3.3.4 THE RELATION OF GRAVITY WAVES AND TURBULENCE IN THE MESOSPHERE

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Gravity-wave saturation in the middle atmosphere is widely assumed to be due to the increase of wave amplitude or from the encountering of a critical level such that convective and/or shear instability limits the wave growth (e.g., FRITTS, 1984). The growth of wave amplitude first results in a steepening of wave velocities, i.e., in the generation of harmonics before the wave eventually breaks into turbulence and gets saturated. As pointed out by WEINSTOCK (1985), the saturation of the wave is accompanied by a near adiabatic lapse rate and turbulence.

VHF MST radars with suitable sensitivity can detect turbulence in the mesosphere if the electron density and its vertical gradient is sufficiently strong. It is unquestionable from many experiments that the radar-detected turbulence is intermittent in space and time. Figure 1 shows an example of layers of mesospheric echoes detected with the SOUSY VHF Radar at the Arecibo Observatory (ROTTGER et al., 1981; CZECHOWSKY et al., 1984). A clear feature in this figure is the splitting into several, periodically arranged layers. Many authors have reported an apparent downward progression of such structures, which is not readily apparent in Figure 1, however. These discrete layers can be due to turbulence or due to very persistent steep electron-density gradients. We cannot imagine that the latter can endure in the daylight ionosphere if they were not controlled by some kind of neutral atmosphere effect. It is often observed that long-period atmospheric gravity waves or tides can give rise to turbulence layer generation (e.g., FRITTS et al., 1986). The layers then should move downward which we do not observe. It is also reported that layers occur preferably in strong wind shear regions (e.g., RUSTER, 1984). Figure 2 shows the simultaneously measured mean wind profiles. These indicate a downward moving shear (trace the zero-crossings, particularly in the meridional component), which is likely to be due to the diurnal tide. Since the shear moves downward, we have to exclude that the observed height-stationary turbulence layers of Figure 1 have to do with the tidal variation of velocity or temperature.

We also cannot believe that these fairly thin and persistent layers (better to be called sheets or laminae because of their narrowness) are generated by short-period gravity waves. A common explanation is that gravity wave breaking causes turbulence (e.g., FRITTS and RASTOGI, 1985) which we should see in our records. Figures 3a and 3b show time series of spectra-intensity plots for different altitudes. The intensity is printed in an absolute reflectivity scale, such that the height and time dependence of turbulence intensity (assuming no substantial electron-density profile change), spectral width and mean radial (= almost vertical at 2.3° zenith angle) velocity can be identified. We notice quite a substantial wave activity at many different periods from 4 minutes upwards. If wave breaking would occur, we should see an increase of intensity and spectrum width at certain phases of these oscillations. Except occasionally in some upper heights, where some intensity bursts are apparent (above 78 km in Figure 3b), we cannot clearly detect such phenomena. The intermittency in space and time of the turbulence

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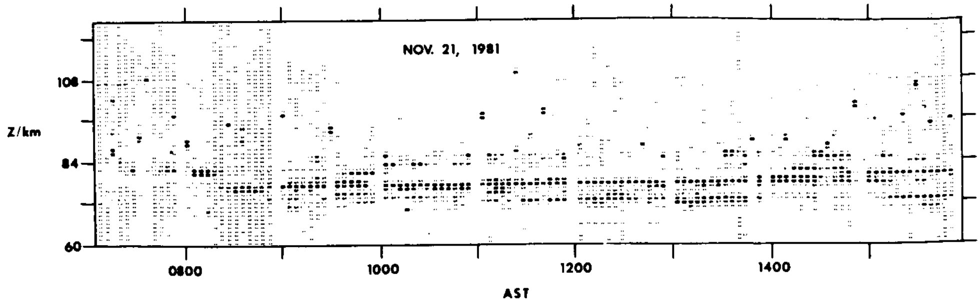

Figure 1. Height-time-intensity plot of mesospheric VHF-radar echoes detected at the Arecibo Observatory. The antenna pointed at 2.3° zenith angle, during even hours towards last and during odd hours towards north (see ROTTGER, 1985).

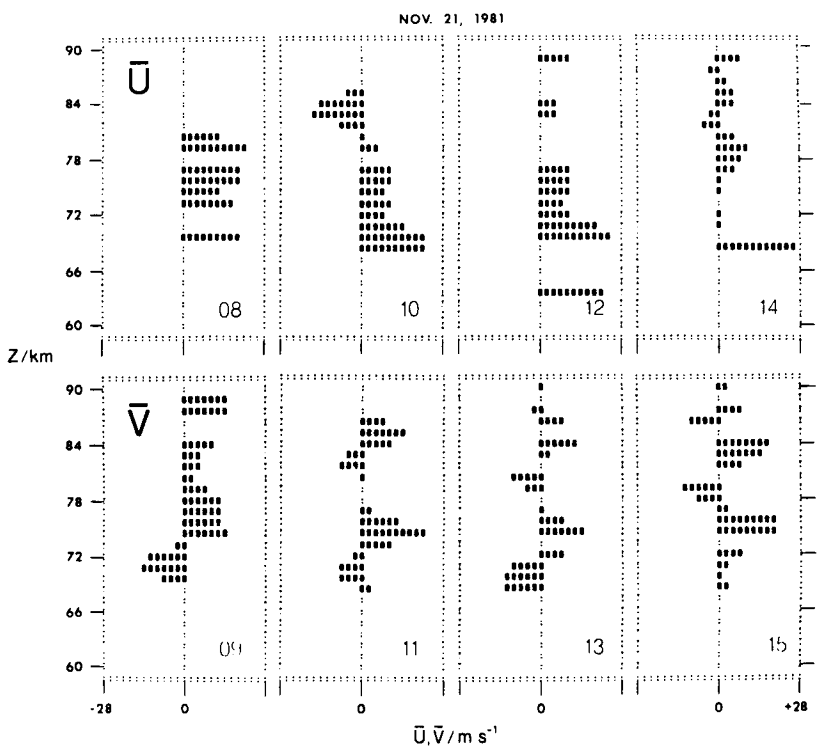

Figure 2. Profiles of zonal (U) and meridional (V) component of the mean wind, measured over periods of 54 min. The numbers denote time in AST.

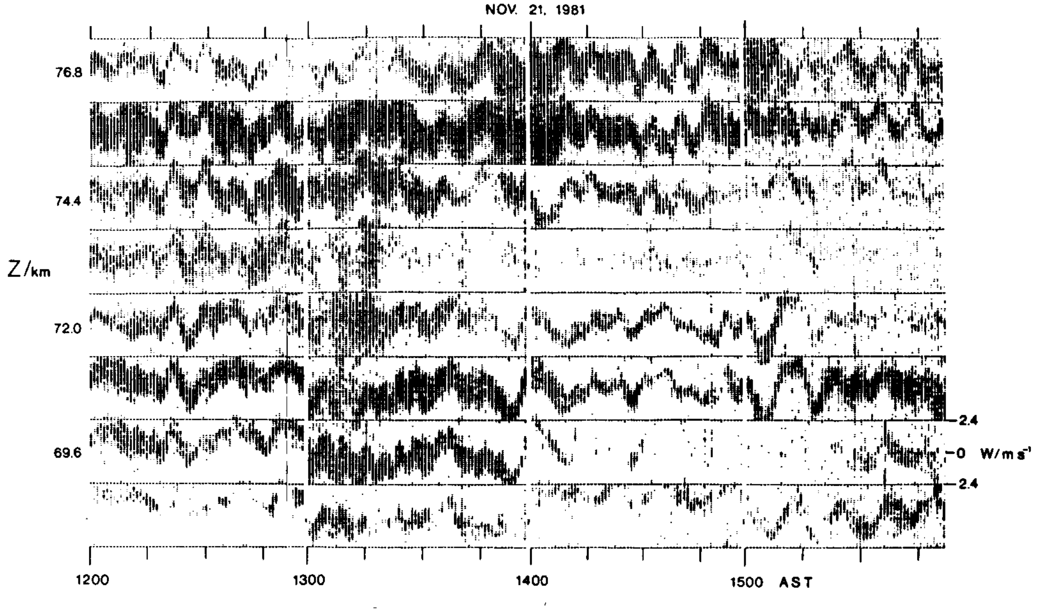

Figure 3a. Intensity plots of spectra (see the layered structure of turbulence in Figure 1).

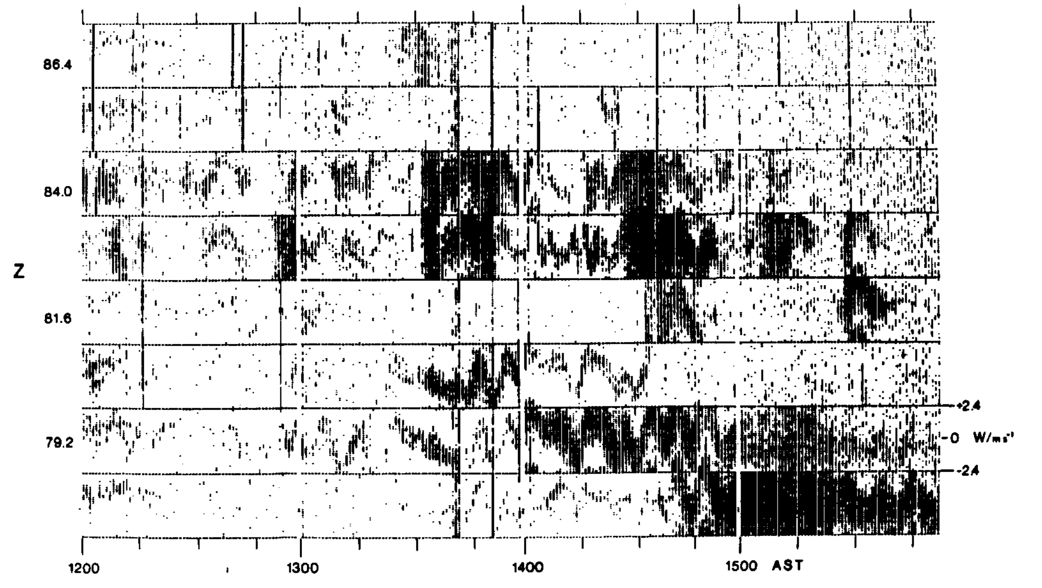

Figure 3b. Intensity plots of spectra (see the layered structure of turbulence in Figure 1).

echoes appears in the majority of times and heights not related to these short-period gravity waves. When carefully viewing the velocity oscillations, we, however, often find clear indications of a nonsinusoidal variation. This indicates a nonlinear steepening effect (WEINSTOCK, 1985), which transfers energy from the fundamental into harmonics -- in our case mostly without leading to breaking into turbulence. Another peculiar effect is seen sometimes, when a high-frequency wave is superimposed on a low-frequency wave oscillation (e.g., at 69.6 km after 13 AST). KLOSTERMEYER (1984) has explained similar observations at thermospheric heights to be due to parametric instabilities.

There is apparently no distinct amplitude growth of these wave oscillations (e.g., fairly clearly seen from 12-13 AST between 69.6 km and 76.8 km, as well as in Figure 4 of ROTTGER, 1985). We, therefore, have to imply a saturation process if we assume that these are vertically propagating waves. Since in our case study we seldom observe a clear indication for wave breaking into turbulence, we have to invoke other dissipation effects which limit the wave growth, such as energy transfer into higher harmonics (nonlinear steepening), parametric instabilities, radiative dampening or dissipation due to kinematic viscosity and heat conduction. We also could assume that the observed short-period gravity waves are locally generated or guided in wave ducts, since most of the oscillations are confined to height ranges of a few kilometers only.

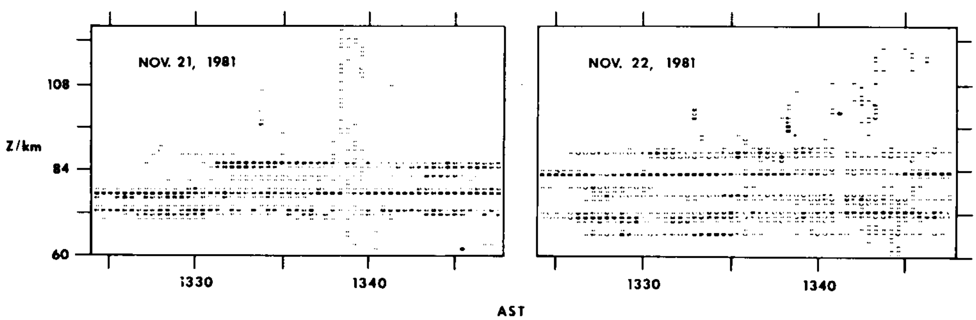

Figure 4. Height-time-intensity plots of mesospheric VHF-radar echoes detected at the same time on two different days.

Since we cannot prove that the mesospheric turbulence layers (Figure 1) are generated by the simultaneously existing short-period gravity waves (Figure 3), we have to invoke other generation mechanisms than wave breaking. Possible mechanisms like lateral convection (ROTTGER, 1980a), quasi-geostrophic flows at mesoscales (LILLY, 1983) or vortical modes of motion as seen in the ocean (MULLER and PUJALET, 1984) could be candidates. We are inclined to see a connection of these layers or laminae with very-long-period internal waves because of the periodicity in their vertical structure and their long mean persistency (see Figure 5, which shows their appearance at two time periods separated by 24 hours). ROTTGER (1980b) had proposed that such structures are due the modulation of the mean temperature and wind profiles by internal waves. The superposition of random or short-term wave-induced wind and temperature fluctuations with the background profile, modulated by very-long-period waves (quasi-inertia waves) then would yield the observed effects, namely could explain the vertical periodicity, the long-term mean persistency as well as some short-term variability of their intensity. Note that this phenomenon does not need the short-term gravity waves to break into turbulence, rather than to add a small shear of temperature variation to the background profile modulated by long-period waves (which cannot be detected with the radars), to lead to very thin laminae where the Richardson number is smaller than its critical value to initiate turbulence.

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