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# 3.3A ANISOTROPY OF THE PERMITTIVITY FIELD INFERRED FROM ASPECT-SENSITIVE RADAR ECHOES*

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This paper attempts to draw some quantitative conclusions regarding the anisotropy of the clear-air back-scattering mechanism based on the measured variation of echo power with zenith angle. The measurements were made by the SOUSY group of the Max Planck Institute for Aeronomy at Lindau, FRG, (ROTTGER et al., 1981; WATERMAN and CZECHOWSKY, 1983). They installed their 47-MHz transmitter and antenna feed in the 300-meter diameter reflector at Arecibo. The resulting 1.7-degree beam was stepped successively through seven 1.7-degree intervals from 1.7 to 11.7 degrees in zenith angle, obtaining about four minutes of data at each setting. This procedure was carried out in an eastward pointing azimuth and in a northward pointing azimuth, the entire set of measurements consuming an hour and twenty minutes. Range resolution was 150 meters.

Figure 1 shows received echo power vs actual height (corrected for slant range) for the seven zenith angles; the data cover two ranges of height intervals, selected for good signal-to-noise ratio and freedom from other complications. The variation of signal with zenith angle is apparent, particularly in the layer at 16.8 km and even more strongly around 14 km.

Figure 2 is an example of the aspect sensitivity at 13.9 km for the eastward looking azimuth. The discrete measured values of echo power at the seven zenith angles are connected by straight line segments, while the smooth curve is a least-mean-squares fit to these data using a specific model of anisotropic scattering.

The specific anisotropic scattering model was taken from GAGE and BALSLEY, (1980) who used the Booker-and-Gordon scattering concept (BOOKER and GORDON, 1950) as modified by STARAS (1955) to take possible anisotropy into account. It leads to an expression for the volume scattering reflectivity which can be written as

$$\eta = \frac{B}{(\sin X)^2 + R^2 (\cos X)^2} . \qquad (1)$$

B is an amplitude constant, X is the zenith angle, and R is the quantity related to the anisotropy. If there is anisotropy in the vertical only, and the permittivity field is horizontally isotropic, then

$$R = \frac{\ell_z}{\ell_x} . \qquad (2)$$

where $\ell_z$ is the vertical axis in the correlation ellipse of the permittivity field and $\ell_x$ is its horizontal axis. If there is anisotropy in the horizontal as well as the vertical, the interpretation of R becomes more complicated, since the horizontal anisotropy ellipse has a minor axis $\ell_y$ and a major axis $\ell_x$ as well as an orientation angle $\phi$ measured from east:

$$R = \left(\frac{\ell_z}{\ell_x}\right) \sqrt{\frac{1 + (\tan \phi)^2}{1 + (\ell_y/\ell_x)^2 (\tan \phi)^2}}$$

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* A more detailed account of this analysis is given in "Measurements of Anisotropic Permittivity structure of upper troposphere with clear-air radar", A. T. Waterman, T.-Z. Hu, P. Czechowsky and J. Rottger, to appear in Radio Science.

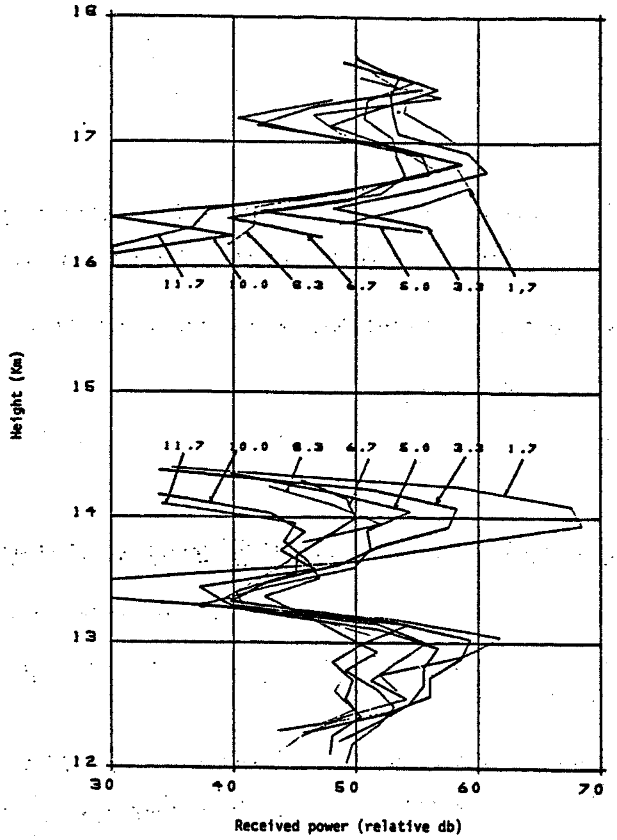

Figure 1. Backscattered power vs height for seven zenith angles (marked, in deg) and eastward azimuth.

From the measurements, the reflectivity as a function of zenith angle X is determined, and the values of B and R giving the least-mean-squares fit are found. This is done for each height for both eastward and westward azimuths. yielding $R_E$ and $R_N$. (The values of B provide redundant information in this model). The three desired quantities. vertical anisotropy $\ell_z/\ell_x$, horizontal anisotropy $\ell_y/\ell_x$, and orientation $\phi$, cannot be uniquely determined from the measurements -- a third azimuth would be needed -- but limits within which these quantities must lie can be found. They are shown in Figure 3.

The right-hand column of Figure 3 shows vertical anisotropy ($\ell_z/\ell_x$) as a function of height. Here the two curves are the upper and lower bounds within which the anisotropy must lie. Remember that the $\ell$-ratios here are minor-to-major-axis ratios, so that low values represent greater anisotropy. (Unity implies isotropy). Except for the region around 13.3 to 13.5 km, a clear vertical anisotropy prevails.

The left-hand column of Figure 3 shown the upper bound on this anisotropy ratio for the horizontal structure -- that is, the atmosphere is at least as anisotropic as the values given by this curve, and may be more so. Associated with this measure of the structure is the orientation of the major axis of the horizontal anisotropy ellipse. The limits within which it must lie are shown by the shaded areas in the center portion of the figure. At low elevations it

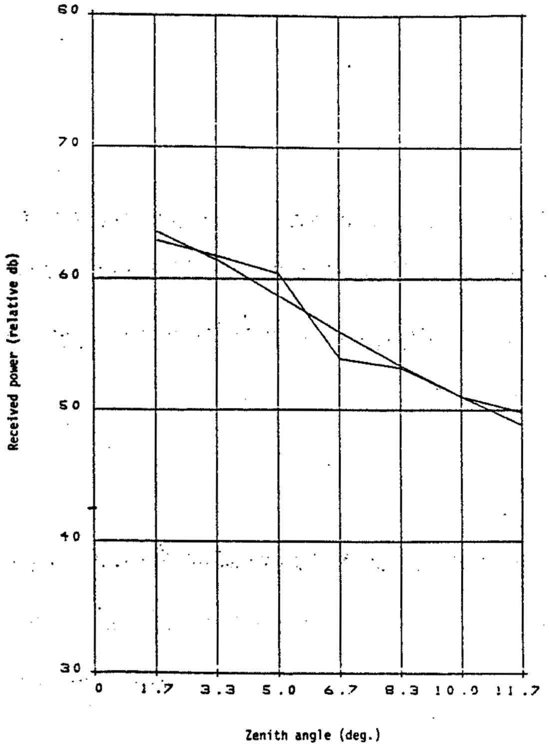

Figure 2. Aspect sensitive backscattered power at 13.9 km. R = 0.1.

starts out with an orientation aligned within ± 30 degrees of east-west. At about 12.5 km it swings around to a more nearly north-south orientation, etc.

Owing to the small amount of data and limitations in the nature of the data, one should not draw too many conclusions from these results. Nevertheless, it is clear that some form of anisotropy exists here, and this analysis is one attempt to put it on a quantitative basis.

## REFERENCES

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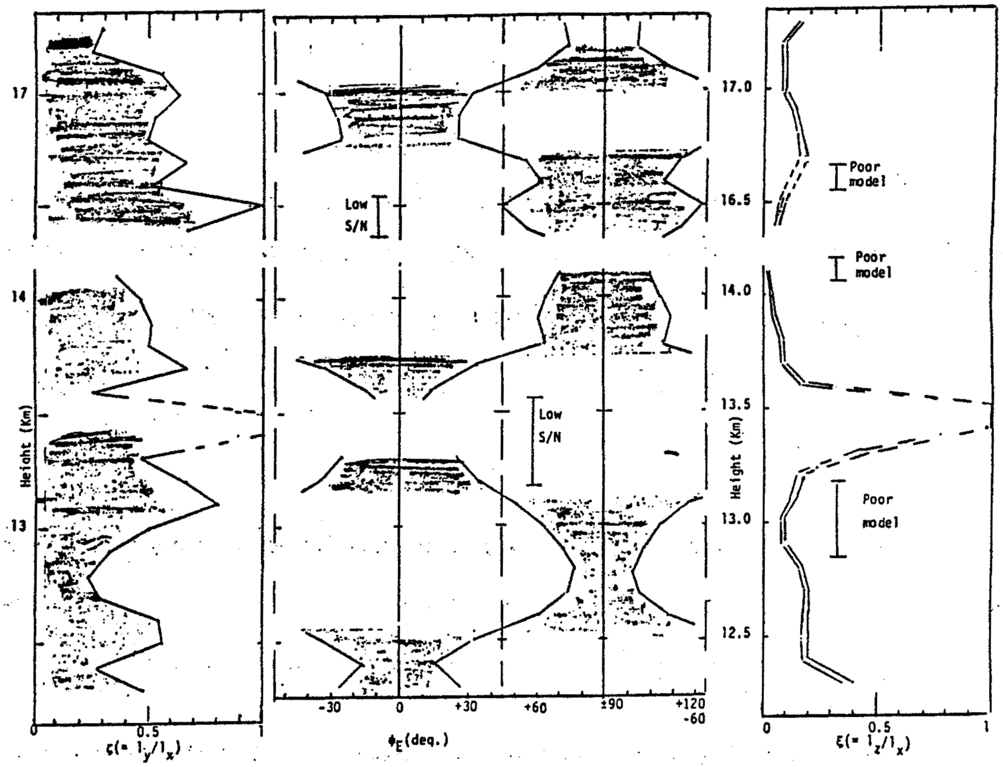

Figure 3. Degree $\zeta$ and orientation $\phi_E$ of horizontal anisotropy; degree of vertical anisotropy $\xi$. Shaded areas show permissable range of values. Low values of $\zeta$ and $\xi$ are most anisotropic.