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N85-32487

2.6B USEFULNESS OF MULTIFREQUENCY MST RADAR MEASUREMENTS

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INTRODUCTION

Scattering of radio waves from atmospheric refractive-index irregularities induced by turbulence was invoked almost four decades ago to explain the characteristics of signals received on VHF/UHF ionospheric and tropospheric forward-scatter links (WIESNER, 1960). Due to the bistatic geometry of these links a slender, horizontally extended, common volume or cell is formed in space. The principal contribution to scattering arises from refractive-index fluctuations in this volume at the Bragg wave number $\underset{\sim}{k}_B = \underset{\sim}{k}_i - \underset{\sim}{k}_s$ corresponding to the difference of the incident and scattered wave propagation vectors. The length scale corresponding to the Bragg wave number is $2\pi/k_B = \lambda/(2 \sin\theta/2)$, where θ is the angle between $\underset{\sim}{k}_i$ and $\underset{\sim}{k}_s$. For backscatter, $\theta = 180°$ and the Bragg wave number corresponds to the length scale $1/2\lambda$ for a radio wavelength λ (BOOKER and GORDON, 1950; BOOKER, 1956).

Since the early days of scatter-propagation research, it has been realized that multifrequency measurements offer the possibility of monitoring the spectrum of refractive-index fluctuations at several distinct Bragg wave numbers (WIESNER, 1960; BLAIR et al., 1961; BOLGIANO, 1963). A quantitative interpretation of such measurements has led to a critical reexamination of the role of turbulence in producing these fluctuations (BOLGIANO, 1958; BOLGIANO, 1960; WHEELON, 1959,1960; HILL and BOWHILL, 1976).

In recent years, multiple-frequency MST radar capabilities have become available at several sites around the world at frequencies ranging from HF, through VHF to UHF. It has been surmised that the use of more than one frequency in probing the middle-atmosphere regions should help resolve several issues pertaining to the scattering mechanism (LIU, 1983). These issues are briefly re-examined in this note. The implications of the radar equation are discussed in the next section. The two following sections consider the problems arising due to layered structure of turbulence and the choice of frequencies most suitable for multifrequency measurements, respectively.

IMPLICATIONS OF THE RADAR EQUATION FOR MULTIFREQUENCY MEASUREMENTS

The radar equation for a uniform random medium with refractive-index fluctuations n relates the received signal power (P_s) to the transmitted power (P_t), the antenna parameters (e.g., its physical aperture A), range (R), range resolution (ΔR), and a radar reflectivity (η) for the medium. For narrow-beam monostatic radars, the radar equation can be written in several different forms. A simple form following ROTTGER (1980) is

$$P_s = \frac{P_t \, L \, A \, \Delta R \, \eta}{4\pi R^2} \qquad (1)$$

where the factor L accounts for the system losses. The reflectivity η for a homogeneous, isotropic field of fluctuations is obtained as

$$\eta = 1/2\pi^2 \, k_B{}^4 \, \Phi_n \, (k_B) \tag{2}$$

where Φ_n (k_B) is the three-dimensional spectrum of refractive-index fluctuations, evaluated over a spherical shell of radius k_B in phase space. For small-scale fluctuations in the inertial range or beyond, Φ_n (k) is related to the refractive index structure constant $C_n{}^2$

$$\eta = 0.033 \; C_n{}^2 \; k^{-11/3} \; \exp[-k^2/k_m{}^2] \tag{3}$$

with $k_m = 5.91/\ell_o$, and ℓ_o the inner scale of turbulence. These results have been discussed by ISHIMARU (1978) and TATARSKII (1971).

Several conditions are essential for obtaining equations (1) and (2). It is assumed that the radar cell lies in the far field of the antenna. Refractive index (and other) fluctuations in the medium must be homogeneous and isotropic, and the medium is assumed to entirely fill the beam and the radar cell. Single scattering and quasi-static approximations must also hold. The numerical coefficient in equation (1) depends on the antenna radiation pattern, and ΔR is a rectangular approximation to the convolution of the pulse shape with receiver-system impulse response.

A strong motivation for multifrequency experiments is the possibility of measuring the form of the spectrum $\Phi_n(k)$ at several Bragg wave numbers through signal power measurements. It should be emphasized that such measurements require absolute radar calibration for each frequency. The current approaches and problems in such calibrations were briefly discussed at the previous workshop (BOWHILL, 1983).

CONSEQUENCES OF LAYERED TURBULENCE STRUCTURES

The assumptions of homogeneity and isotropy of refractive-index fluctuations, and that they fill the radar beam and the radar cell, are most readily violated in the presence of turbulent layers. These layers have indeed been observed throughout the middle atmosphere (WOODMAN and RASTOGI, 1984; ROTTGER et al., 1979).

The first consequence of layered turbulence is that there is a range of wave numbers in the vicinity of k_B that contribute to scattering. This range Δk_B depends inversely on the layer thickness L_T (RASTOGI and BOWHILL, 1976)

$$\Delta k_B \sim \frac{2\pi}{L_T} \tag{4}$$

This produces a smearing of the underlying spectrum in the vicinity of k_B. The extent of this smearing depends on the distribution of refractive-index variance in the layer, and can be quite serious for a normal layer thickness of 100 m (Figure 1).

The second consequence of layered turbulence is due to quasi-specular or diffused reflections that are produced from the edges of these layers. HOCKING and ROTTGER (1983) have considered modifications to the radar equation due to this effect.

To minimize the effect of layered turbulence in multifrequency experiments it is important to keep the common volume fixed. This requires that the antennas be scaled with frequency to give the same beam widths, and in addition, the pulse shape, receiver system impulse response and range delays be kept identical for all frequencies.

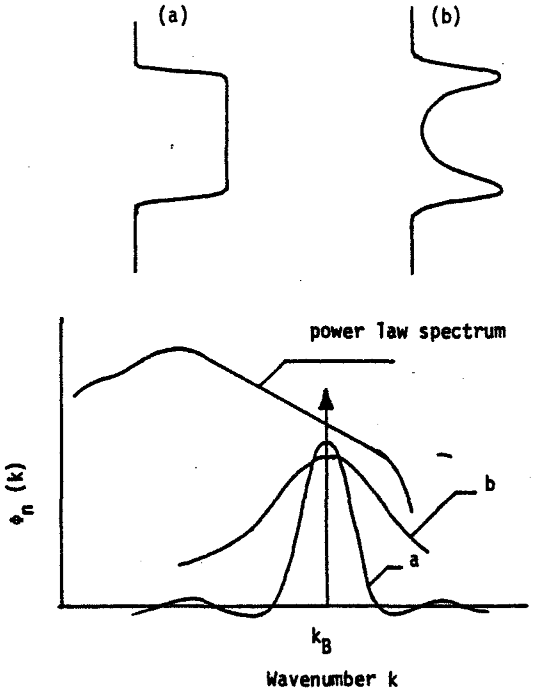

Figure 1. Two possible distributions (a) and (b) of refractive-index variance across a thin layer. The arrow shows the ideal Bragg filter at wave number k_B for an infinite scattering volume. The shapes labelled (a) and (b) show the Bragg filters corresponding to the distributions above. The power law spectrum is only a plausible form for $\Phi_n(k)$.

CHOICE OF FREQUENCIES

The range of frequencies currently available for MST radars is ~3 MHz to well above 1 GHz. Only the HF and lower VHF radars are sensitive to turbulent fluctuations in the mesosphere. Sensitive UHF radars can be used to probe the D-region ionization (MATHEWS, 1984). The widest choice of frequencies is available at EISCAT and Arecibo.

Figure 2 shows schematically the Bragg length scales associated with several radars. Also shown in this figure are the energy spectra associated with strong and weak turbulence in the troposphere and mesosphere. The form of these spectra are qualitative and no distinction is made between energy spectra and the spectra of refractive-index fluctuations.

In the mesosphere, the Bragg length scale for VHF radars is comparable to the inner scale of turbulence. For this reason two VHF radars with a frequency spacing of a few MHz can provide useful information about the spectra associated with small-scale turbulence. The use of a UHF radar in addition can provide information about D region electron-densities and their gradients that is vital for interpreting the behavior of VHF returns.

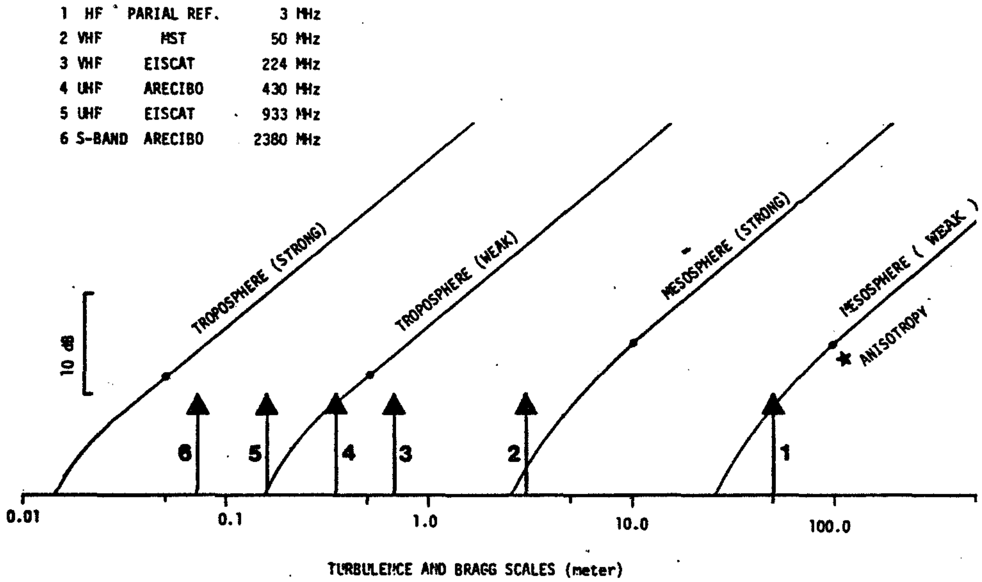

Figure 2. Bragg length scales (λ/2) for six backscatter radars are shown by the arrows. Tropospheric and mesospheric spectra for strong and weak (by 10,000 times) turbulence have been superimposed. The form of these spectra are qualitative and no distinction is made between energy spectra and spectra of refractivity fluctuations. Dots show a length scale that is 5 x the wavelength associated with the turbulence inner scale. At smaller length scales, the inertial-range form is invalid. At Bragg scales $\gtrsim$50 m, anisotropy effects become significant.

HF radars usually lack a fine altitude resolution (typically 3 km or worse). The X- and O-mode returns suffer, however, different attenuations and their corresponding propagation vectors k_x and k_o become significantly different in the upper D region. For this reason, a range-time cross-correlation analysis of several closely spaced HF frequencies will complement the conventional partial-reflection experiments (RASTOGI and HOLT, 1981).

In the vicinity of the tropopause, the turbulence inner scale is just a few centimeters. Two widely separated frequencies (e.g., 224 MHz and 933.5 MHz for the EISCAT radars) offer the possibility of detecting large variations in the intensity of turbulence through their effect on the inner scale.

In some cases, especially with VHF radars, it may be possible, even advantageous, to use two rather closely spaced frequencies. This would allow the use of the same radar at two frequencies with only a slight degradation in performance.

A careful reexamination of the frequency dependence of the turbulence and refractive-index spectra, and of scattering from thin turbulent layers is essential for interpretation of multifrequency measurements.

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