9.3 VHF RADAR MEASUREMENTS IN THE SUMMER POLAR MESOSPHERE

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Measurements in the mesosphere over Andoya/Norway (69°N, 16°E) have been carried out using the mobile SOUSY-VHF radar with an extended beam configuration during the MAC/SINE campaign in summer 1987. First results of a 48-h and a 3-h observational period for heights between about 83 and 91 km are presented. Zonal mean winds are characterized by a strong westward flow of up to 50 ms^{-1}, whereas the equatorward directed meridional component is weaker. The dominating semidiurnal tide has amplitudes up to 30 ms^{-1} and a vertical wavelength of about 55 km. The diurnal tide is less pronounced. The total upward flux of horizontal momentum takes values of $-2\ m^2s^{-2}$ near 84 km and increases with increasing height, reaching a maximum value of 22 m^2s^{-2} for both the zonal and meridional components. However, measurements of the horizontal isotropy of the wave field suggest significant anisotropy. The major contribution to the momentum flux is from the 10 min - 1 h period range below about 87 km, and from the 1 - 6 h period range above this height.

Figure 1 shows a characteristic height-time plot of the echo power received in the vertically point beam for 24 h. VHF-radar echoes from the summer polar mesosphere are typically observed in the height range from about 83 to 92 km. A more detailed discussion of the layered structure, the aspect sensitivity and other characteristic features is the subject of the subsequent paper by Czechowsky et al.

The average height profile of the observed wind components is presented in Figure 2. The solid and dashed curves refer to the zonal and meridional components, respectively. As expected, the zonal wind field in summer is characterized by a strong westward flow up to altitudes of about 92 km. Above that height the results indicate a change of westward to eastward flow. The meridional wind pattern reveals a summer equatorward motion. The vertical component is on average about 10 cm/s and it shows a clear directional change from downward to upward around 87 km. According to Coy et al. [1988] this time average velocity (Eulerian average) may not be directly related to the averaged parcel motion (Lagrangian average) due to the Stokes drift resulting from upward propagating waves.

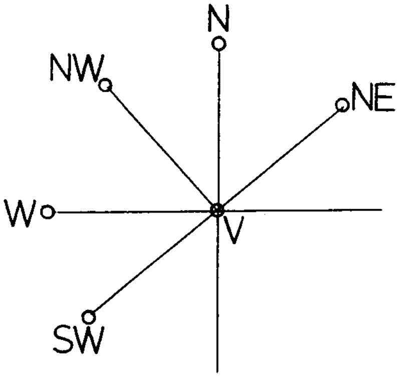
The main propagating tidal wave at high latitudes in summer is the semidiurnal tide. Figure 3 presents the height profiles of the amplitude A and local time of maximum T_{max} for both the zonal and meridional components. At all heights the amplitude of the zonal component exceeds that of the meridional one. Both amplitudes vary between about 15 and 30 ms^{-1}. The apparent vertical wavelength resulting from the very stable phase variation with height is estimated to be about 55 km.

Figure 4 (a) shows the total upward flux of momentum for the 10 min to 48 h period range (solid line) and for the 12 - 48 h period range (dashed line). Note that the contributions of the 12 and 24 h tides have been removed. The 12 - 48 h contribution is relatively small at heights below 87 km, and insignificant above this height. The total upward flux of horizontal momentum takes values of $-2\ m^2s^{-2}$ near 84 km, and increases with increasing height, reaching a maximum value of 22 m^2s^{-2} for both the zonal and meridional components. However, measurements of the horizontal isotropy of the wave field suggest significant anisotropy. This is shown in Figure 4(b). In the 12 - 48 h period range, the zonal component is dominant, while in the 10 min - 48 h range the height variation is somewhat more complicated. The w'^2 -data (Figures 4c, 5c) consistently show a strong decrease in magnitude with decreasing frequency, i.e., the Doppler shift of the measured frequencies is likely to be negligible.

The contributions to both the flux and anisotropy from motions in the 10 min - 12 h period range are presented in Figure 5(a),(b). (a) shows that the major contribution to the momentum flux is from the 10 min - 1 h period range below about 87 km, and from the 1 - 6 h period range above this height. It is also evident that each of the three period ranges tends to increase with height, reaching maximum values near 89 - 90 km. The anisotropy (Figure 5(b)) for the 6 - 12 h period range indicates dominance of the meridional component above 87 km, with little consistent variation below this height. This is possibly consistent with removal of a portion of the zonal component through filtering. In the 1 - 6 h period range the anisotropy varies with height and is somewhat suggestive of a wave motion of about 2 km vertical wavelength. The 10 min - 1 h period range also shows a wave-like variation.

The upward flux of horizontal momentum for a 3-h period showing some of the strongest echoes observed during the whole campaign is presented in Figure 6 for periods between 120 and 160 min, between 10 and 53 min, and between 53 and 160 min. The mean number of 5 min data points for the NE and SW beam is given in parenthesis for each height. The maximum number possible is 30. In the 10 - 160 min interval, values range from 15 to 66 m^2s^{-2}. The largest values occur above the peak in the vertical power profile, and the most abrupt increase is noted in the first range above the 3 dB point of the vertical power profile (shaded area). Below 86 km the major contribution to the total flux comes from the 53 - 160 min interval. Above 86 km, motions in the 53 - 160 min and 10 - 53 min period ranges contribute approximately equally. The anisotropy of the horizontal wind fields is shown in Figure 6b. For the 10 - 160 min and 10 - 53 min period ranges, the largest variations are noted just above the peak vertical power, while in the 53 - 160 min period range, the maximum anisotropy occurs near the peak. The zonal component dominates the 10 - 160 min period range, with the major contribution coming from those motions in the 10 - 53 min period range. These would appear to be the first unbiased mesospheric measurements of the anisotropy term made with Doppler radar [After Reid, et al., *Geophys. Res. Lett.*, in press].

Table 1. Beam configuration used in the measurements; the Reynolds stress tensor; the terms that have been obtained directly from the variances of the radial velocities.



$$\begin{pmatrix} \overline{u'^2} & \overline{u'v'} & \overline{u'w'} \\ \overline{v'w'} & \overline{v'^2} & \overline{v'w'} \\ \overline{w'u'} & \overline{w'v'} & \overline{w'^2} \end{pmatrix}$$

$$\begin{aligned} \overline{u'w'} + \overline{v'w'} &= \left(\overline{V_{NE}'^2} - \overline{V_{SW}'^2}\right) / \sqrt{2} sin 2\theta_{E_1} \\ \overline{v'^2} - \overline{u'^2} &= \left(\overline{V_N'^2} - \overline{V_W'^2}\right) / sin^2\theta_{E_2} - 2\left(\overline{u'w'} + \overline{v'w'}\right) cot\theta_{E_2} \end{aligned}$$

Table 2. Summary of the observational results.

SOUSY VHF Radar — 23 – 25 June 1987
16 June 1987
Andenes/Norway — (83 – 91 km)

Mean Winds	: $\overline{u} \approx -50 \rightarrow -10\,ms^{-1}$	; $\overline{v} \approx -10 \rightarrow -30\,ms^{-1}$
Tide (12 h)	: $A \approx 20 \rightarrow 30\,ms^{-1}$	; $\lambda_z \approx 55\,km$
Tide (24 h)	: $A \approx 10\,ms^{-1}$	; $(\lambda_z = 10\,km?)$
$\left(\overline{u'w'} + \overline{v'w'}\right)_{total}$	: $-2 \rightarrow 20\,m^2s^{-2}$ (for 48 h)	; $20 \rightarrow 60\,m^2s^{-2}$ (for 3 h)

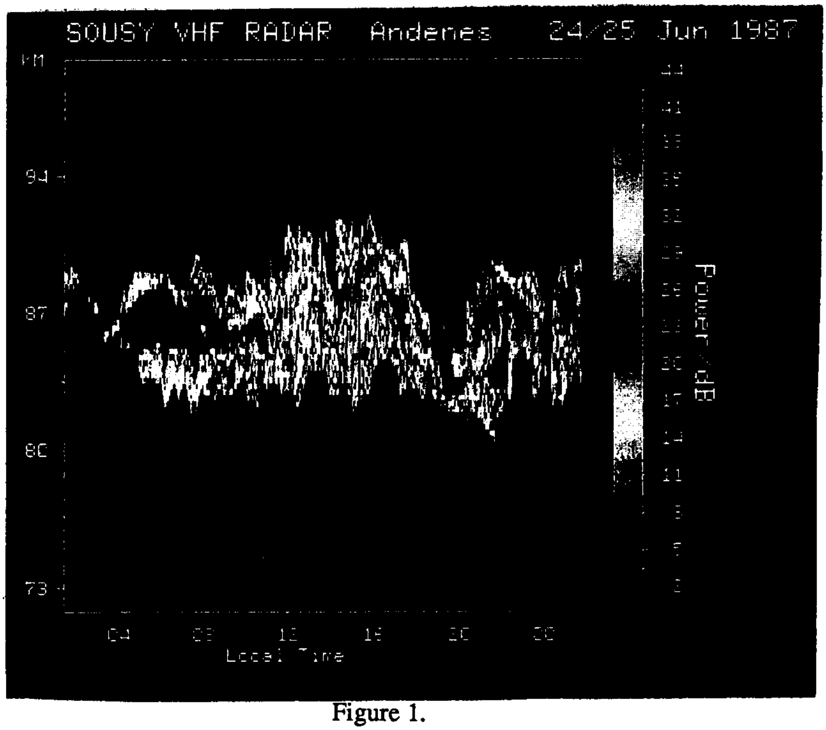


Figure 1.

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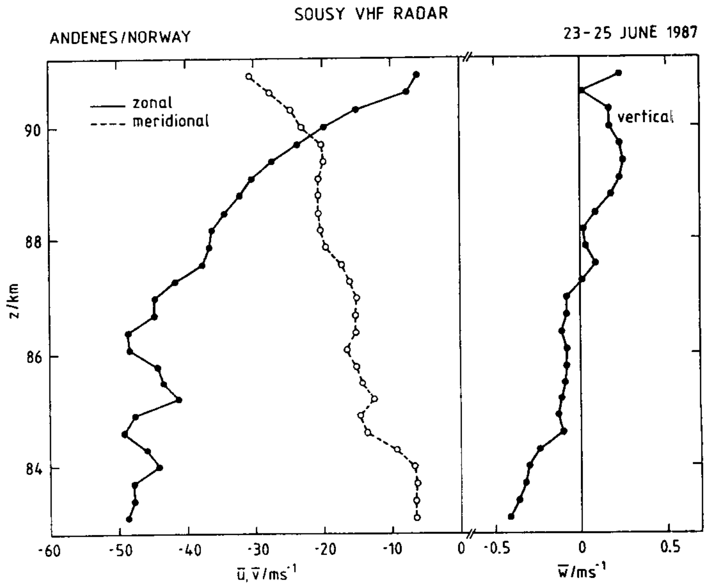

Figure 2.

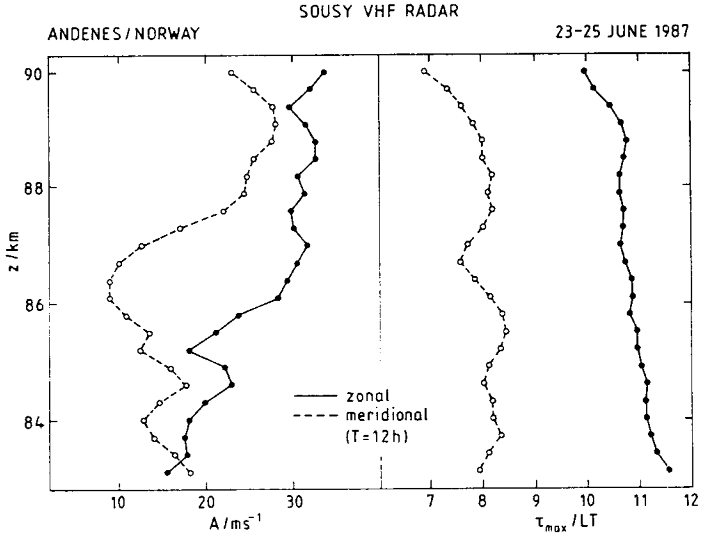

Figure 3.

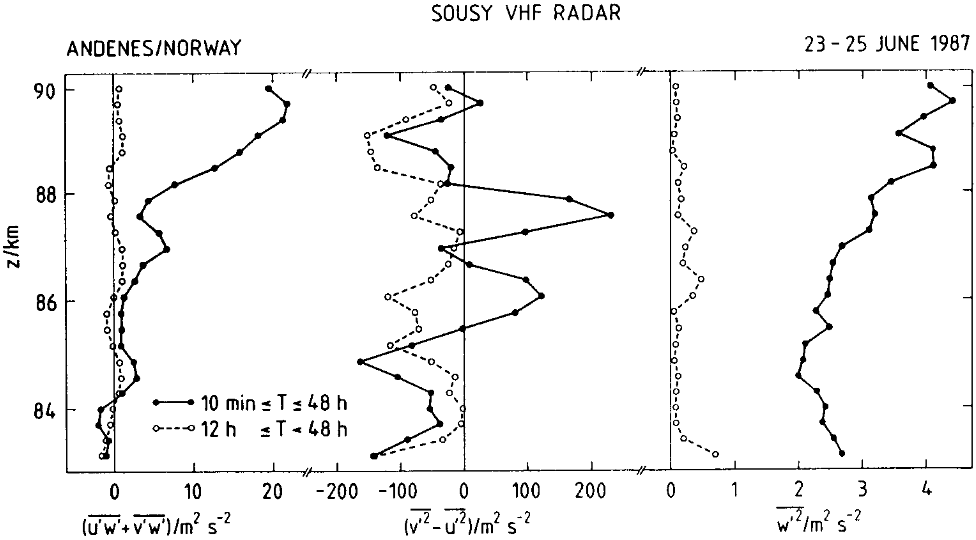

Figure 4.

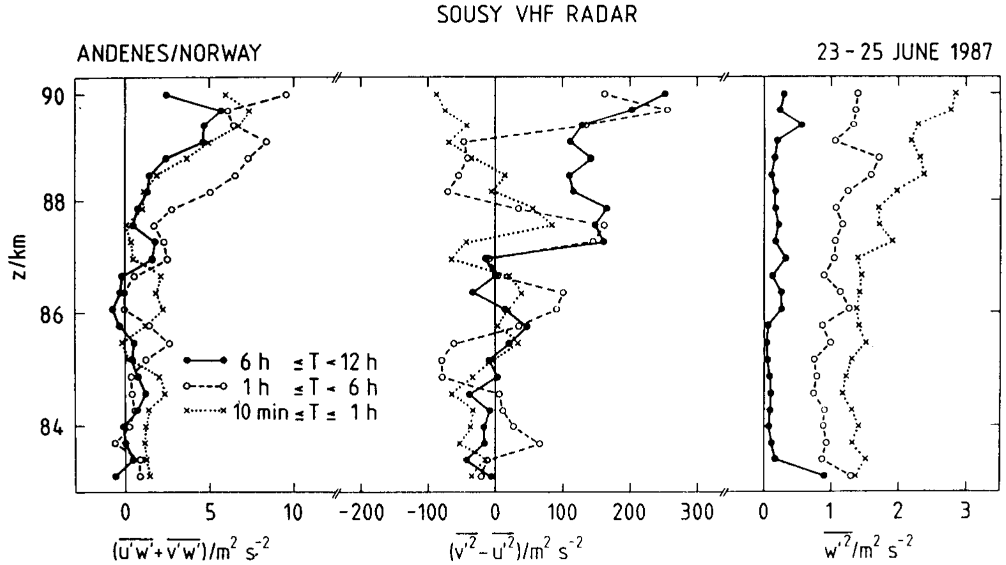

Figure 5.

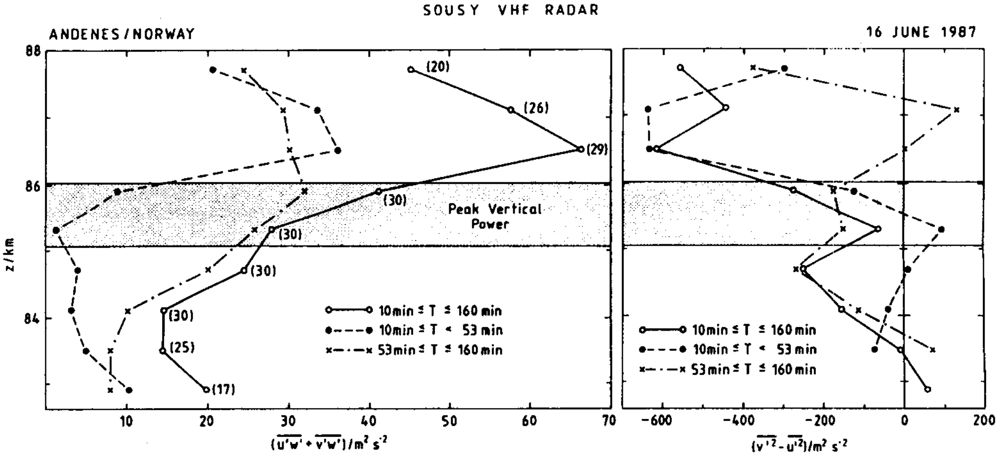
SOUSY VHF RADAR
ANDENES / NORWAY
16 JUNE 1987
88
86
84
z / km
(20)
(26)
(29)
(30)
(30)
(30)
(30)
(25)
(17)
Peak Vertical Power
10min ≤ T ≤ 160 min
10min ≤ T < 53 min
53min ≤ T ≤ 160 min
10
20
30
40
50
60
70
$(\overline{u'w'}+\overline{v'w'})/m^2 s^{-2}$
-600
-400
-200
0
200
$(\overline{v'^2}-\overline{u'^2})/m^2 s^{-2}$

Figure 6.