through February 23, 1984. To complete the presentation down to the surface, 51 radiosonde soundings from Bodø, situated 200 km south of Andøya, have been added.

2. TEMPERATURE MEASUREMENTS

2.1 Data Reduction

26 temperature profiles were obtained using datasondes. Datasondes measure temperature directly by means of a thermistor. Corrections were applied after Krumins (Ref. 2) accounting for aerodynamic heating, infrared heat transer, time lag and and solar heating. The latter was necessary only for one sunlit launch while all other launches were performed during the (polar) night. The correction parameters are available up to 70 km, where the correction itself may exceed values of 25 degrees. Pressure and density were computed from the temperature profiles taking the tie-on level pressure from hemispheric pressure maps (30 to 10 hPa) and applying the hydrostatic equation.

Passive falling spheres were used in connection with Viper 3A boosters for density measurements within the altitude range 95 to 35 km. More than 40 profiles were obtained during the MAP/WINE winter. Unfortunately, some of these do not reach into the stratosphere because of a too high collapse altitude of the sphere. The air density is calculated from the deceleration of the sphere during its descent assuming that vertical winds are much smaller than the fall velocity (Ref. 3). Temperature and pressure are obtained through the integration of the density profile from the top downwards. This requires an initial temperature at the upper boundary around 95 km. In the standard reduction program this value is taken from a fixed model atmosphere, which, however, leads to erroneous results if the reference temperature and the actual temperature differ too much. Although the error decreases exponentially with decreasing height, one order of magnitude within 2 scale heights, the choice of the model atmosphere would determine to some extent the magnitude of temperatures derived from spheres above 80 km. Thus it was deemed advantageous to normalize the sphere derived temperatures to those obtained from hydroxyl nightglow observations.

The OH-spectrometer of the University of Wuppertal (Ref. 4) was operated at the launch site almost continuously throughout the period of rocket launches. In the following it is assumed that the OH-temperatures represent a weighted mean temperature of an atmospheric layer around 86 km with 8 km as the full width at half maximum. The sphere temperature data was obtained by varying the initial temperature such that the weighted mean of the resulting temperature profile over the OH-layer fits the OH-measurements within ± 3 K. For the adjustment 10 minute mean values of OH-measurements around launch time were taken, if available, otherwise adjacent night mean temperatures were used. These computations are also believed to give more reliable results than the standard computation above 85 km and

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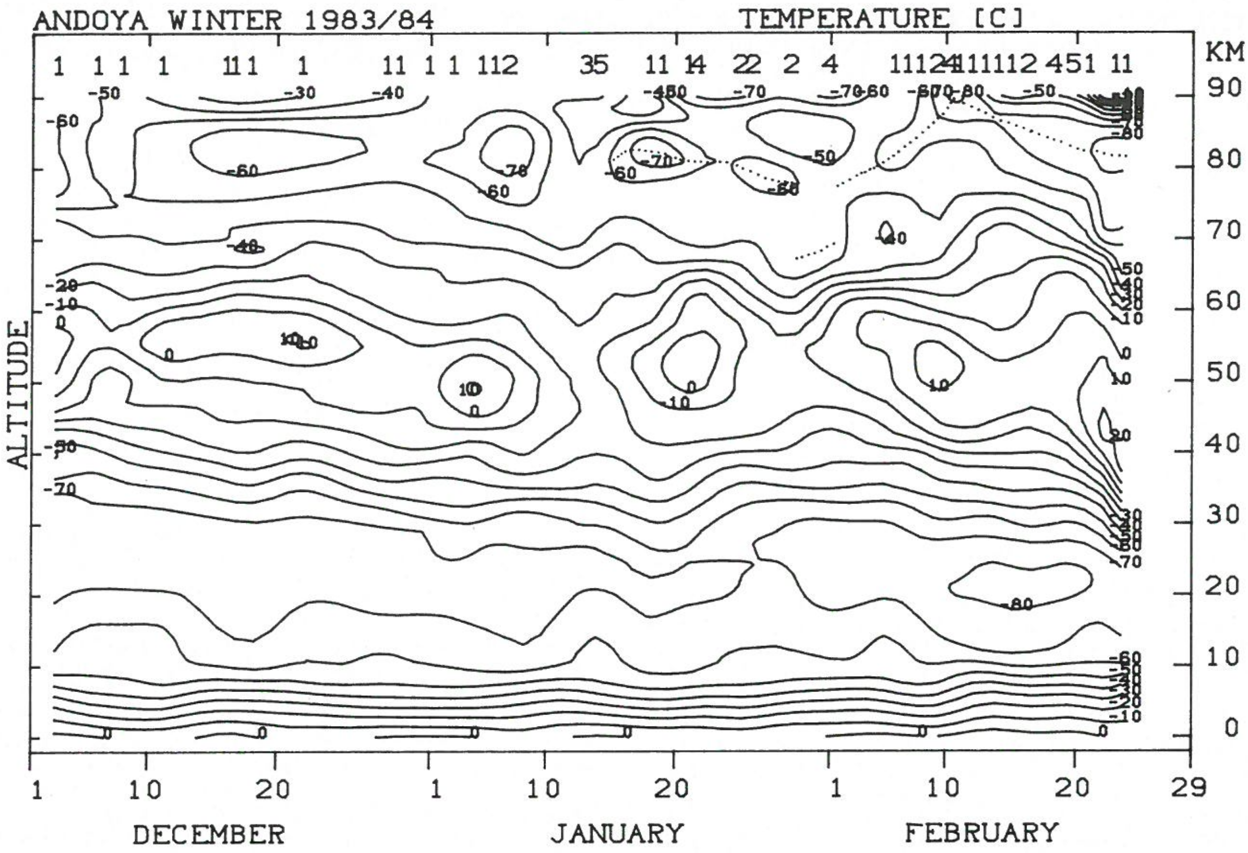
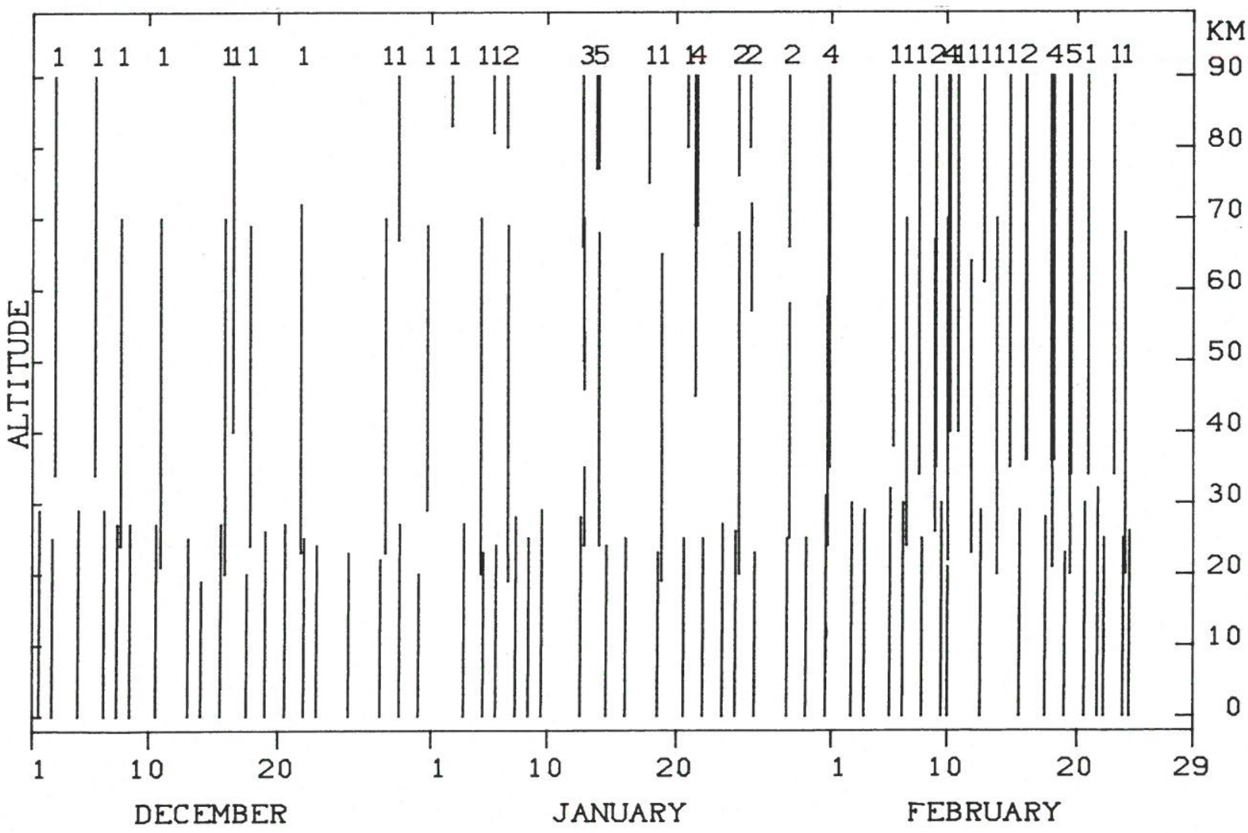


Figure 1. Temperature cross-section. Spacing between the contour lines is 10 degrees centigrade. The figures on top denote the number of temperature profiles within 12 hours.

Figure 2. Coverage of temperature profiles which were used for Figure 1.



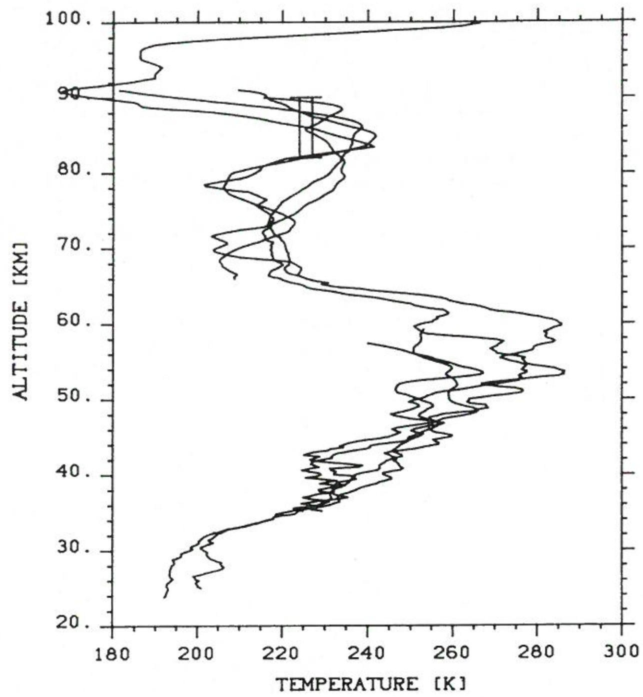


Figure 3. Temperature profiles derived from one falling sphere (Jan. 28), two datasondes (Jan. 28 and Jan. 31), two falling spheres (Jan. 31) and one instrumented sphere (Jan. 31). The bars represent OH-temperature measurements.

will therefore be presented here up to 90 km. Below 80 km this adjustment did not lead to serious changes in temperature compared to the standard reduction.

2.2 Thermodynamic data above Andøya

Figure 1 shows the temporal temperature structure over Andøya. The cross-section was plotted automatically applying a weighted running mean to linear interpolated data points with an effective averaging interval of 4 km in altitude and 3.5 days in time. In Figure 2 the distribution of the launches which were used for the contours is given. The data coverage is excellent in particular after Feb. 4 throughout the whole altitude range. On the other hand, throughout the middle of December 1983 there is the rather poor coverage of the altitude region 70 to 90 km.

As can be seen in Figure 1 the region of maximum stratospheric lapse rate is descending continuously during the first half of the winter until January 20 accompanied by a warming of the middle stratosphere.

Several warming peaks seem to occur almost regularly in the stratopause level. These are observed around Dec. 3, Dec. 12, Dec. 22, Jan. 4, Jan. 21, Feb. 9, Feb. 22 in our data using the grid-point-basis for the plot. The latter warming was identified by Labitzke et al. (Ref. 5) as a major stratospheric final warming. Minor stratospheric warmings were reported to have developed around Dec. 31, Jan. 20, and Feb. 10. Similar temporal changes in the upper stratosphere temperature over Andøya

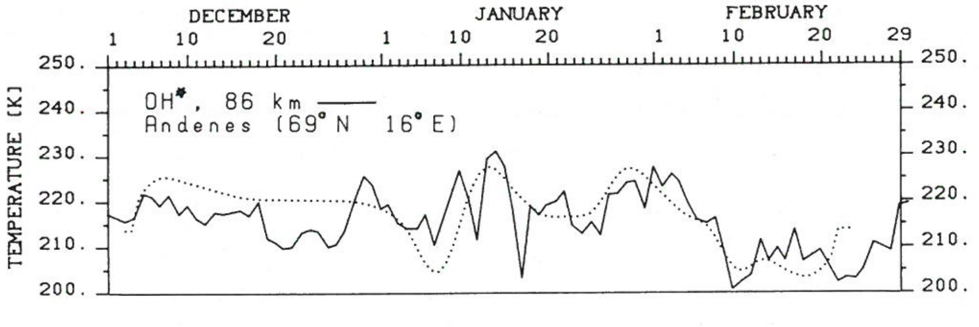


Figure 4. Night means of OH-temperatures (solid line).
Average sphere temperatures over the OH-layer (dotted line).

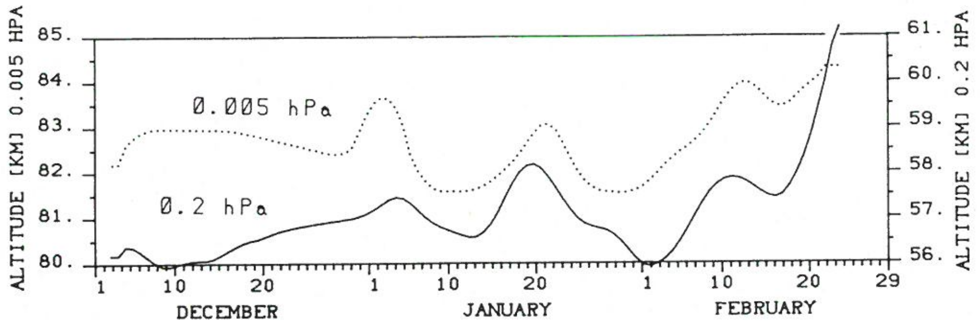


Figure 5. Mean heights of constant pressure.

were also measured by channel 27 of the SSU instrument (maximum of the weighting function between 40 and 45 km) onboard the NOAA Satellite, however, with a tendency to occur one or two days later.

The response of the mesosphere to sudden stratospheric warmings has been discussed and examined by several authors (Ref. 4, 6, 7). Our measurements confirm the findings of Labitzke (Ref. 6) of a simultaneous mesospheric cooling which started in the middle of February when a very warm mesosphere of -30°C was observed. This is seen in Figure 1 to propagate downwards during the second half of February with a small interruption around Feb. 16 and ending as the major final warming on Feb. 23 near 40 km. The observed cooling and warming rates are about -15°C/day around 65 km and +15°C/day between 35 and 45 km. Peak temperature values of more than 35°C were measured by the last falling sphere on Feb. 22 in 43 km and by the last datasonde on Feb. 23 in 39 km. The mesopause, which shall be defined here as the first temperature minimum above the stratopause is very cold (-80°C) during this period and descends from 90 to 80 km (dotted line in Figure 1).

Before the onset of the warming on Feb. 9 an unusual temperature distribution was observed in the mesosphere (Figure 3). Several metrocket measurements and an active falling sphere on January 28 and January 31, show a pronounced temperature minimum to be located near 70 km. Maximum temperatures of 240 K were measured at 85 km, whereas a first minimum (210 K) is indicated at 70 km. Two falling sphere measurements indicate a near-adiabatic lapse rate between 60 and 70 km.

In Figure 4 the OH-temperature series is shown as night mean values. The range of temperature variation is seen to be relatively small (± 15 K). For a comparison the OH-layer temperature has been reproduced here with the grid-point-basis for the contour plot taking weights from 90 to 82 km (which is not the full range which has been used for the adjustment). These mean sphere values (dotted line in Figure 4) follow the general OH-temperature trend in a reasonable way. It should be mentioned that for all data after Feb. 13 the standard sphere reduction program tends to give generally much lower temperatures (185 K) near 86 km altitude. To compensate for this in our reduction program very high initial temperatures, sometimes greater than 300 K, were necessary for the adjustment to the OH-values. The possibility cannot be excluded, that our assumption of a constant altitude for the OH-layer needs modification during the build-up phase of a major stratospheric warming.

The pressure surfaces in Figure 5 were also calculated from a grid-point-array, entering individual pressure measurements into the interpolating and smoothing program. The height of the 0.005 hPa pressure surface is only very slightly influenced by the OH-adjustment. The pressure maxima are clearly connected to the minor stratospheric warmings at the beginning of January, around Jan. 21 and around Feb. 11 even up to 85 km. The major warming led to a lift of the atmosphere by 50% and 30% of its mean scale height around 58 and 83 km, respectively, compared to conditions at the end of January and taking the seasonal pressure variation into account. Above 70 km these measurements are somewhat in contrast to the warm and cold models given in Ref. 8, not with respect to the magnitude of the mean pressure but in comparison with the influence of the warmings up to the height of the mesopause. The warm model atmospheres are intended to reflect probable conditions during sudden stratospheric warmings in latitudes between 60° and 75° in January. The difference in the pressure height compared to normal January conditions changes its sign in these models at about 75 km suggesting a reversed response of the pressure surface above this altitude. The warming events on Jan. 21, Feb. 10 and the major final warming during the MAP/WINE observation period indicate, however, an almost in-phase relationship between near-stratopause and mesopause pressures.

3. MEAN WINDS OVER ANDØYA

The zonal and meridional wind contours in Figures 6 and 7, respectively, were derived in the same way as the temperature field. Figure 8 gives an overview about the data coverage. The wind data of the radiosondes released from Bodø have been cut at 20 km because of data inconsistencies above 20 km. The reduction of wind data from falling spheres and chaff clouds is described in Ref. 10.

The long-term zonal wind pattern in the stratosphere is dominated by two periods of intense westerlies, in the middle of December and at the end of January, where mean maximum winds of 90 m/s were observed at the stratopause level. This magnitude of zonal wind speed is typical for middle latitudes. Here, it indicates either the intensification of the polar vortex or a shift of the vortex center. This will be examined, however, in detail in connection with hemispheric pressure maps (Ref. 9). There is also evidence for the periodic occurrence of secondary zonal wind maxima around Dec. 14, Dec. 22, Jan. 3, Jan. 14, Jan. 29, Feb. 12, Feb. 22 between 40 and 65 km, which may be related to travelling planetary waves with a period of about 12 days. Above 58 km altitude the average zonal wind speed over the whole period decreases from 45 m/s to 15 m/s in 70 km at a constant rate of 2.5 m/s per km.

The wind structure in the mesosphere is governed by cells of an alternately weak or even reversed and moderate mean zonal wind. For example a reversed zonal flow is observed around 75 km during the major final warming and after the minor warming around Jan. 21. In the mesopause region (85 to 90 km) the amplitude of the fluctuations increases strongly. Some caveats in interpreting the highest altitude data should be made at this point, however. The RMS differences of the individual launches to the contour plot may increase to more than 30 m/s at these altitudes. Also a tidal correction has not been applied. Hence, above 80 km the contours may not be representative of the "prevailing" winds. Nevertheless, the wind reversals on Jan. 2 and the "relative" wind reversal on Feb. 10 are in agreement with the observations in 95 km altitude at the Observatory of Kühlungsborn, GDR, and at Sheffield, United Kingdom, (priv. comm. K. Labitzke) where each statospheric warming pulse seems to be accompanied by a breakdown of the zonal wind component in the lower thermosphere.

Referring again to the pressure surfaces in Figure 5 one might explain the magnitude of the observed wind reversals in the mesosphere by geostrophic forcing. If one assumes the horizontal extent of the warm areas to be 4000 km and the associated pressure maxima to have constant amplitude and phase speed during their propagation one yields a horizontal pressure gradient from the temporal changes in Figure 4. The resulting range of geostrophic wind changes of about 80 m/s is then in

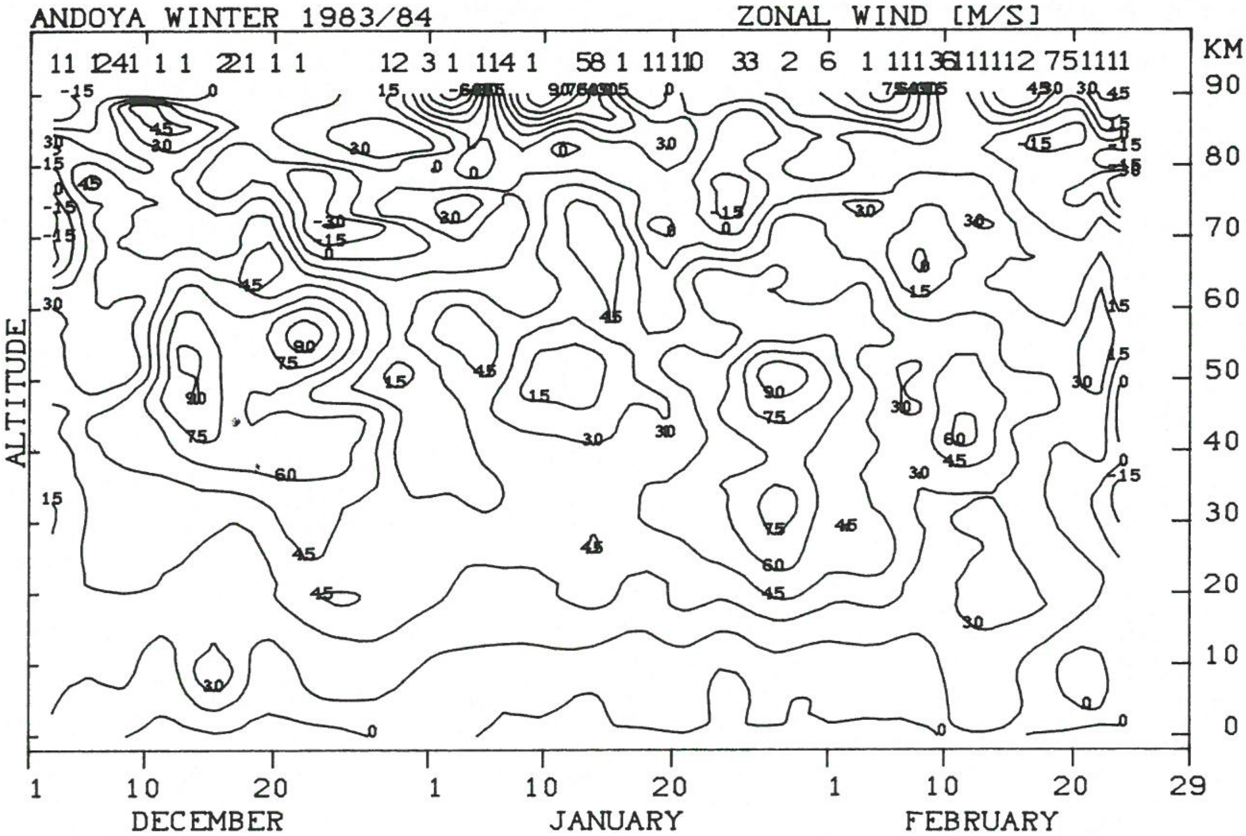


Figure 6. Zonal wind cross-section. Spacing between the contour lines is 15 m/s. The top figures denote the number of wind profiles within 12 hours.

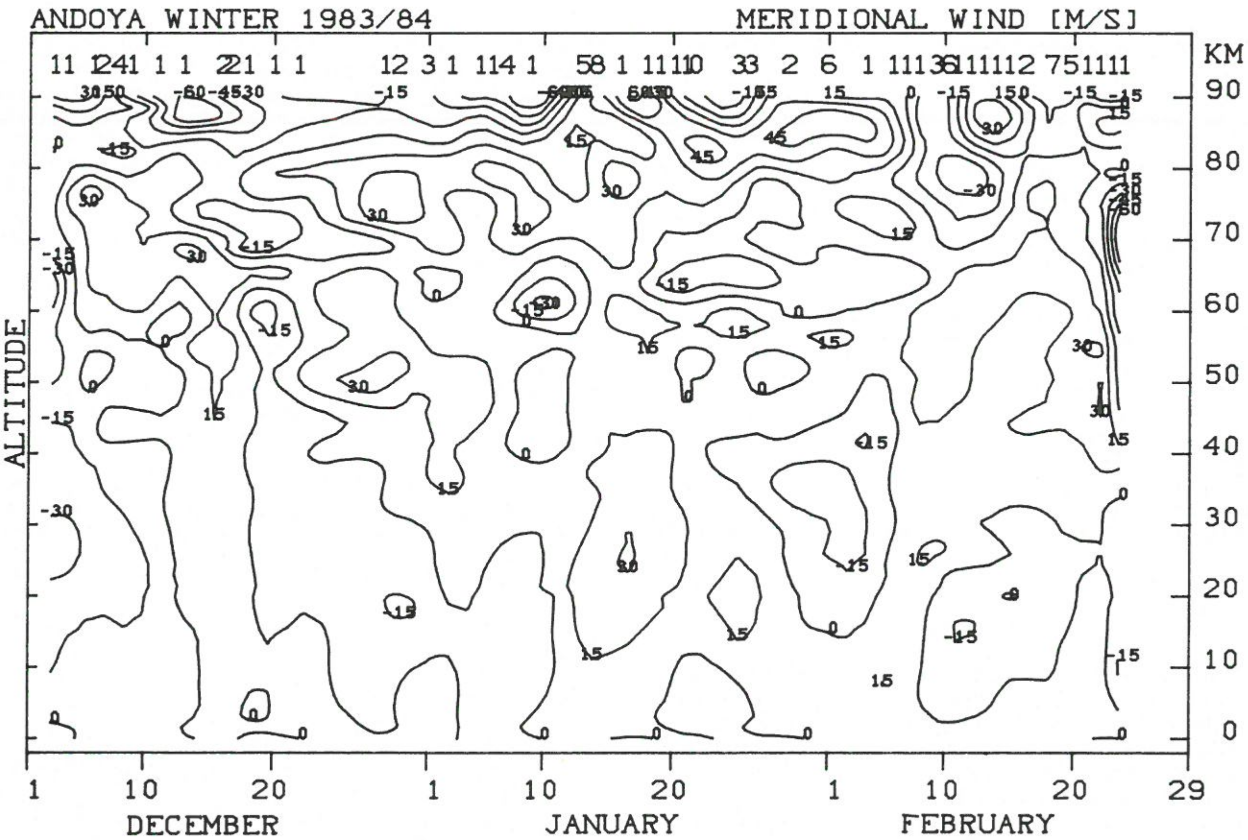


Figure 7. Meridional wind cross-section (comments as for zonal wind).

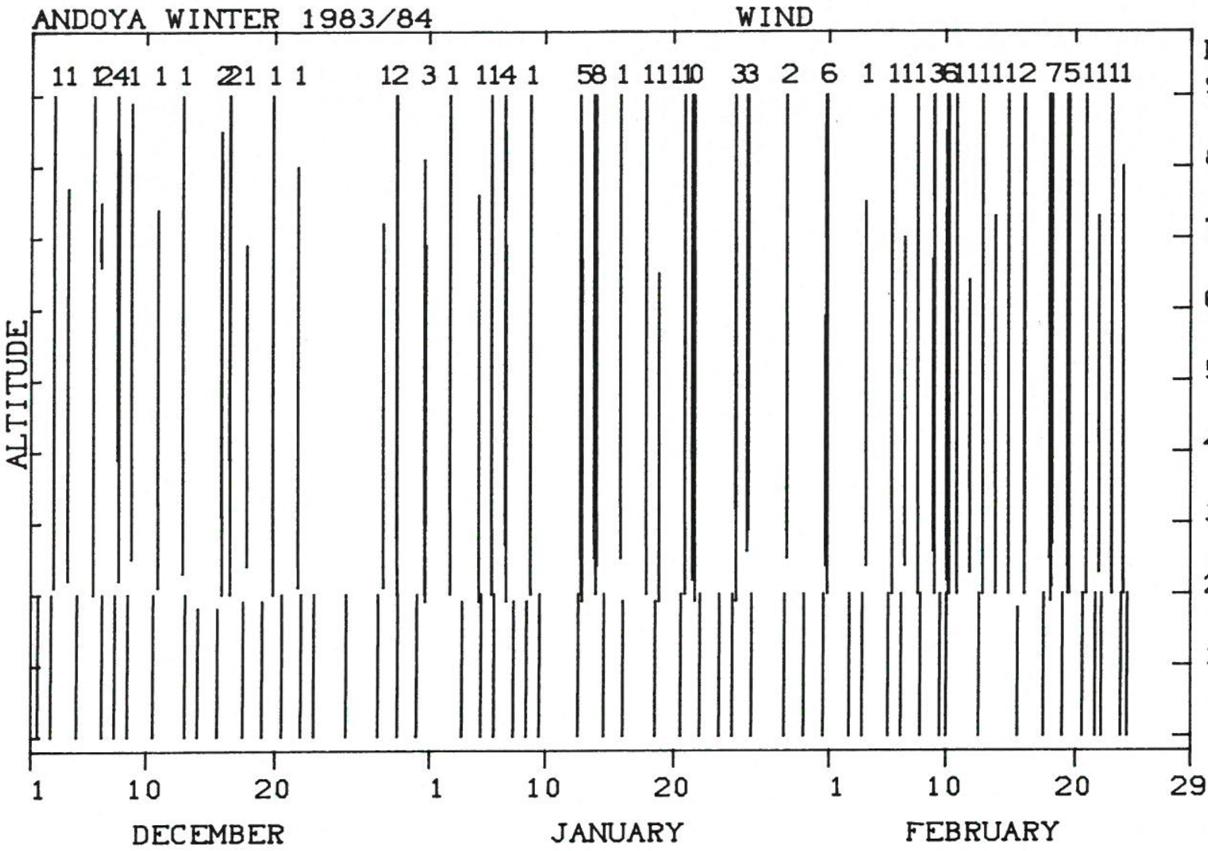


Figure 8. Coverage of wind profiles which were used for Figure 6 and Figure 7.

approximate agreement with the observed wind variation.

The meridional wind field (Figure 7) shows relatively weak longtime variation in the stratosphere. Smaller scale perturbations stand out in the lower mesosphere which increase in intensity at the height of the mesopause similar to the zonal wind. Relatively strong northerly winds are seen in the mesosphere during the major warming.

One noteworthy feature that should be mentioned here is a band of southerly winds with a layer thickness of 10 km sloping from 75 km around Dec. 20 to 85 km on February 6. This seems to be interesting with respect to a global circulation scheme because many other observations (Ref. 11, 12, 13) show a tendency for positive meridional winds in this altitude. Again, this structure in our data might be effected somewhat by tides, but hardly enough to change the wind pattern significantly.

4. FUTURE OUTLOOK

The metrocket launch series during the MAP/WINE camaign provided important data material for the understanding of a wide range of dynamic scales in the middle atmosphere. To the cross-sections shown here two improvements will be made in the future. Wind measurements performed near the rocket launch site with the SOUSY MST-radar will be added and tidal correction are to be applied derived from the EISCAT UHF-radar wind measurements.

It should also be investigated as to what extent temperature measurements from falling spheres and from datasondes agree in various altitude ranges. There is evidence in our data, as was also found earlier by F.J. Schmidlin (Ref. 14), that sphere derived temperatures between 50 and 60 km are generally a few Kelvin higher than in the datasonde temperature profiles, whereas at 70 km the agreement between both data sets is found quite good in the MAP/WINE data.

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6. REFERENCES

1. von Zahn U 1983, The research project "Winter in Northern Europe (WINE) of the international "Middle Atmosphere Program (MAP)", Proceedings of the 6th ESA Symposium on European Rocket and Ballon Programmes and Related Research, Interlaken, Switzerland, ESA-SP 183, 147-159.

2. Federal Meteorological Handbook No. 10 1975: Meteorological Rocket Observations, National Aeronautics and Space Administration.

3. Jones L M and Peterson J W 1968, Falling sphere measurements, 30 to 120 km, Met Monogr. 8 No. 31, 176-189.

4. Offermann D, Gerndt R, Lange G and Trinks H 1983, Variation of Mesopause temperatures in Europe, Adv Space Res. 3 No. 1, 21-23.

5. Labitzke K, Naujokat B, Lenschow R, Petzold K and O'Neill A 1984, The second winter of MAP-Dynamics, 1983/84: The winter of MAP/WINE, Beilage zur Berliner Wetterkarte 56/84 SO 15/84.

6. Labitzke K 1971, Temperature changes in the mesosphere and stratosphere connected with circulation changes in winter, J Atmos Sci. 28, 1479-1494.

7. Brown G M and Williams D C 1971, Pressure variations in the Stratosphere and Ionosphere, J atmos terr Phys. 33, 1321-1328.

8. Cole A E and Kantor A J 1978, Air Force Reference Atmospheres, Air Force Geophysics Laboratory, AFGL-TR-78-0051.

9. Petzoldt K 1985, Large scale structure of the Middle Atmosphere during the winter 1983/84, Proceedings of the 7th ESA Symposium on European Rocket and Ballon Programmes and Related Research, Loen, Norway.

10. Meyer W 1985, Intercomparison of wind measure ments performed with metrockets, Proceedings of the 7th ESA Symposium on European Rocket and Balloon Programmes and Related Research, Loen, Norway.

11. Groves V G 1980, Seasonal and diurnal variations of middle atmosphere winds, Phil Trans R Soc Lond. A 296, 19-40.

12. Manson A H and Meek C E 1983, Winds and tidal oscillations in the upper atmosphere at Saskatoon (52° N, 107°W, L=4.3) during the year June 1982 - May 1983, Plan Space Sci. 32 No. 9, 1087-1099.

13. Gage K S and Balsley B B 1984, MST Radar studies of wind and turbulence in the Middle Atmosphere, J atmos terr Phys. 46 No. 9, 739-753.

14. Schmidlin F J et al. 1980, Results of the August 1977 Soviet and American Meteorological Rocketsonde Intercomparison Held at Wallops Island, Virginia, NASA Reference Publication 1053.