2.6A JICAMARCA MESOSPHERIC OBSERVATIONS

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In explaining the scattering of VHF radar signals from the mesosphere there are two observational facts that must be accounted for. These are: 1) the aspect sensitivity of the scattered signal and that this aspect sensitivity is largest in the lower part of the mesosphere; and 2) the correlation between the scattered power and the signal correlation time. This correlation tends to be positive in the lower part of the mesosphere, but changes to negative in the upper part of the mesosphere.

This behavior is similar to that of the scattering from the troposphere/stratosphere region, and it has been suggested that the scattering mechanisms are similar in these three regions. In particular, it has been suggested that a mixture of scattering from isotropic irregularities and partial reflection from stratified layers could explain the observed characteristics of radar signal returns from the mesosphere.

Several different experiments have been performed at the Jicamarca radar in Peru. They all show strong indications of aspect sensitivity and changing correlation between scattered power and correlation time. The results from two of these experiments will be considered here.

If as suggested, the aspect dependence of scattered power and signal correlation time is due to a mixture of scattering from isotropic irregularities and reflections from stratified layers, one would expect to see a clear difference in the signal spectra in the vertical and off-vertical antennas. Perhaps a near Gaussian distribution of scattered power in the off-vertical antenna representing the turbulent scatter, and a superposition of the same Gaussian and one or more discrete peaks in the vertical antenna, representing both the scattered and the reflected component of the received signal. As can be seen from the two examples in Figure 2, the spectra in the two antennas are very similar and there is no hint of a reflecting layer in the vertical antenna. Nevertheless, there is a substantial aspect sensitivity where the scattered power in the vertical antenna is about 50% larger than that of the off-vertical antenna. There is also a slight tendency for the correlation time in the vertical antenna to be larger than that in the off-vertical antenna, as one would expect from the correlation times in Figure 1. We tentatively conclude from these data that there is no indication of stratified reflecting layers unless these layers are modulated in space and time to a degree that they cannot be distinguished from turbulence in any other way than that they cause somewhat aspect sensitive scattering.

An interferometer technique can be used to study small-scale horizontal variation in the amount and Doppler shift of the scattered signal. Data were obtained during the spaced antenna drifts experiment run on October 17, 1981 (ROYRVIK, 1983). By forming the cross spectra between sets of two antenna sections we can determine the principal direction to the scattering volume with a certain Doppler shift. Direction differences transform into horizontal distances at a certain altitude range.

In Figure 3 frequency spectra are presented for five altitudes having substantial scattered power. The phase of the frequency component has been plotted only for those frequencies with substantial power in order to reduce clut-

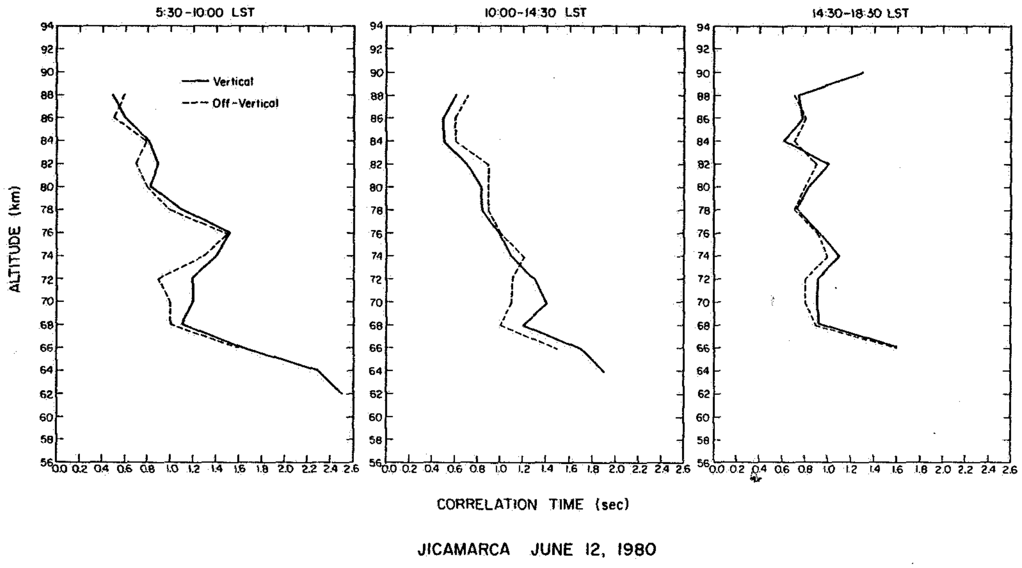

Figure 1. Signal correlation time for June 12, 1980 for vertical and west antenna sections.

ter in the figures. It can be seen from the figure that there is a tendency for the direction of the scattered signal to change systematically with changing frequency for all altitudes except 70 km. From closer study of the data it appears that the tendency at the higher altitudes is quite clear in aligning these variations in the east-west direction, whereas at 67 km the direction of alignment appears more random. Also the occurrence of these phase changes is limited to short (1-3 min) intermittent time periods. One might suspect these observations to be the result of beam width broadening due to the differential line-of-sight velocity component of the horizontal velocity. However, this differential velocity is negligible in an antenna beam of only 1° beam width. In the present case where the horizontal velocity is shown to be about 10 m/s (ROYRVIK, 1983) the broadening of the spectra will be about 0.03 Hz, or only a couple of percent Doppler broadening. Also the phase shift that would result from the observed wind field (ROYRVIK, 1983) is opposite to the phase shift actually observed. The most likely explanation appears to be one where individual peaks in the frequency spectra represent individual scattering cells with large-scale organized motions. For example, a turbulent cell caused by wind shear would have a large-scale rotating motion corresponding to the outer scale of turbulence. In the simple case where only one cell is present within the antenna beam, one would expect to observe different Doppler shifts in different directions as the one seen at 79 km in Figure 3. From the examples in Figure 3, and other examples, it is estimated that typical horizontal dimensions of these scattering cells are from 200 to 600 meters, with a few occasions where there are indications of even larger horizontal dimensions. At about 67 km the horizontal dimension seems to be somewhat smaller, but still in the range of hundreds of meters. Also the rotational velocity is smaller at lower altitudes resulting in narrower spectra. Most of the irregularities that show a directional dependence of the spectra indicate positive Doppler shift to the east and negative Doppler shift to the west. This is consistent with a rotating cell of irregularities resulting from a wind shear where higher westward wind velocities occur at higher altitudes. Seen by the radar, only the vertical velocities will show up in the spectra and one would expect the most positive Doppler shift to be to the east (Figure 4).

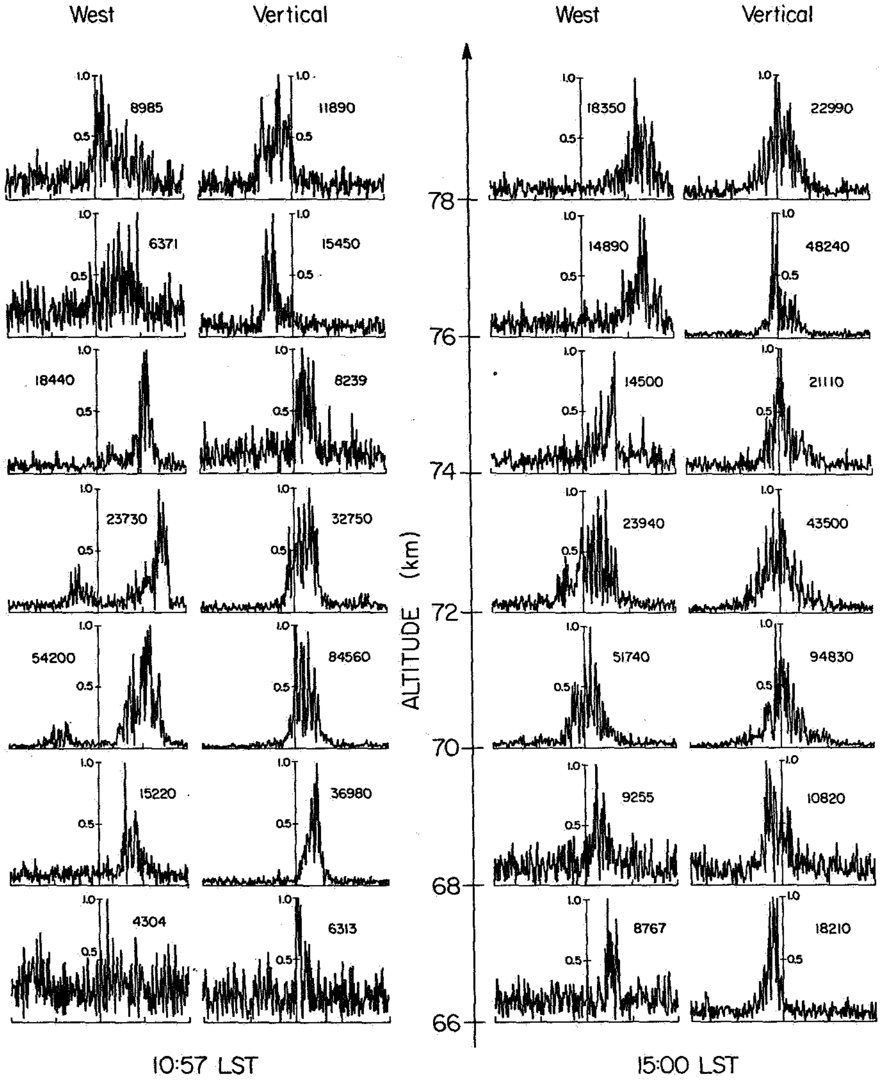

Figure 2. Frequency spectra for vertical and west antenna sections for June 12, 1980.

DISCUSSION

A substantial amount of effort has gone into the study of the mechanism scattering HF and VHF radio waves from the mesosphere between 60 and 90 km although the question is far from settled. Stratified layers have been suggested as a source for that part of the scattered signal that is aspect sensitive. It has also generally been taken for granted that turbulence-induced irregularities in the refractive index are both isotropic and homogeneous, and thus accounts for that part of the scattered power that is not aspect sensitive. It cannot be concluded from these data that no stratified layers give rise to reflection from the mesosphere, but if stably stratified layers exist, they are not stable and stratified enough to be easily distinguished

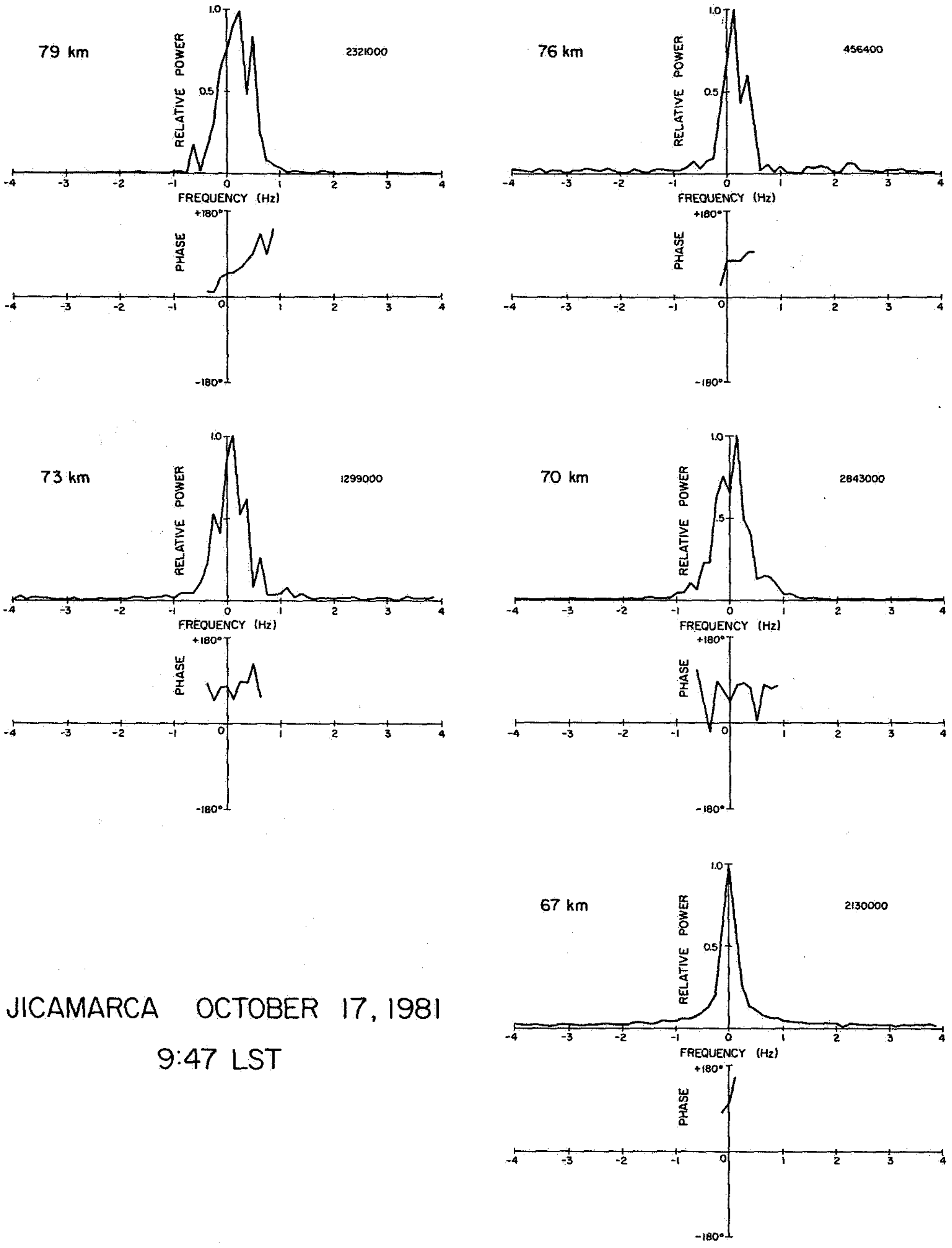

Figure 3. Cross spectra for October 17, 1981. To reduce clutter the phase has been deleted from those frequencies where the scattered power is small.

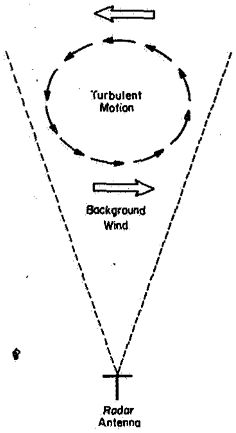

Figure 4 Diagram showing the rotating motion resulting from a wind shear.

from turbulence scatter occurring in the same range gates. It is also difficult to believe that a stratified layer could form and survive for any length of time; and it surely must take some time to form in the presence of shear induced turbulence.

Also, in the lower part of the mesosphere around 60 km, the temperature profile is such that the atmosphere is close to being convectively unstable, whereas at altitudes above 60 km it becomes more and more stable with increasing altitude throughout the mesosphere. It thus seems strange to suggest that stable stratified layers should form in the lower, but not in the upper, part of the mesosphere.

It seems more likely that the turbulence is anisotropic with larger horizontal than vertical dimensions. Such anisotropic irregularities have been reported in boundary layers observations (STEWART, 1969; MESTAYER et al., 1976 and GIBSON et al., 1977) which show anistropy in both temperature and velocity variations. To the degree that temperature is a scalar tracer in these experiments, and that the condition in surface boundary layers and jets apply to the situation of shear layers in the mesosphere, it is of interest to study these results further.

Clearly from these evidences it is not satisfactory to consider the turbulence in the mesosphere as isotropic, homogeneous and time stationary. It seems much more appropriate to discuss the scattering from the viewpoint of generation and decay of Kelvin-Helmholtz instabilities as presented by WOODS (1969); PELTIER et al. (1978); SYKES and LEWELLEN (1982) and other.

It seems reasonable to interpret the rotating cells as Kelvin-Helmholtz vortexes in the process of being "rolled-up". Given a typical observed value for the horizontal dimension of a K-H billow in the mesosphere of 300 m and assuming a Richardson number of 0.2 we find from comparison with the computer results of SYKES and LEWELLEN (1982) that the billow layer should be about 100-200 m thick.

It is also seen from the computer model study that irregularities are generated not only in the K-H billows, but also in the braids that connect the billows, and in a broader turbulent region resulting from the horizontal spreading and collapse of the billows. The large-scale irregularities are nearly horizontally stratified. It may be assumed that the mean shear that causes the large-scale anisotropy also causes anisotropy in the small-scale irregularities responsible for the scattering of the 50-MHz radio waves. Although this does not necessarily follow from the computer study of SYKES and LEWELLEN (1982), strong experimental evidence for this anisotropy exists.

It appears that there should be no problem in explaining the aspect sensitivity of scattered radio signals as resulting from anisotropic turbulence at the scale of 3 meters. It does become a problem, however, to explain why this aspect sensitivity is substantial at 60-70 km, but decreases to almost zero at higher altitudes. Perhaps it is a result of changing turbulent conditions resulting from a change in the mean temperature gradient and/or a change in the viscosity of the atmosphere.

There remains the problem of positive correlation between scattered power and signal correlation time below 70 km and the change to a negative correlation above this altitude. The negative correlation is generally believed to be related to isotropic turbulence following the Kolmogorof model. The explanation for the positive correlation may be found in the spatial and temporal differences in the distribution of turbulent kinetic energy affecting the correlation time, and the distribution of electron-density variations representing scattered power. Comparing Figures 2 and 10 of SYKES and LEWELLEN (1982) it is seen that the strongest scatter ought to occur in the remnants of the braids, a region that has little turbulent kinetic energy. On the other hand, somewhat less scattering will occur at the periphery of the K-H billows, in a region where there is quite strong turbulent velocity fluctuations. Since the time scale of this development is on the order of 10 minutes, it is reasonable that the positive correlation between scattered power and signal correlation time should be observed when the integration period is on the order of one minute. Furthermore, it appears from the correlation between aspect sensitivity and correlation time that the largest anisotropy of the scattering irregularities ought to occur in the braids and not in the billows. Again, the question to be answered is, why does the scattering change from being dominated by the large-scale K-H instabilities at altitudes below 75 km to be almost homogeneous and isotropic above this altitude. One possible answer is that both the inner and outer scale of turbulence increases with increasing height, bringing the scattering wavelength further and further away from the horizontally stratified region at the outer scale, and close to what may be an isotropic region at the inner scale of turbulence.

On the other hand, if it is assumed that the received signal results from a mixture of scattering and partial reflection, one must conclude that the amplitude of the reflected signal varies more than that of the scattered signal, in order to explain the positive correlation between scattered power and signal correlation time. This can be proven mathematically, however, two short examples are more instructive.

First assume a constant reflecting layer with correlation time of say 1 min. Add a continuously increasing amount of scattered signal with 1 s correlation time. It is clear that as the amount of scattered signal, and thus total signal, increases the total signal correlation time will decrease. This will give a negative correlation between scattered power and signal correlation time.

Secondly, assume a constant amount of scattered power with correlation time ot 1 s. Add a continuously increasing amount of reflected signal with 1 min correlation time. As the reflected signal and the total signal increase the signal correlation time will increase from 1 s to 1 min. This gives a positive correlation between the signal power, and the signal correlation time.

This larger variation in reflecting layers than in scattering turbulence may be hard to explain.

It is concluded that there is no strong evidence for a mixture of scattered and reflected signals from the mesosphere. Anisotropic turbulent scatter appears to be a more likely explanation.

ACKNOWLEDGMENT

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