D15 N85-32481

2.1A MORPHOLOGY OF THE SCATTERING TARGETS: FRESNEL AND TURBULENT MECHANISMS

O. Royrvik

Department of Electrical and Computer Engineering,
University of Illinois
Urbana, IL 61801

INTRODUCTION

Refractive index fluctuations cause coherent scattering and reflection of VHF radio waves from the clear air in the altitude region between 0 and approximately 90 km. Similar echoes from the stratosphere/troposphere and the mesosphere are observed at UHF and MF/HF frequencies, respectively. The nature of the refractive index fluctuations has been studied for many years without producing a clear consensus on what mechanism causes them. It is believed that the irregularities can originate from two different mechanisms: turbulent mixing of the gradient of refractive index, and stable horizontally stratified laminae of sharp gradients in the refractive index.

In order to explain observations of volume dependence and aspect sensitivity of the echo power in the MST region, a diversity of submechanisms has been proposed. They include isotropic and anisotropic turbulent scattering, Fresnel scattering and reflection, and diffuse reflection (Figure 1).

Isotropic turbulent scattering is believed to cause a majority of the clear-air echoes observed by MST radars. Echoes showing no apparent aspect sensitivity are expected to be of this type. The mechanism requires active turbulence mixing of a preexisting gradient in the refractive index profile.

Anisotropic turbulent scattering also requires active turbulence mixing of a gradient in the refractive index profile. At the larger scales, turbulence must be anisotropic in the direction of the shear velocity, resulting in anisotropic scattering at radio wavelengths comparable to these large turbulent irregularities. At some unknown smaller scale, the irregularities are expected to become isotropic.

Fresnel reflection, also called partial reflection, results when a radio signal encounters a single sharp, horizontally stratified ledge in the refractive index. If perfect stratification is assumed, reflected signals would be received only from the vertical direction.

Fresnel scattering is similar to Fresnel reflection except that it consists of multiple stratified layers reflecting individually with random phase. This concept has been introduced to explain the pulse length dependence of some aspect-sensitive echoes.

Diffuse reflection results from a corrugated layer of sharp changes in the refractive index. The concept was introduced to explain observations showing significant amounts of radar scattering from large off-vertical angles in layers that are believed to be horizontally stratified.

TURBULENCE

The subject of turbulence is a very involved one, and no clear consensus exists as to what signatures radar echoes from turbulent layers should have. Some of the questions arising from interpretation of turbulent scattering of radio waves will be considered below.

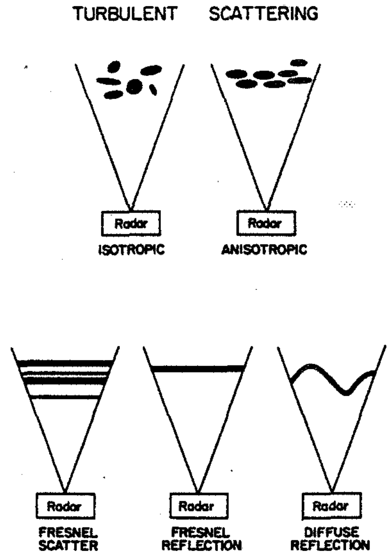

Figure 1. Diagram depicting different forms of irregularities causing VHF radar echoes in the MST regions.

(a) Aspect Sensitivity

In order to simplify considerations of shear-layer turbulence, it is usually assumed that turbulent irregularities at scales smaller than the outer scale of turbulence are statistically isotropic (TENNEKES and LUMLEY, 1972) and should therefore scatter radio waves isotropically. However, it is recognized that individual turbulent irregularities are not isotropic and that they have a tendency to be aligned along the direction of the shear flow velocity. In fact, STEWART (1969) and others have shown from experiments that anisotropy extends throughout the inertial subrange and well into the dissipation subrange of turbulence. This might indicate that isotropic scattering from shear-layer turbulence is more an abnormality than a normal state of affairs.

It seems likely, therefore, that aspect sensitivity would decrease with decreasing radar wavelength until isotropy is obtained, perhaps inside the dissipative subrange. Thus it appears that aspect sensitivity is not a good discriminator between partial reflection and scattering from shear-layer turbulence.

(b) P/C Correlation

In radar signals scattered from clear air, there exists a relationship between signal correlation time and echo power. In some regions of the atmosphere the correlation is positive, whereas it is negative in other regions. It is believed that negative P/C correlation is a manifestation of turbulent scattering (ROTTGER, 1980). RASTOGI and BOWHILL (1976) attempted to explain the positive P/C correlation as resulting from stronger turbulence occurring in narrower layers. However, LIU and YEH (1980) have shown that the effect of narrowing a turbulent layer is not enough to cause positive P/C correlation. Thus FUKAO et al. (1980) and ROTTGER (1980) have suggested that positive P/C correlation may be a manifestation of partial reflections from horizontally stratified layers. In the mesosphere, however, it is difficult to see how stable layers of widths less than 3 m can be maintained, since the inner scale of turbulence tends to be larger than 3 m. Positive P/C correlation may, however, be explainable if an approach similar to that of BOLGIANO (1968) is taken. In the mesosphere, positive or negative P/C correlation is obtained when the radar wavelength is within the inertial or dissipative subrange of turbulence, respectively. However, this approach requires slowly varying shear-layer turbulence that is compared to the mixing time within the turbulent layer.

(c) Turbulent Spectra

It has generally been taken for granted that the radar Bragg wavelength must be within the dissipative subrange of turbulence in order for the radar to observe scattering from turbulent irregularities (CRANE, 1980). RASTOGI and BOWHILL (1976) estimated that the inner scale of turbulence in the mesosphere is larger than 3 m. Nevertheless, radar echoes from clear air are readily received on 50 MHz all the way up to about 90 km. Recent rocket data now show that the inner scale of turbulence in the upper mesosphere is almost one order of magnitude larger than the radar Bragg wavelength (ROYRVIK and SMITH, 1984). The large but finite negative gradient of the wave number spectrum in the dissipative subrange provides enough irregularities to cause scattering at frequencies as high as 50 MHz. Only in the lowest part of the mesosphere will a 50-MHz radar operate within the inertial subrange of the spectrum.

(d) Convective Instability

Whereas turbulence causing radar returns of VHF is usually considered to be caused by layers of strong velocity shears, it may also be of the convective instability type. BALSLEY et al. (1983) have argued that convective instabilities resulting from breaking gravity waves may cause a major fraction of the radio-wave scattering in the high-latitude winter mesosphere. Some recent Langmuir probe data from high-latitude winter mesosphere have shown that the inner scale of turbulence is considerably smaller than that measured at the equator, possibly indicating a difference between shear-layer and convective-instability turbulence.

PARTIAL REFLECTION

While the nature of radar echoes due to partial reflection is fairly easy to understand, it is more difficult to explain the stability and short vertical scale height of layers reflecting radio waves at VHF frequencies. This is particularly true for the mesosphere. Stratified layers reflecting VHF radio frequencies must be horizontally stratified over at least one Fresnel zone (several hundred meters in the mesosphere). The change in the refractive index must be a fraction of 1% within a vertical distance that is small compared to the radio wavelength. At VHF frequencies, that means one meter or less. In the mesosphere the refractive index is due to the ambient electron density. It is clear that such a sharp and limited ledge in the electron density cannot be generated by the natural production and loss mechanisms of the ionization (HAUG et al., 1977). Even if they could be generated, they would disappear within a few tens of seconds due to diffusion.

BOLGIANO (1968) has suggested that turbulence acting on a gradient in the refractive index would generate sharp stratified ledges at the boundary of the active turbulent region. These boundary ledges might then cause partial reflections of the radio waves. Although this appears to be a feasible mechanism for the troposphere/stratosphere region, it is unlikely that it can generate stratified layers in the mesosphere capable of reflecting at VHF frequencies all the time the radio wavelength is equal to or smaller than the inner scale of turbulence.

VANZANDT and VINCENT (1983) have suggested that the stratified layers in the troposphere/stratosphere can be formed by a spectrum of buoyancy waves with very short wavelengths and near-horizontal phase surfaces acting on a gradient of refractive index. A detailed evaluation of this mechanism has not been made since it has not been possible to observe waves with wavelengths as short as a few meters.

Some of the mechanisms associated with radar echoes at VHF from the MST region have been considered, and some of the problems with each mechanism have been pointed out. It seems fairly well documented that turbulence generates a large fraction of refractive index structures responsible for scattering of the VHF radio waves. As for other mechanisms (for instance. buoyancy waves of vertical wavelength equal to the radar Bragg wavelength), no definitive answer is available. However, even horizontally stratified laminae of refractive index may be generated by turbulence. so a generalized turbulence theory may provide all the answers.

ACKNOWLEDGMENT

The work described was supported by the National Aeronautics and Space Administration under grant NSG 7506.

REFERENCES

Balsley, B. B., W. L. Ecklund, and D. C. Fritts (1983), VHF echoes from the high-latitude mesosphere and lower thermosphere: Observations and interpretations, J. Atmos. Sci., 40, 2451.

Bolgiano, R., Jr. (1968), Winds and Turbulence in the Stratosphere, Mesosphere and Ionosphere, (Edited by K. Rawer), pp. 371-400, North-Holland Amsterdam.

Crane, R. K. (1980), A review of radar observations of turbulence in the lower stratosphere, Radio Sci., 15, 177.

Fukao, S., T. Sato, R. M. Harper and S. Kato (1980), Radio wave scattering from the tropical mesosphere observed with the Jicamarca radar, Radio Sci., 15, 447.

Haug, A., E. V. Thrane. K. Bjorna. A. Brekke and O. Holt (1977), Observations of unusually strong partial reflections in the auroral D-region during an absorption event, J. Atmos. Terr. Phys., 39, 1333.

Liu, C. H. and K. C. Yeh (1980), Scattering of VHF and UHF radar signals from the turbulent air, Radio Sci., 15, 277.

Rastogi, P. K. and S. A. Bowhill (1976), Scattering of radio waves from the mesosphere - 2. Evidence for intermittent mesospheric turbulence. J. Atmos. Terr. Phys., 38, 449.

Rottger, J. (1980), Reflection and scattering of VHF radar signals from atmospheric refractivity structures, Radio Sci., 15, 259.

Royrvik, O. and L. G. Smith (1984), Comparison of mesospheric VHF radar echoes and rocket-probe electron concentration measurements, J. Geophys. Res., submitted.

Stewart, R. W. (1969), Turbulence and waves in a stratified atmosphere, Radio Sci., 4, 1269.

Tennekes, H. and Lumley, J. L. (1972), A First Course in Turbulence, The MIT Press, Cambridge, MA.

VanZandt, T. E. and R. A. Vincent (1983), Is VHF Fresnel reflectivity due to low frequency buoyancy waves? Handbook for MAP, Vol. 9, 78-80. S. A. Bowhill and B. Edwards (eds.), Univ. of Illinois, Urbana-Champaign.