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Radar Measurements of Neutral Winds and Temperatures in the Equatorial E Region

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The phase velocity of type 1 irregularities in the equatorial electrojet, which can be easily measured by radar, depends upon both the ion acoustic velocity (and hence the temperature) in the medium and the neutral wind velocity. By measuring the phase velocity at several zenith angles both of these quantities in principle can be determined. This note describes the technique and its limitations and presents a few preliminary results obtained at 50 MHz at the Jicamarca Radar Observatory in Peru. These results show E region east-west wind velocities as large as 100 m/s, temperature variations of greater than 100°K, and substantial longitudinal variations, at times, in both wind velocity and temperature.

INTRODUCTION

Type 1 electron density irregularities in the equatorial electrojet have been studied extensively during the last decade (see review by Farley [1974] and references therein). They are generated by a plasma instability and have a phase velocity close to the ion acoustic velocity in the frame of reference of the ions, which move with the neutral gas. The total observed phase velocity will include the effect of any neutral winds. By observing at two or more zenith angles in the east-west plane it is in principle possible to separate the effect of the temperature (which determines the acoustic velocity) from the effect of an east-west wind, as long as both are independent of position throughout the region studied. North-south winds cannot be studied in this way because echoes are obtained only when the radar is directed normal to the earth's magnetic field.

The idea that radar studies of the type 1 irregularities can be used to measure parameters of the equatorial neutral atmosphere has been discussed in earlier papers (Balsley and Farley, 1971; Cohen, 1973; Fejer et al., 1975; Cohen and Hooke, 1975). E region wind velocities of many tens of meters per second and temperature fluctuations of up to 25% were inferred. There were problems with this earlier work, however, due at least in part to the limited number of zenith angles studied (usually 30°, 45°, and 60° to either the east or west) and the fact that the temperature and/or wind velocity apparently sometimes varies substantially with longitude. In the present work we take a preliminary look at these problems by examining a larger number of zenith angles than were examined in the past.

MEASUREMENT THEORY

We begin with the important assumption that the phase velocity of the type 1 waves in the frame of reference of the ions is the ion acoustic velocity $V_a$, or is at least proportional to $V_a$, the constant of proportionality differing only slightly from unity. Since the ions in the region of interest (~103–108 km) move with the background neutral gas, the Doppler velocity observed by a radar on the ground will be

$$V_\phi = V_a + k \cdot V_n$$

where $V_\phi$ is the wave phase velocity, $V_n$ is the neutral wind velocity, and $k$ is the radar wave vector. If $V_a$ is taken to be horizontal and in the east-west direction (north-south winds have no effect), (1) becomes

$$V_\phi = V_a + V_{gw} \sin \theta$$

where $\theta$ is the zenith angle of the radar beam. If $V_\phi$ is now measured at a number of zenith angles and the results are plotted as a function of $\sin \theta$, the slope of the best-fit straight line should give the east-west wind velocity, and the intercept should give the ion acoustic velocity and hence the temperature, since

$$V_a = \left[ \frac{K(T_e + T_t)}{m_i} \right]^{1/2}$$

where $K$ is Boltzmann's constant and $T_e \approx T_t \approx T_a$ in this strongly collision dominated region.

In practice, there are a number of restrictions and limitations to the use of this technique which should be kept in mind.

1. It is only useful when the Doppler spectra are of the sharply peaked type 1 form. This restricts the observing time to a few hours near midday and perhaps (but see below) a few hours at night.

2. At night the threshold velocity, which is $V_{ta}$ during the day, may be altered by the effect of sharp electron density gradients (Farley and Fejer, 1975).

3. The ad hoc assumption that the type 1 phase velocity is equal to the ion acoustic velocity in the absence of winds is just that, an ad hoc assumption that seems to be consistent with the data but which has no firm theoretical support. It is certainly approximately true but perhaps no more than that. Furthermore, the value of $V_{ta}$ given by (3) assumes isothermal electrons and ions. In fact, the electrons are not completely isothermal, particularly in the upper portion of the scattering region, and so the actual value of $V_{ta}$ should probably be at least a few percent higher than that given by (3). As a result, the measurements of $\Delta T/T$ obtained with this technique should be more accurate than the absolute measurements of temperature.

4. Although, according to (2), vertical measurements of $V_\phi$ should give the ion acoustic velocity directly, it is often difficult to measure the Doppler shift of the type 1 echoes accu-
Fig. 1. Two series of spectra at several different zenith angles. The curves were normalized so as to have comparable maximum values.

rately when looking vertically during the day, since the spectrum is always dominated by type 2 echoes [Fejer et al., 1976].

5. The effects of winds and temperature are separable only if neither varies over some appreciable range of zenith angle (i.e., longitude). This problem could be avoided (i.e., (2) would always apply) if the same scattering volume could be probed simultaneously by many radars at different angles, but in practice, only a single radar is available which can scan in the east-west direction.

DATA

A series of electrojet spectral measurements over a wide range of zenith angles was made during the period February 12–15, 1971, at the Jicamarca Radar Observatory in Peru. The 50-MHz transmitter, operating with a peak pulse power of about 1 MW, a pulse width of 50 µs, and a pulse repetition rate of 380 s⁻¹, was fed into a single dipole located a quarter wavelength above ground. The receiving antennas consisted of two mattress arrays (north-south beamwidth of ≈40°, east-west beamwidth of ≈25°) directed 45° to the east and west, so that the main lobes covered a reasonably wide range of zenith angles, while overhead echoes were available via the first side lobes. The received signals were tape recorded for later analysis. The recorded signals corresponded to zenith angles ranging from 0° (overhead) to about 74°, except for a narrow region near the first null of the receiving antenna pattern at about 15°. Since the type 1 echoes come only from a narrow altitude range centered at about 107 km, different echo ranges correspond to different zenith angles; the zenith angle was easily varied during the data analysis by simply varying the time after the transmitter pulse at which the received signal was sampled. By replaying the tape, many zenith angles could be investigated simultaneously.

Some of the results obtained in this way were discussed in an earlier paper [Fejer et al., 1976]. Two series of spectra pertinent to the present topic are shown in Figure 1. These spectra represent an integration time of about 90 s. Note that the type 1 peak is weak or absent for the vertical observations. The positions of the type 1 peak scaled from these and other spectra are shown in Figure 2 for three separate times on February 15, which was a magnetically disturbed day. Note that the abscissa is linear in sin θ, so that if (2) is valid, the points will lie on a straight line whose slope and 0° intercept will give Vₑw and Vₑa, respectively. The data for 1032 (75°W time) can be fitted to two straight lines with a common intercept but slightly different slopes to well within the experimental accuracy (ap-
proximately ±10 m/s except for small zenith angles) and indicate a westward directed neutral wind (i.e., in the same direction as the electron flow) of about 110 m/s in the west and 100 m/s in the east. The temperature determined from (3) was 260°K.

The lower part of Figure 2 indicates a considerably different wind and temperature structure. The slopes for the eastern data at both 1248 and 1258 indicate a westward wind velocity of about 65 m/s, while the intercepts correspond to temperatures of 360°K and 320°K, respectively. In the west, on the other hand, the wind velocity is negligible and the inferred temperatures are 360°K and 320°K. It was not possible to measure \( V_a \) directly when observing overhead at either 1248 or 1258 (cf. Figure 1).

**Discussion**

These results indicate that the winds and temperature in the \( E \) region can sometimes vary appreciably in a distance of a few hundred kilometers and/or a time interval of the order of 10 min, scales suggestive of gravity wave effects. Unfortunately, various technical problems prevented a more thorough study of this period. Other data taken in February 1971 show similar characteristics, and in some cases the structure appeared to be too complex to analyze by using these methods (i.e., points plotted as those in Figure 2 did not fall even approximately on a straight line).

The main point we wish to make here is that this method, when used with care and good data, does seem to provide a good means for investigating the neutral atmosphere. When the spatial structure becomes too complex, however, the method breaks down. We are currently undertaking a more systematic investigation of this sort using a far larger set of data and an improved antenna system.

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**REFERENCES**


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