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3.3.3 THE USE OF THE EXPERIMENTALLY DEDUCED BRUNT-VAISALA FREQUENCY AND TURBULENT VELOCITY FLUCTUATIONS TO ESTIMATE THE EDDY DIFFUSION COEFFICIENT

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The determination of the turbulent energy dissipation rate or the eddy diffusion coefficient from radar observations can be done through the turbulence refractive index structure constant, deduced from calibrated echo power measurements, or through the turbulent velocity fluctuations, deduced from the echo spectrum width. Besides the radar parameters, power and spectrum width, the first approach needs knowledge of profiles of temperature (and electron density in the mesosphere) and the fraction of the radar volume filled with turbulence, and the latter approach needs knowledge of the temperature profile, namely, the Brunt-Vaisala frequency. HOCKING (1985b) has recently reviewed these techniques. WEINSTOCK (1981a) has shown that the energy dissipation rate is of turbulence in the stable free atmosphere:

$$\varepsilon = 0.4 \cdot \langle W^2 \rangle \cdot \omega_B. \qquad (1)$$

The mean squared velocity $\langle W^2 \rangle$ can be directly reduced from the width of the radar power spectrum, provided that the effects of wind shear and beam width broadening are negligible. It is shown by ROTTGER (1985a) that also the Brunt-Vaisala frequency ω_B can be estimated from radar observations. Thus, the energy dissipation rate ε can be directly deduced from radar data without the need of any supplementary data or assumptions. The eddy diffusion coefficient K, similarly is given by radar observations (e.g. WEINSTOCK, 1981b).

$$K = \frac{0.8\varepsilon}{{\omega_B}^2} = 0.32 \langle W^2 \rangle / \omega_B \qquad (2)$$

The factor of 0.8 in Equation (2) is not well known yet, however.

Mesospheric data were taken during an ATMAP campaign, in November 1981, with the SOUSY VHF Radar at the Arecibo Observatory using an average power of 6 kW on 46.8 MHz and a height resolution of 1.2 km, applying an 8-bit complementary code. The main dish of the Observatory was used as an antenna yielding a half-power beam width of 1.7°. The beam was pointed 2.3° off the zenith such that a quasi-vertical velocity was measured, allowing to investigate short-period gravity waves. The beam was kept fixed at the E- or N- direction for about one hour, such that also the mean horizontal wind could be measured.

Figure 1 shows the average horizontal velocity profiles, and Figure 2 shows the spectra of the quasi-vertical velocity variations deduced from velocity time series (see ROTTGER, 1985a). We notice fairly low horizontal velocities smaller than 20 ms^{-1}, and we also notice a clear cutoff of the spectra at periods of a few minutes. Following the arguments of ROTTGER (1985a), we assume that this cutoff is at the Brunt-Vaisala frequency. Since the mean wind velocities were fairly low, only a small Doppler shift did result and the spectra mostly indicate a clear cutoff. This is also seen in the spectra intensity plots of Figure 3. To accentuate the consistency of the cutoff with height and time, the spectra intensities are normalized separately for each hour and altitude. The cutoff deduced from Figure 3, which is assumed to be consistent with the Brunt-Vaisala frequency ω_B, is shown in Figure 4.

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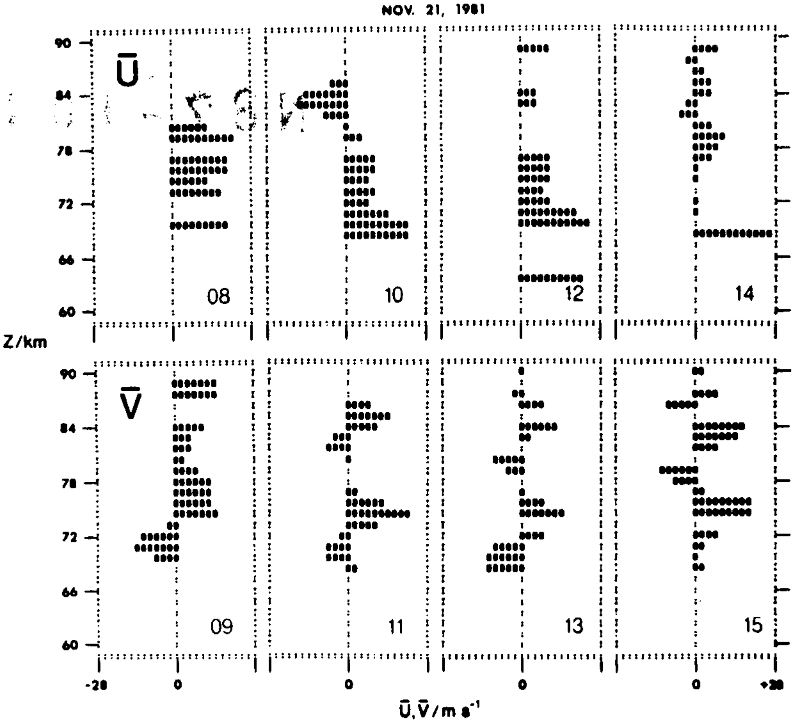

Figure 1. Average profiles of zonal (U) and meridional (V) winds in the mesosphere. Time (numbers) is AST.

This is an average over 8 hours of mesospheric observations from 08 to 16 UT. Since we have not observed an apparent anisotropy of the wave phenomena, i.e., the E- and N-beam spectra were not significantly different, data of all 8 hours were combined in Figure 4 to yield the average ω_B. We clearly see a significant increase of the average ω_B with height above 77 km. This increase is expected to be an indication of the mesopause, which we estimate from these data to be around 80 km. Furthermore, we can deduce the profiles of mean square wave velocity $\langle \tilde{W}^2 \rangle$ from the velocity time series, and the mean square turbulent velocity $\langle W^2 \rangle$ from the spectral widths (average over 50 s). The latter deduction can be done without applying corrections, since beam width and wind shear broadening effects are estimated to be small (see HOCKING, 1985b).

Since the mean square wave velocity $\langle \tilde{W}^2 \rangle$ is about constant with height and does not follow the exponential increase (continuous curve in Figure 4), we assume that the waves were dissipated (see also ROTTGER, 1985b). This is consistent with other mesospheric observations (e.g., FRITTS et al., 1984). If we assume that the gravity waves are dissipated into turbulence, we would assume an increase in the energy dissipation rate. This quantity can be deduced from the mean square turbulent velocity and the Brunt-Vaisala frequency profiles (see Equation (1)). The energy dissipation rate is proportional to the eddy diffusion coefficient, which is shown in Figure 5. It apparently has a maximum between 70 and 78 km, where the wave velocity stays almost constant. Above 78 km, the eddy diffusion coefficient is small and constant. This is

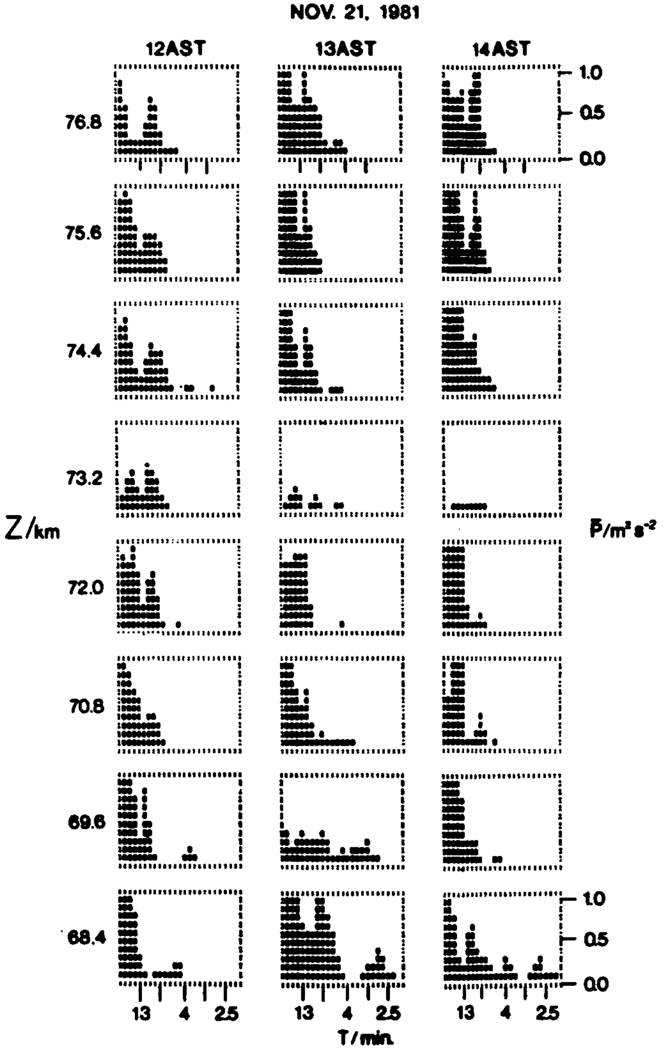

Figure 2. Spectra of quasi-vertical velocity, averaged over 54 minutes. P = 1 m^2 s^{-2} corresponds to a power density of 3.2 · 10^3 m^2 s^{-2} /Hz.

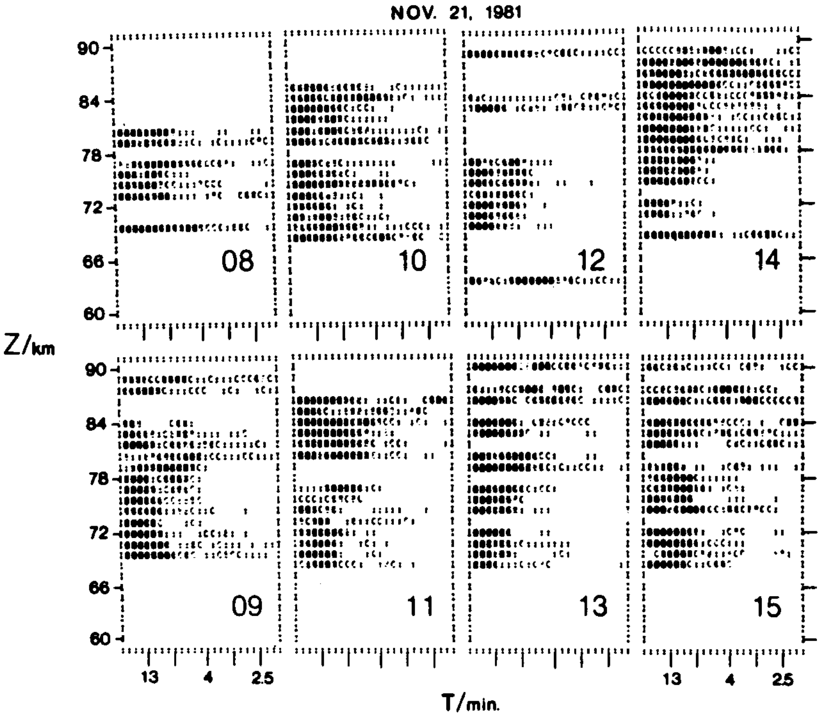

Figure 3. Spectra intensity plots. Time is in AST; even hours with beam at 2.3° zenith angle to the east and odd hours to the north.

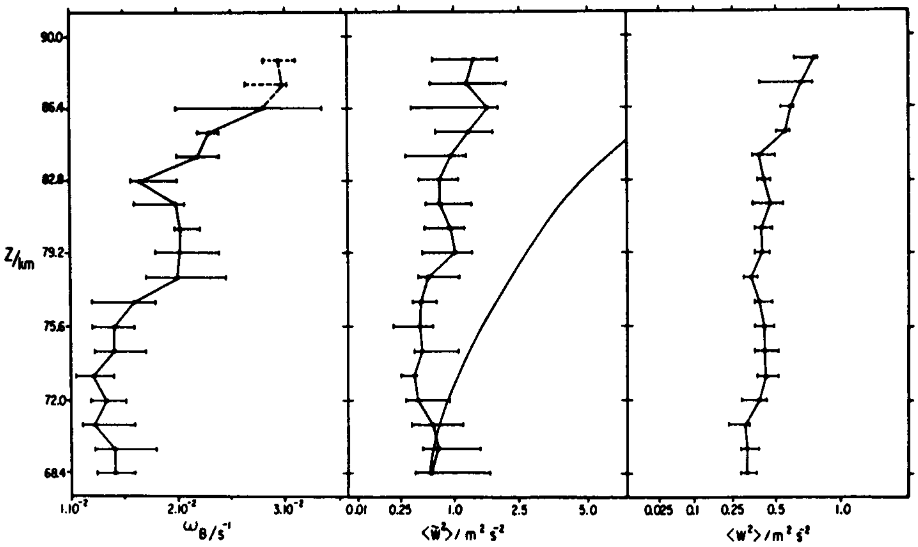

Figure 4. Profiles of average (8 hours) estimate of Brunt-Vaisala frequency ω_B, mean square wave velocity $\langle \hat{W}^2 \rangle$ and mean square turbulent velocity $\langle W^2 \rangle$. The continuous curve in the middle diagrams indicates the exponential increase.

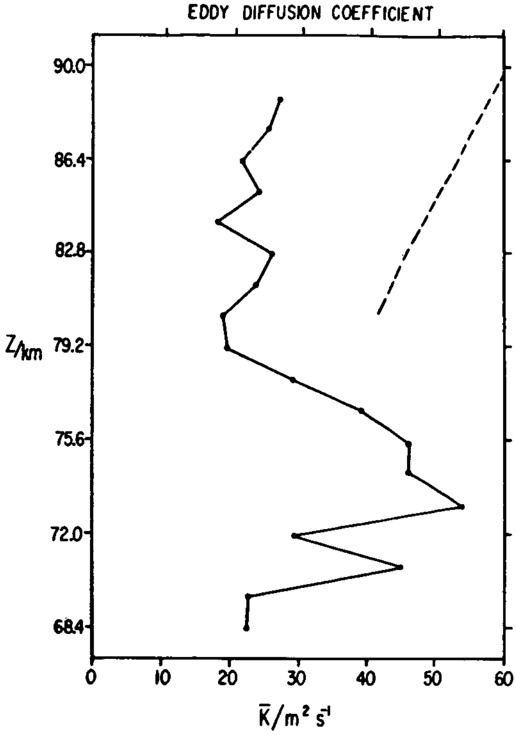

Figure 5. Profile of mean eddy diffusion coefficient (solid line) deduced from Figure 4. The dashed lines is from HOCKING (1985).

quite consistent with the observation that the mean wave velocity again starts to increase with height above 78 km.

In Figure 5, also the mean eddy diffusion coefficient (dashed line) from HOCKING (1985a) is included for heights above 80 km. It is about a factor of 2 larger than our values and it appears to be in the minimum of the mean values given by HOCKING (1985a). Since our data are averages over one day only, they, however, may not be representative for an average energy dissipation rate but also large variations around mean values may occur. Since we are fairly confident on the exact and well-defined deduction of the spectrum width, a Brunt-Vaisala frequency 2 times smaller than our deducted ω_B would be necessary to increase the eddy diffusion coefficient K. Such a low Brunt-Vaisala frequency ($\sim 10^{-2}$ Hz) cannot be found from our spectra. We therefore conclude that our profile of K is the most exact estimate available from radar observations.

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