East-west and vertical spectral asymmetry associated with equatorial type I waves during strong electrojet conditions:

1. Pohnpei radar observations


1. Introduction

The equatorial electrojet is a channel of enhanced east-west electrical current located between 93 and 113 km altitude in the E region of Earth’s ionosphere. It has been a subject of considerable interest to space scientists since the very start of radio probing. Extensive observations have been made of the current system as well as the plasma density irregularities generated by this current system using a variety of techniques (see Kelley [1989] for a comprehensive review). On the basis of the spectral characteristics obtained with coherent backscatter radar, the plasma density irregularities are categorized broadly in two different types, namely type I and type II irregularities. Type I, which has a Doppler shift of the order of the ion-acoustic velocity, has relatively narrow spectra and are believed to be generated primarily by the two-stream instability when the streaming velocity in the electrojet exceeds the ion-acoustic velocity [Farley, 1963; Buneman, 1963]. The other type of irregularities, type II, has much broader spectra while their mean Doppler shift is measurably less than the ion-acoustic speed. Type II irregularities are attributed to the excitation of large-scale gradient drift instabilities triggering a cascade from the large wavelengths. The process is sometimes described in terms of multiple wave coupling interactions [Sudan, 1983; Hu and Bhattacharjee, 1998].

VHF radar observations at Jicamarca show that during intense daytime electrojet streaming, type I plasma density irregularities appear mostly between 103 km and 107 km. The phase velocity of these irregularities is more than the isothermal ion-acoustic speed and is found in both the upward and the downward directions. When viewed at vertical incidence, however, an asymmetry is often seen between downward and upward moving type I waves, both in time and space. That is to say, the spectral peak with an upward phase velocity (downshifted Doppler frequency) dominates over the peak with a downward phase velocity in terms of its period of occurrence as well as its power [Cohen and Bowles, 1967; Kudeki et al., 1987]. This asymmetry is referred to as the “up-down” vertical asymmetry. We note that most of the earlier observations with the Jicamarca radar were conducted at a coarse range resolution (1.75 km or more) so that any change with altitude in the spatial asymmetry was not evident in these data. However, to render the picture murkier, higher spatial resolution studies (~600 m) conducted in Brazil have also detected a dominance of downward phase velocities above 105 km during strongly driven irregularity conditions [Swartz, 1997a], when there was also a clear persistence of upward waves at lower altitudes, in agreement, this time, with the usual asymmetry that had come to be expected.

In addition to the asymmetry observed at vertical incidence, there exists an asymmetry in the strength of radar backscatter echoes observed at oblique beam positions.
Early observations with the Jicamarca radar, using steerable antennas, have shown that echoes at a given zenith angle looking west are consistently stronger than those looking east at the same zenith angle [Balsley, 1965; Cohen and Bowles, 1967; Balsley et al., 1976]. Similar observations were also reported from Africa [see Hanuise and Crochet, 1978, and references therein]. Recent measurements with the wide beam CUPRI radar at Alcantara, Brazil, have shown similar results, with power levels in the east beam down by a factor of 2.1. System Description

2. Experimental Description

2.1. System Description

[6] The 49.8 MHz Pohnpei radar is located in the western Pacific at 6.95° north, 158.19° east (geographic), 0.7° magnetic dip. The radar antenna array is 100 by 100 m and consists of 32 strings of 100-m long coaxial/collinear (COCO) antenna in which adjacent strings are separated by a half wavelength. The array is configured so that the antenna beam can be steered electronically between the magnetic east and west directions. The full two-way 3 dB antenna beam widths are about 2.3 degrees. The transmitter peak power is 4 kW and the observations can be made at radial resolutions of 1, 2, 5, and 10 km.

[7] In this paper we present the results of an experiment conducted with a 1 km range resolution. Doppler spectra (256 points) were computed at 110 range gates along each beam. The recorded data for each beam consisted of an average of 75 such spectra, obtained over a period of about 48 s. The average 256-point Doppler spectra provided coverage over a range of ±1075 m/s with a point spacing of 8.4 m/s. The radar cycled through the three beam positions sequentially with 1 km resolution and then 5 km resolution (data not used here) providing a time resolution for the 1 km data of approximately 5 min. Data from the three positions were therefore obtained a couple of minutes apart from one another.

2.2. Method of Analysis

[8] The Doppler spectrum of the radio waves scattered from the electrojet is a composite of both the type I and type II irregularities present inside the sampled radar volume. When type I irregularities are present, their contribution to the power spectrum, by definition, tends to dominate over that of type II irregularities. St.-Maurice et al. [2003] presented examples of mixed type I and type II spectra obtained using Pohnpei radar during strong electrojet conditions. They showed the power spectrum consisting of type I spectra of varying strength superposed on the broader type II spectra. Of particular interest in the Pohnpei data are the “two-step” type I spectra which have both upward and downward moving type I irregularities present simultaneously at a particular range bin. While fairly common at vertical incidence, these triple type of spectra (type II at small frequencies sandwiched in Doppler frequency between type I spectral components of both signs) are fairly rare in the east and west beam positions.

[9] Discriminating between type I and type II irregularities from the composite radar spectrum poses a problem if we consider that a precise theoretical understanding of the spectral details is still lacking. Initial efforts to separate the contributions of the two irregularities in the spectrum were based on a spectral decomposition technique [Cohen, 1973]. Assuming that the experimental spectra can be decomposed in various Gaussian spectra, the standard spectral decomposition technique involves the application of one type I component and one type II Gaussian component, each characterized by three variable parameters (namely, the amplitude, displacement, and width), to fit the observed spectral points. However, Cohen [1973], realizing that a two-way decomposition does not fit the experimental data properly, applied a three-way decomposition involving one type I and two type II Gaussians. In the case of Pohnpei radar observations, in which a weak type II spectral component is sometimes quite visible between two strong two-step type I spectra during strong electrojet conditions [St.-Maurice et al., 2003], a spectral decomposition along these lines would then have to involve three to five Gaussians.

[10] In the present study, since we are concerned with the type I irregularities only, we have gone to a less conventional approach to estimate the three spectral moments. Realizing that broad type II spectra necessarily introduced a skewness when it came to an analysis of the type I component, we applied a nonrecursive high pass numerical filter [Hamming, 1983] to taper off the broad signature of type II spectra. In Figure 1, we present three examples of the types of spectra discussed by St.-Maurice et al. [2003] and the output of the filter. In the first example (Figure 1a), we have only a type II spectrum. The application of the filter results in the same type II, albeit with a reduced power level. In the second example, we have two strong two-step type I spectra sandwiching the central weak type II spectra. The filtered output, shown with continuous line in Figure 1b, brings the central type II power level to zero while two type I spectra, above the zero power level are quite identifiable. The effect of the filter is more evident in Figure 1c, in which we have two type I spectra riding over a comparatively powerful type II spectrum. The filtered spectrum retains only the type I fluctuations bringing the broad type II spectra to a near-zero level.

[11] Next, in order to estimate the three radar moments, namely the power, Doppler shift, and Doppler width, we selected the highest peak in the filtered power spectrum on
both sides of zero. To determine a type I window, we moved down along each side of highest peak and determined the two frequencies where the filtered spectrum reached a zero power level. The area encompassed by the spectrum between the two frequencies was our type I spectrum. Once the window was fixed, the three spectral moments were computed through a numerical integration using expressions given by \textit{Woodman} [1985].

In addition to taking the first moment of the Doppler spectrum, we considered the frequency with the highest power inside the resolved type I windows (as explained by \textit{St.-Maurice et al.} [2003], we assumed that the largest amplitude waves were the only ones to reveal the speed of the irregularities). This had to be done because the first moment can introduce extra deviations in the Doppler shift estimation because the mixed type I and type II spectra skew the type I part of the spectra toward zero frequencies. In the case of very strong type I peaks the skewness was minimal; hence the peak and first moment rendered the same values. However, for weaker type I peaks the skewness can produce fairly different answers for the peak and the actual average. For this reason, as well as to ensure that our peak was not an artifact of some noise at low power level, we required that the peak deviated by less than 10 m/s (roughly the spectral resolution) from the first moment estimated from the filtered spectrum. We made the selection criterion even more stringent by adding the condition that the signal to noise ratio (SNR) computed for the spectrum be more than 0 dB while the third moment (Doppler width) had to be more than 10 m/s. If these conditions were not all satisfied, the spectrum was simply rejected from the type I data subset. This stringent procedure created a substantial loss in the number of type I samples that we kept in the final data set. This strongly biased our study to the most powerful echo situations. This was the price to pay to ensure that noise and skewness would not significantly influence the analysis.

3. Results

[13] As mentioned in the introduction, both the up-down (seen at vertical incidence) and east-west spectral asymmetries are consistent features of the equatorial electrojet. The observations reveal that downshifted (upward moving) type I waves are more prominent than upshifted ones in vertical beams, while west beam type I observations have more power than east beam observations. However, we show here, on the basis of our detailed analysis of Pohnpei radar data, that the asymmetry changes with the strength of the echoes. It also vanishes and can ultimately reverse itself at times, when the electrojet echoes are strongest. We are also able to show the connection between the evolution of the east-west and the up-down asymmetries as the strength of the echoes evolve. The progression of the asymmetry with echo strength appears to complement the findings of \textit{Swartz} [1997a] who had observed a reversal of the asymmetry at higher altitudes during very strong electrojet conditions. The connection between east-west and up-down asymmetries evolution has, to our knowledge, not been investigated before. We now present these intriguing new observations in more detail.

3.1. General Features

[14] The spectral characteristics associated with type I waves observed at different beam positions can quickly be grasped by displaying the evolution of the radar power spectrum as a function of time. This is done in Figures 2 and 3, where we present a comparison between the east, vertical, and west beam observations that were made between 2101 UT on 4 April 2000 and 0447 UT on 5 April 2000 at altitudes of 102.5 and 104.5 km, respectively. At 102.5 km altitude the echoes were powerful for the longest time, for our particular observations. The 104.5 km altitude was chosen because of its peculiar behavior between frames 20 and 30 when the usual up-down asymmetry momentarily clearly reversed itself. We note that the east-west asymmetry reversed at around the same time as the up-down one, though this is not easy to see from the format used in Figures 2 and 3. Finally, Figures 2 and 3 and others like it display the original spectra rather than the filtered ones. We
nevertheless applied our filtering technique to process the
spectral moments, using the method described in section 2.
[15] As seen in Figures 2 and 3, field-aligned irregular-
ities started to appear around 2127 UT (scan number 6). The
spectra were initially broad compared to their mean Doppler
shift (pure type II signatures). They started to broaden further
with time until around 2212 UT (15th scan), when a distinct
type I signature started to emerge on top of the type II trace.
The same progression was observed through all three beam
positions. The phase velocity of the type I echoes continued

Figure 2. Successive spectra obtained in the west, vertical, and east beams as a function of scan number, starting at 2101 UT on 4 April 2000 for the first scan. The scans are 5 min apart, which is the time it took to sample through the three radar positions. The spectra are normalized in such a way that the integral under the trace is proportional to the total received power.

Figure 3. Same as Figure 2 but for 104.5 instead of 102.5 km altitude.
to increase with increasing scan number (time), until it saturated very near the expected nonisothermal ion-acoustic speed [St.-Maurice et al., 2003]. Not long afterward, the phase velocity started to decrease. Ultimately, around 0230 UT (scan number 65 in the west beam at 102.5 km), the type I signatures disappeared while pure type II echoes stuck around for a while longer before disappearing.

3.2. East-West and Up-Down Power Asymmetry

3.2.1. East-West Power Asymmetry

[Spectral comparisons between the west and east beams highlight marked differences. Ideally, this should not be the case: the radar beams at the two viewing positions should simply observe a symmetric wave phenomenon from symmetric viewing directions. As long as the east-west electric field of the gradient-drift wave responsible for the type I observations oscillates in symmetric fashion between its troughs and crests, structures seen from the west beam moving away from the radar should produce a mirror image of the spectrum produced by structures moving towards the radar in the east beam. This, of course, has not been seen to be the case in past observations, nor is it the case with our own observations.]

When we compare the time evolution of type I spectra in the east and west beams, we notice, as others have before us, a clear asymmetry. This asymmetry is visible already in Figure 2 where it is seen that the power of the downshifted type I waves in the west beam exceeds the power of upshifted type I waves in the east beam. The power is also stronger in the west beams and the type I waves are seen for a longer time interval in the west beam. Likewise, there is more power in the downshifted type I waves than in the upshifted waves in vertical spectra.

To facilitate the comparison between east and west power levels, we have introduced grayscale plots of the power of the dominant type I waves in the west and east beams in Figure 4. Figure 4 shows that in the west beam, downshifted type I waves started to appear at 2210 UT (scan 15) and continued until 0230 UT the next day (scan 65). By contrast, strong upshifted type I echoes appeared in the east beam a bit later, after 2227 UT (scan 18); they disappeared quite a bit sooner than their west beam counterpart, by 0205 UT (scan 60). Thus type-I waves appeared 15 min earlier and stayed for about 30 min longer for the west beam compared to the east beam.

The east-west asymmetry was not limited to the power of the dominant peak either. As seen in Figure 2, some weak upshifted type I waves were also observed between 2245 (scan 22) and 0001 UT (scan 35) in the west beam near the altitudes of strongest echoes (102.5 km). Likewise, weak downshifted waves were present in the east beam at around the same time. One can also clearly notice that when downshifted type I waves were observed in the east beam they appeared sooner and were stronger than upshifted waves in the west beam. When considering the
predominance of downshifted waves in the vertical beam (as seen in Figure 2, which is representative of the normal behavior), these signatures all indicate a preference for the plasma processes to drive downshifted waves harder.

While Figures 2 to 4 indicate that the power asymmetry is usually in agreement with past observations of east-west and up-down observations, there are some interesting exceptions to the rule that are not easy to see with the format used in Figures 2 to 4. These exceptions show a clear unambiguous reversal of the asymmetry that goes first through a disappearance of said asymmetry. In Figure 5, we show the altitude evolution in the east-west asymmetry at a time when the reversal was particularly clear. Specifically, we compare east and west spectra obtained between 102 and 106 km for the period centered on 2305 UT.

Both upshifted and downshifted type I waves can be identified in Figure 5. As expected from the general trends, upshifted waves at lower altitudes dominate the east beam echoes while downshifted waves dominate the west beam spectrum. However, Figure 5 shows that at the time of this particular asymmetry reversal, as the altitude increases, there is an interesting evolution in how the spectra compare, with the reversal favoring higher altitudes. At 102.5 km, the power associated with downshifted type I waves in the west beam is greater than the power associated with upshifted type I waves in the east beam. Furthermore, we find no noticeable upshifted type I waves in the west beam, while the east beam exhibits a clear downshifted type I peak. However, for the time period under consideration, this particular feature reverses itself as the altitude increases. That is to say, the power associated with upshifted type I waves in the east beam increases with increasing height at a time when the echo power is particularly strong. By 104.5 km, the power in the east beam upshifted waves becomes comparable to the power of downshifted type I waves in the west beam. A bit higher up, at 105.5 km, the asymmetry has actually changed sign, to the point that the upshifted type I waves associated with the east beam now dominate over the downshifted type I waves of the west beam. Such an intriguing result has not, to our knowledge, been reported before for the east-west type I asymmetry, presumably because it is so rare to detect it with such a clean signature.

Perhaps not too surprisingly in view of our earlier discussion, there is an evolution with time in the vertical beam power differences between upshifted and downshifted waves. This difference is highly reminiscent of the evolution found in the east-west waves power asymmetry. For one thing, the downshifted type I waves appear earlier than the upshifted waves. For another, the downshifted waves generally dominate the upshifted waves even when both types are seen, in agreement with earlier findings.

In Figure 6 we show an example of a reversal in the up-down power asymmetry in the vertical beam. The data were obtained in the middle of the time interval displayed in Figure 5 for the east-west case. The same transition from normal to reversal can be seen as a function of height, with the same high-quality spectra that make the exception to the rule impossible to argue with. While this type of upper altitude reversal in the up-down asymmetry was also obtained by Swartz [1997a] during strongly driven conditions, an added detail in our data is the simultaneous occurrence in the east-west asymmetry reversal at similar altitudes. We should note, however, that the reversal in the vertical up-down power asymmetry occurs at somewhat
lower altitudes, 103.8 km, than the reversal in the east-west power asymmetry. At 103.5 km the downshifted west beam type I echoes are still more powerful than the upshifted east beam type I echoes (Figure 5). Furthermore, above 104.5 km, the power associated with the downshifted west and upshifted east beams are almost similar whereas in the vertical beam, one can see upshifted type I waves completely dominating the spectrum at 104.8 km.

3.2.3. Simultaneous Evolution of East-West and Up-Down Power Asymmetries

[24] In terms of a temporal relation between the vertical and east-west power asymmetries, we have observed that the downshifted/upshifted waves in the vertical beam only appear at a time when they already appear in the west/east beam positions. However, the vertical type I waves disappear earlier than their east-west counterpart (the delay is not seen at the beginning of the event, presumably because the event progressed very quickly at first while taking a longer time to decay). Thus after 0051 UT, only broad type II waves appear in the vertical beam position, whereas type I echoes are seen up to 0230 UT in the off-vertical positions.

[25] Still, while Figures 5 and 6 show that there can be no argument about the existence in the reversal of a power asymmetry, all our figures thus far fail to display the detailed evolution of the power asymmetry because of the inability to present the information in a compact form. A contour plot of the power ratio as a function of time and altitude also fails because the variations in power ratios can change rapidly and make the job of drawing contours difficult to say the least. We have therefore resorted to another method to allow the reader to see how the power asymmetry and its reversal evolved with altitude and time, namely, we used a bubble plot. This plot is shown in Figure 7 and contains all the information in as succinct a manner as we could think of.

[26] Figure 7 contains two types of bubbles. The bubbles drawn with a light line describe two things: (1) the ratio of the west downshifted power to the east upshifted power when that ratio is greater than 1 (normal asymmetry situation), and (2) the ratio of the vertical downshifted power to the vertical upshifted power when the downshifted waves have more power than the upshifted ones (again, the normal asymmetry situation). The radii of the bubbles change with the logarithm of the power ratio: smaller bubbles have ratios closer to 1, while large bubbles show a very strong asymmetry. Bubbles drawn with heavy lines show the opposite situation when the up-down and east-west asymmetries are reversed. In this case the size of the bubbles represent the logarithm of the ratio of the upshifted power to the downshifted power in both the east-west and up-down comparisons. Finally, one can distinguish between the vertical and east-west results by looking at the altitude bands: the lower altitude in each band is for east-west comparisons, while the upper altitude in the band is for vertical up-down comparisons.

[27] Figure 7 makes several points. First, it shows that in spite of weaker power levels, the power asymmetry was often greater in the up-down observations than in the east-west ones. Second, it is clear that the asymmetry reversal occurred in the same regions in time and space in both the east-west and up-down data. Third, the asymmetry reversal underwent a clear evolution with time, starting rather suddenly and being very strong at the upper altitudes first before coming down and becoming less visible lower down, following an evolution similar to the maximum in scattered power (Figure 4) in the process. Finally, we note that away from the top altitudes, for a fixed height, say 102.5 or 103.5 km, there was a clear temporal progression from a strong asymmetry favoring downshifted waves at first, to a weaker asymmetry to a reversal that went through a maxi-

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**Figure 6.** Same as Figure 5, but for vertical beam observations made at 2301 UT on 4 April 2000.
mum before the whole process reversed itself as the power simultaneously went back to lower levels.

3.3. East-West and Up-Down Asymmetries in the Doppler Shift

A related aspect of spectral asymmetry is an asymmetry in the phase velocity of type I waves, not just their power. It has been noted before that the phase velocity of downshifted type I waves in west beams is larger than the phase velocity of upshifted type I waves seen at the same magnetic zenith angle in east beams [Kudeki et al., 1982; Ravindran and Murthy, 1997]. However, somewhat similar to the evolution in the power asymmetry, we have also uncovered an evolution in this Doppler shift difference in our data set. The difference is once again related to echo power itself. As a case in point, in Figure 8, we compare the Doppler shift observed in our east and west beam positions as a function of time (scan number), using the method described in section 2.2 to obtain the Doppler shift. Figure 8 allows us to contrast the variation in the Doppler shift with the variation in the power.

More specifically, the left panel of Figure 8 shows the temporal evolution of the power associated with downshifted type I echoes in the west beam together with that of upshifted type I echoes in the east beam. We selected four height levels that characterized rather well the overall evolution with altitude, namely, 101.5 km, 102.5 km, 103.5 km, and 104.5 km. The right panel of Figure 8 shows a similar variation for the Doppler shift of the dominant type I spectral components. Figure 8 shows that for weaker power levels, there was a clear east-west asymmetry in the Doppler shifts, which were, nevertheless, all above the isothermal ion-acoustic speed [St.-Maurice et al., 2003]. There was also a general tendency for the Doppler shift to follow the power in the sense that the Doppler shift increased as the power went up and decreased when the power went down. However, by contrast with the power results, there was no asymmetry reversal in the Doppler

![Figure 7. Bubble plot describing the evolution of both the east-west and up-down asymmetry in power as a function of height and time (scan number). Light transparent bubbles represent downshifted to upshifted power ratio under normal asymmetry situations (ratio >1). Heavy filled bubbles represent upshifted to downshifted power ratio under asymmetry reversal (ratio >1 still). The size of the bubbles increases logarithmically with the power ratios.](image)

![Figure 8. Spectral moment estimates for type I waves as a function of time (scan number) at four different altitudes. On the left are the powers estimated for the dominant spectral peaks of the east (full circles connected by a dash-dot line) and west (open circles connected by a full line) beams. On the right are the estimated phase speeds associated with these spectral peaks. Only clear-cut cases were used in the production of these plots.](image)
Figure 8
shift data. When the power asymmetry vanished and/or reversed, the upshifted Doppler shifts were very similar to the downshifted ones. When the power asymmetry was pronounced and favored downshifted echoes, the upshifted Doppler shifts were smaller than the downshifted ones. Similar results were obtained (not shown) with the up-down type I data.

4. Summary and Discussion
[30] The results shown in section 3 can be summarized as follows:
[31] 1. In symmetric east and west beam positions, we have found, as others have before us, that there generally exists an asymmetry in the power and Doppler velocity of type I irregularities.
[32] 2. In the west beam, type I echoes are predominantly downshifted (moving away from the radar). They are also more powerful and are observed for longer times than the type I echoes in the east beam. The latter are predominantly upshifted (moving toward the radar).
[33] 3. Up-down power asymmetries of a similar nature were observed in the vertical beam. The type I waves were much less powerful than in the east and west beams and only showed up when the power in the east and west beams exceeded a certain level.
[34] 4. During a time period when the echoes were particularly strong, we have uncovered a temporary reversal in the east-west power asymmetry which was strongest above 102 km. At that time, upshifted type I waves observed in the east beam became more powerful than the downshifted type I echoes seen in the west beam.
[35] 5. The up-down power asymmetry observed in the vertical type I waves had essentially the same signature as the east-west asymmetry, including the brief reversal, at the time of maximum echo power, of the asymmetry. The power asymmetry reversal in the vertical beam was particularly important at the higher altitudes of the echo region, i.e., 104 km.
[36] 6. We have found a similar asymmetry in the type I Doppler velocities, with stronger Doppler shifts in the downshifted waves, overall. However, this asymmetry is only visible when the power asymmetry is strong while favoring downshifted waves; at those times, significantly larger Doppler shifts are observed in the downshifted waves. On the other hand, at the times when the power asymmetry vanished or reversed, the Doppler asymmetry disappeared but did not reverse. We also noted that because of the nonisothermal properties of the waves, all type I waves in this study were moving at a speed clearly greater than the isothermal ion-acoustic speed.
[37] As underscored in the introduction, the existence of an east-west asymmetry in the power and Doppler velocities of equatorial electrojet irregularities is not new. Several reports in this regard can be found in the literature [Cohen and Bowles, 1967; Balsley et al., 1976; Hanise and Crochet, 1978; Kudeki et al., 1985; Swartz, 1997a]. However, our own findings indicate that the power asymmetry can disappear and even change its sign as the irregularities become strongly driven (at which point type I signatures are the norm). Our inferred linkage to a strongly driven process is simply based on the fact that both the power and Doppler shift of the irregularities reach their maximum at the point where the asymmetry vanishes or even reverses. This kind of observation has not, to our knowledge, been reported so far for any of the radars operating in the equatorial electrojet region. Another interesting aspect of our observations is that the up-down asymmetry observed in the vertical beam has essentially the same signatures as the east-west asymmetry, including its temporary reversal at higher altitudes during a particularly strongly driven episode.
[38] Taken together, our results indicate that the degree of east-west asymmetry in both the power and the mean Doppler speeds of the type-I irregularities depends on the strength of the echoes itself: the power asymmetry vanishes and can even reverse when the scattered power becomes large enough while a similar asymmetry in Doppler shift is also observed (although without an actual reversal). In particular, the evolution in the power asymmetry with the power itself points to a connection between the asymmetry and the growth rate of the primary kilometer-size irregularities that drive type I waves at the nearly vertical zenith angles used in our experiment. In turn, this points to a connection with the electrojet itself since the growth and saturation amplitude of the large-scale gradient drift irregularities that drive the type I waves should depend on the vertical electric field (and, of course, on the ambient vertical density gradients). In paper 2 [St.-Maurice and Choudhary, 2006] we propose a mechanism that could be responsible for the dependence of the east-west and up-down asymmetries on driving conditions associated with the kilometer-size gradient drift waves. The mechanism is based on a nonlinear description of the evolution of gradient drift instability. It uses intermittency to describe the rotation and decrease in the electric field of substructures developing along the wave fronts of the original large-scale gradient drift waves.

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