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2.6A RADAR ECHOES AT 2.66 AND 40.92 MHz FROM THE MESOSPHERE

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INTRODUCTION

Radars operating in the frequency range from 1 to 60 MHz have been used extensively during the last decades to study the ionospheric D region. Some progress has been made in understanding the mechanism that cause the reflection/scattering of the transmitted radio waves although some problems remain to be solved. THRANE et al. (1981) compared rocket measurements of ion density irregularities to radar echo observations at 2.75 MHz and concluded that the received radar signal was due to scattering from isotropic and homogenous turbulence in the altitude region between 70 and 95 km. HOCKING and VINCENT (1982) on the other hand, compared scattering cross section at two frequencies. 2 and 6 MHz. and suggested that the radar echo from the region below 80 km was in part due to partial reflection from stratified layers.

It is well known that the VHF scattering cross section is aspect sensitive in the D region below about 75 km. whereas it tends to be isotropic at higher altitudes (COUNTRYMAN and BOWHILL, 1979; FUKAO et al. 1980; ROYRVIK 1983). FUKAO et al. suggested this to be the result of a mixture of scattering and reflection at the lower altitudes, and pure isotropic scattering at higher altitudes. However. ROYRVIK (1983) studying Doppler spectra of the mesospheric echoes. suggested that the aspect sensitive part of the signal is due to scattering from anisotropic turbulence. ROTTGER et al (1979) rejected partial reflection of VHF radio waves from ledges in the refractive index bordering a turbulent region (BOLGIANO. 1968) because the inner scale of turbulence in the mesosphere is larger than the radar Bragg wavelength.

Positive correlations between scattered signal power and signal correlation time (P/C-correlation) have been observed by VHF radars in the lower mesosphere by FUKAO et al. (1980) who concluded that it might be an additional indication of partial reflection from stratified layers (ROTTGER and LIU. 1978). In the upper mesosphere where the P/C correlation for the VHF signals is negative. it is believed that the scattering is caused by isotropic turbulence. Recently, however. ROYRVIK (1984) has argued that steady-state shear-induced turbulence should result in a positive P/C-correlation if the Bragg wavelength is within the dissipative subrange of turbulence.

The Aeronomy Laboratory Field Station at the University of Illinois contains a 41-MHz MST radar (MILLER et al. 1978) and a 2.66-MHz partial-reflection antenna radar (RUGGERIO and BOWHILL, 1982). Initially these two radars used the same computer for data acquisition, and thus simultaneous runs were not possible. Recently. however. a set of microcomputers have been adapted for separate data collection from the two radars (RUGGERIO and BOWHILL, 1982). Several simultaneous runs have been made in order to compare both measured horizontal velocities and variations in scattered power measured by the two radar systems. The results of the wind measurements have been reported by RUGGERIO and BOWHILL (1982). Here we will report some preliminary results from comparison of the radar scattering cross section at the two radar frequencies.

EXPERIMENTAL TECHNIQUE AND CALIBRATION

The Urbana MST radar operates at a frequency of 40.92 MHz in a pulsed, monostatic mode. Peak transmitted power is 1.4 MW in 20 μs pulses. Pulse repetition frequency is 400 Hz. The transmitting/receiving antenna consist of a rectangular array of 1008 half-wave dipoles with a physical aperture of 11000 m^2. The receiving system consists of a transmit/receive switch, a blanker/preamplifier and a receiver with IF frequency of 5.5 MHz. Autocorrelation functions with twelve 1/8 s lags of the complex received signal are calculated on line and stored every minute in 20 altitude bins spaced 1.5 km apart.

The partial-reflection radar operates on a frequency of 2.66 MHz with a peak transmitted power of 3.5 kW. Pulse length is 25 μs and pulse repetition frequency is 200 Hz. Separate transmitting and receiving antennas are used. The transmitting antenna consists of a 60 half-wave dipole array. The receiving antenna consists of an almost identical array which is divided into four sections. The signal strength from each section is separately detected for use in a spaced antenna experiment. Scattered signal power for each antenna, and horizontal wind velocities are estimated and recorded every minute in eight altitude ranges spaced 4.5 km apart, i.e., a slight undersampling in altitude (RUGGERIO and BOWHILL, 1982).

Both radars were calibrated so that absolute scattering cross section could be estimated from the echo strength. The nature of this calibration is different for the two radars and will be outlined in the following sections. The 41-MHz scattering cross section is calculated from the radar equation in the form given by VANZANDT et al. (1978)

$$\eta = \frac{9\pi}{2} \frac{ck\ B\ (T_c + T_{rx}/\alpha)}{\alpha\ P_t\ F_r\ A_e} \left(\frac{r}{\Delta r}\right)^2 \left(\frac{S}{N}\right) \tag{1}$$

Here the signal-to-noise ratio S/N is measured directly from the autocorrelation function, r is the range of the scattering volume, and c is the velocity of light. The remaining constants are defined, and values given in Table 1. The noise temperature (T_{rx}) of the receiving system was measured by a noise diode to approximately 90 K°. This is reasonable considering that the manufacturer of the preamplifier quotes a 1-dB noise figure and a 20-dB gain. Measurement of the antenna efficiency factor (α) gave a value of 0.35. This value is considerably better than that measured by ALLMAN and BOWHILL (1976) and approximately equal to the value predicted with a preamplifier inserted immediately following the transmit/receive switch. Considering the uncertainties involved in equation (1) it is estimated that the scattering cross section can be measured to within a factor of two.

At 2.66 MHz the sky noise temperature (T_C) is highly variable and cannot be used as a convenient reference to compare the scattered power. Thus the partial-reflection radar was calibrated against nighttime F-layer reflection using the equation

$$P_r = \frac{\alpha^2\ P_t\ A_e^{\ 2}}{4\lambda^2\ r^2}\ |\rho|^2 = X\ \frac{|\rho|^2}{r^2} \tag{2}$$

Here X is a constant including all radar parameters. X can be found by measuring P_r at night and assuming that the nighttime F-layer reflection is total, i.e., $|\rho|^2 = 1$. Initial calibration of the partial-reflection radar was out during a 2-hour run around midnight between May 3 and 4, 1984. From this experiment we calculated $X = 1.27 \times 10^{27}$. The scattering cross section per unit volume can then be calculated from the equation

Table 1

λ	wavelength	1.3 m
m	samples coherently integrated	24
P_t	peak pulse power	1.4 MW
α	efficiency of radar antenna	0.35
A	effective antenna area	1.1×10^4 m^2
Δr	range resolution	2×10^3 m
f	radar frequency	41 MHz
F_r	pulse repetition frequency	400 Hz
B	bandwidth of integration filter	8 Hz
T_c	cosmic noise temperature	10^4 °K
T_{rx}	receiver noise temperature	90 °K

$$\eta = \frac{|\rho|^2}{\Delta r} = P_r \frac{r^2}{X\,\Delta r} \tag{3}$$

Use of equation (3) as opposed to (2) assumes volume scattering, an assumption that may be debated. However, VINCENT and BELROSE (1977) from a study of 2.66-MHz radar signals found that the majority of echoes were due to incoherent scattering from a number of irregularities.

Calibration of the 2.66-MHz radar is inherently more difficult than calibrating the 41-MHz radar. Consequently, the uncertainties in the measurements of the scattering cross section are larger at 2.66 MHz; perhaps as large as a factor of five.

OBSERVATIONS

Several days of simultaneous observations by the two radars were made in late April and early May 1984. Some problems with the partial-reflection data recording system were encountered, however, a total of approximately 24 hours of data were recorded. Both radars were obtaining scattered power profiles between approximately 60 and 90 km altitude. Observations of the real time display showed that there usually were one or two scattering layers in both radars. The altitude of the layers in the two radars seemed to agree most of the time, but there also were occasions when the scattered power profiles looked quite different. Most importantly, perhaps, was the fact that the short period (~1 min) time variations in the amount of scattered power did not appear to be related in the two radars even in layers that were clearly occupying the same altitude region. This made data comparison quite difficult. However, as a preliminary comparison, data were chosen from times when the temporal variations were small.

Examples of scattered power as observed by the two radars are given in Figures 1 and 2. Four different sets of data have been compared on the assumption that the echoes are due to turbulent scatter. The comparison

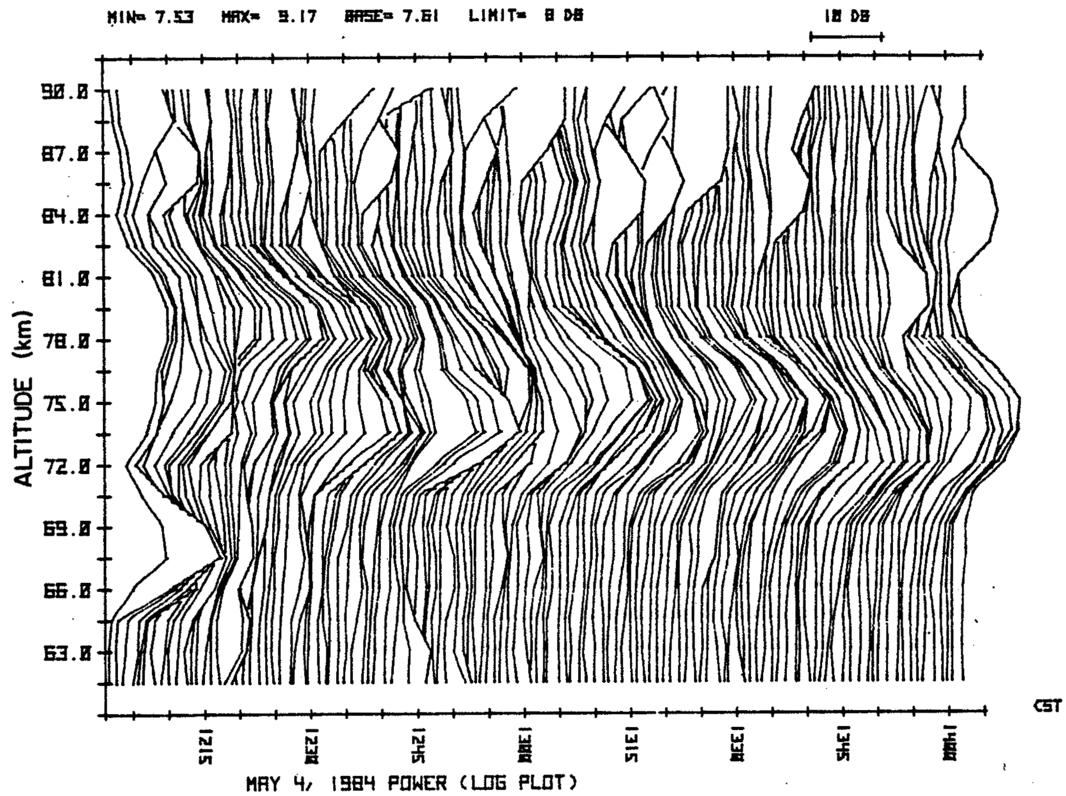

Figure 1. Scattered power profiles from the 41-MHz radar, May 4, 1984.

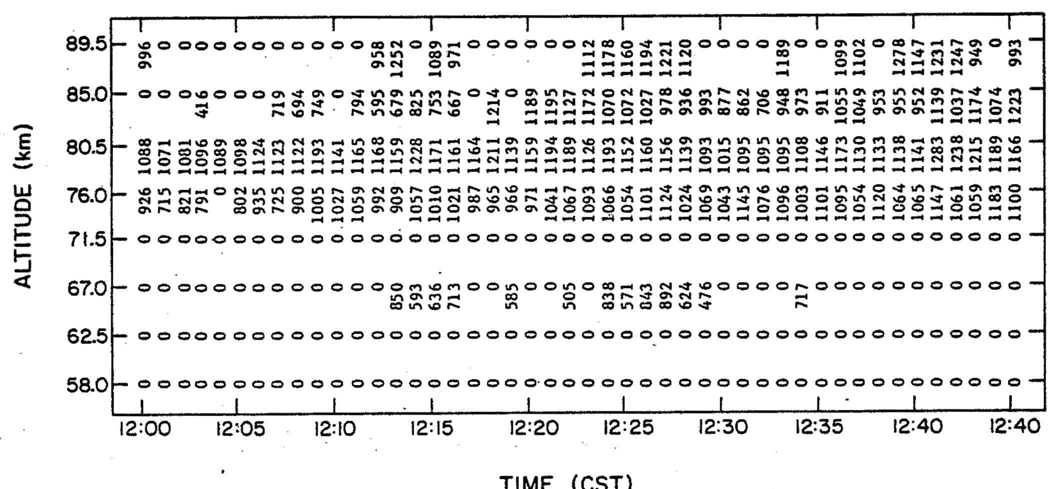

Figure 2. Map of scattered power from the 2.67-MHz radar in dB x 10), May 4, 1984. Zeros indicate time and altitudes where correlation time is less than one time lag in the correlation function. This represents noise level.

involves several steps as explained in the following sections.

For each data set the scattering cross section observed at 2.66 MHz is taken as a reference. Then the corresponding scattering cross section for the 41-MHz radar was calculated from the equation

$$\eta = 6.18 \times 10^2 \left(\frac{P}{kT}\right)^2 C_R^{\,2}\, C^{-4}\, \lambda^{11/3} \qquad (4)$$

obtained from GAGE and BALSLEY (1980). However, this equation assumes that the radar Bragg wavelength is within the inertial subrange of turbulence. RASTOGI and BOWHILL (1976) have indicated that the Bragg wavelength of a VHF radar is in the dissipative subrange of turbulence in the mesosphere. ROYRVIK and SMITH (1984) showed spectra of turbulent irregularities that confirmed this and indicated that the spectral slope in the dissipative subrange is close to -7.

We now assume that the discrepancy between the observed cross section for 41 MHz and the cross section calculated using equation (4) is due to the rapid falloff of the irregularity spectra in the dissipative subrange. The amount of discrepancy observed should be a function of the inner scale of turbulence. The inner scale of turbulence needed to explain the discrepancy in each case is found at the intersection between the lines with slopes -5/3 and -7 in Figure 3. These values, plus additional values, of the inner scale as a function of altitude have been plotted in Figure 4 along with an estimate of the limiting values of the inner scale. As can be seen, these estimated values are reasonable indicating that the radar echoes at both 2.66 and 41 MHz are due to scattering from the same layer of turbulence-generated irregularities. Note in particular that the scattering cross section of the 41-MHz radar is never significantly above the value predicted from the 2.66-MHz cross section if turbulent scatter is assumed.

A continuation of this work will include calculation of signal correlation

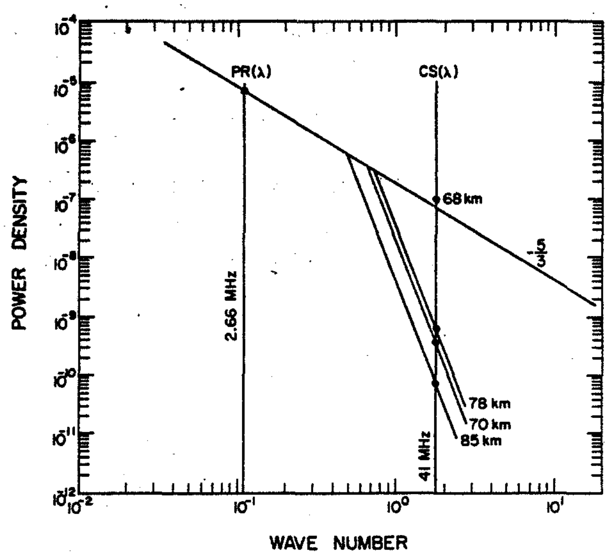

Figure 3. Spectra of scattering irregularities with the 2.67-MHz radar cross section as reference. The figure only gives information of the relative cross section between the radars.

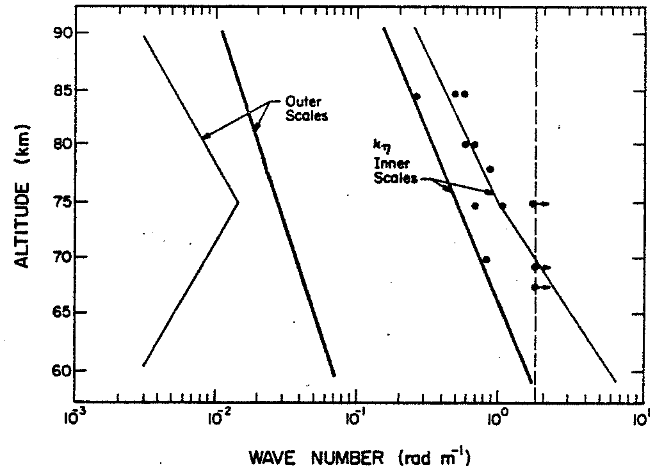

Figure 4. Limits of inner and outer scales of turbulence calculated from signal correlation times at the Jicamarca 50-MHz radar. The solid dots indicate deduced inner scales of turbulence. The dots with arrows indicate that the inner scales are equal to or smaller than the 41-MHz Bragg wavelength.

time. and estimates of energy dissipation rate as a function of altitude. This will allow independent estimates of the inner scale of turbulence that can be compared to the values shown in Figure 4. A particularly interesting study would be the comparison of the time variations of the scattering cross sections in the two radars at altitudes where the 41-MHz radar operates within the dissipative subrange of the turbulent spectrum (ROYRVIK, 1984).

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