Radar scatter from equatorial electrojet waves: An explanation for the constancy of the Type I Doppler shift with zenith angle

M. C. Kelley,1 R. A. Cuevas,1 and D. L. Hysell2

Received 30 November 2007; revised 17 January 2008; accepted 25 January 2008; published 26 February 2008.

1 School of Electrical and Computer Engineering, Cornell University, Ithaca, New York, USA.
2 School of Earth and Atmospheric Sciences, Cornell University, Ithaca, New York, USA.

This equatorial experimental result is also in apparent disagreement with the new auroral zone observations, which indicate that Type I waves are only generated in a narrow cone near the flow velocity [Bahcivan et al., 2005].

2. On the Constant Wave Phase Velocity Versus Radar Elevation Angle

[6] Data from the two systems are presented in Figure 1 in a range/Doppler shift intensity format. The range resolution or range gate for AMISR-P (430 MHz) is 0.6 km and for JULIA (50 MHz) it is 1.5 km. The bright red regions, which are particularly clear in the JULIA data at 51 from zenith and the AMISR data at 20, are due to the Type I echoes. Type I waves can also be seen in the vertical AMISR beam and weakly in the other two panels. The centroid of these features all fall around the acoustic speed.

[7] The key to understanding the equatorial results is based on two important factors. First, the drift velocity of importance is the total electron drift velocity, which is equal to the vector sum of the zero-order horizontal drift and the drift induced by intense, large-scale waves. Second, a radar will respond to the most intense wave in the field of view and hence will record the Doppler shift of the most strongly driven waves in the range sampled. If, as we suggest here, there is some portion of the sampled region with a line-of-sight electron drift near $C_e$, that Doppler will be recorded. Furthermore, Bahcivan et al. [2005] have shown that Type I waves are only generated in a narrow cone about the (total) electron drift velocity, which, in the auroral zone, is the same as the zero-order velocity, since large-scale waves rarely seem to occur there.
To show this result, we use the rocket observations made during the Condor campaign in Peru as reproduced in Figure 2 [Pfaff et al., 1987; Kelley, 1989]. The plasma density during the flight had a positive vertical gradient up to the altitude of 107 km. For a few km up to that height, intense horizontal electric fields, and hence large vertical drifts corresponding to large-scale waves, were detected. This is the height range in which both the two-stream and gradient drift instabilities operate. Above this height, the wave amplitude dropped abruptly and the dominant wavelength in the vertical velocities shifted from several km to several meters [Pfaff et al., 1987; Kelley, 1989]. It is interesting to note that the field strength, when converted to velocity, seems to saturate at the value \((1 + \psi_0)C_s\), as plotted with the dashed line. Note that these are the only in situ electric field measurements made in the equatorial electrojet to date under two-stream conditions.

To make our main point, we appeal to prior radar observations (some of which were made during the same event shown in Figure 2), which show that the horizontal wavelengths of daytime large-scale waves are in the range of 2–3 km [Kudeki et al., 1987]. Furthermore, the large horizontal electric fields are present coherently over an altitude range of 4 km. The low apogee of the Condor rocket means that the horizontal velocity of the rocket in the electrojet was comparable to the vertical velocity. We used these experimental results to generate a perturbation vertical velocity, \(\delta V_z\), every 30 meters along the trajectory. Since the plasma was unstable to the Farley-Buneman (FB) process, the zero-order horizontal drift velocity, \(V_x\), must have exceeded 400 m/s. The electric field data published by Pfaff et al. [1997] show that this drift component is nearly independent of height in the region of interest. For each of the vertical drift data points, then, we can compute the

**Figure 1.** Range-Velocity-Intensity for (top) JULIA and (bottom) AMISR.

**Figure 2.** Observations from the Condor rocket campaign in 1987 (adapted from Pfaff et al. [1987]).
total electron drift velocity, \( V_T = (V_x^2 + V_z^2)^{1/2} \). The \( V_T \) we determine lies roughly along a 45° angle in a region approximately 10 km × 10 km. Since the horizontal perturbation and vertical fields are nearly independent of altitude, the drifts along the trajectory are representative of the entire volume.

[10] Figure 3 shows how a region with these total drift vectors would be interrogated by the JULIA radar at three different zenith angles for the system beam width and range resolution, as well as for the AMISR-P radar at its two zenith angles. The red regions in Figure 3 correspond to range/azimuth bins in which the line-of-sight velocity exceeded the factor of 0.9(1 + \( \Psi_0 \))\( C_s \). For this purpose, we used the isothermal value for \( C_s \). Almost certainly, the most intense waves are those with a phase velocity vector nearest the flow angle. Furthermore, the results of Bahcivan et al. [2005] indicate that the only two-stream waves generated are near the flow direction. This implies that the radar will preferentially detect such waves if they are in the range gate and will hence register their Doppler velocity. By our criterion, this echo will be registered at a phase velocity in excess of 0.9\( C_s \). Thus, it is clear that, at the equator, the radars will always see a near-constant Doppler shift as a function of angle when the horizontal drift velocity is large and when intense, large-scale waves are present. The long-standing problem seems resolved.

3. Conclusions

The results reported by Bahcivan et al. [2005] that the narrow spectral component of electrojet waves is generated in a small cone of angles about the total electron flow velocity seems to explain both the auroral zone results and those at the magnetic equator. The long-standing question as to why the equatorial Doppler shift is independent of radar elevation seems to be solved.

Acknowledgments. We thank Wesley Swartz for his assistance with preparations to conduct the experiments in Peru. One of us (R.C.) extends his gratitude to the Center for Geospace Studies at SRI International, in particular to John Kelly, as well as to Jorge Chau and the staff at JRO for their assistance. The work at Cornell was performed under grant ATM-0538343 from the Atmospheric Science Section of the National Science Foundation.

References


R. A. Cuevas and M. C. Kelley, School of Electrical and Computer Engineering, Cornell University, 320 Rhodes Hall, Ithaca, NY 14853, USA. (mikek@ece.cornell.edu)
D. L. Hysell, School of Earth and Atmospheric Sciences, Cornell University, 2108 Snee Hall, Ithaca, NY 14853, USA.