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Measuring ionospheric densities, temperatures, and drift velocities simultaneously at Jicamarca

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Abstract. Incoherent scatter autocorrelation function measurements are difficult to make in the F region at Jicamarca because of very strong clutter contamination by coherent echoes from unstable plasma waves in the E-region electrojet that are aligned with the magnetic field. We have developed a more effective way to deal with this clutter that improves the quality of the temperature (and composition when light ions are present) data. Other coherent echoes (much weaker than electrojet echoes but stronger than incoherent scatter) are also received through the antenna sidelobes from field-aligned irregularities in the 140–170 km altitude range during daytime. These latter echoes have a very narrow bandwidth, and so it is easy to measure their Doppler shift and obtain the vertical plasma drift velocity, which is proportional to the zonal electric field.

1. Introduction

The experiment we call Faraday/Double Pulse is the standard mode used to measure electron density, electron and ion temperatures, and ion composition in the F-region ionosphere at the Jicamarca Observatory in Peru using incoherent scatter [*Farley*, 1969a, b, 1991]. Faraday rotation is used to obtain absolute electron density profiles, and a sequence of variably spaced double pulses is used to generate autocorrelation functions (ACFs) that yield the temperatures and ion composition. These experiments require that the antenna be pointed 3–6° off perpendicular to the Earth's magnetic field, since the perpendicular direction would eliminate the Faraday rotation and drastically affect the shape of the autocorrelation function.

This ACF measurement has always been more difficult to do at Jicamarca than at other incoherent scatter radar (ISR) observatories because of the low radar frequency (50 MHz) and the equatorial location. The low frequency requires us to measure the ACF out to lags of the order of 2 ms, corresponding to range differences of up to 300 km. This means that echoes from the first pulse are mixed in the receiver with clutter echoes from the second pulse from altitudes as much as 300-km lower. At most altitudes we can reduce this clutter problem by transmitting and receiving the two pulses in orthogonal polarizations (essentially right and left circular polarization). However, the equatorial location means that we have to contend with strong clutter from field aligned irregularities in the equatorial electrojet and sometimes also with nighttime clutter from F-region irregularities, even though both enter through antenna sidelobes. Echoes from ground clutter and/or the equatorial electrojet, for example, can be 50 dB or more stronger than incoherent scatter, and so in spite of rejection by the antenna pattern (the electrojet echoes come only from directions normal to the magnetic field) and the pulse polarization discrimination (whose isolation is never perfect), the clutter can still dominate.

The clutter is uncorrelated with the wanted F-region echoes, and so after integration the effect of this clutter is not always obvious. The affected lagged products often seem to have values that are "reasonable." This

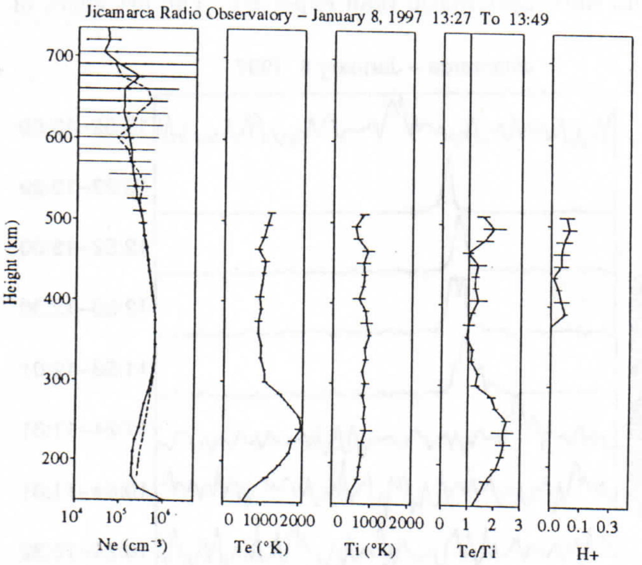

Figure 1. Typical altitude profiles of electron density, electron and ion temperature and the ratio, and proton percentage. In the density panel, the dashed curve represents the Faraday rotation measurement and the solid curve is from power measurements, normalized to fit the Faraday curve where the temperature ratio is unity. The solid curve gives lower values in the lower F region because of the temperature ratio factor, but higher values at 150 km because of the enhanced echoes from field aligned irregularities.

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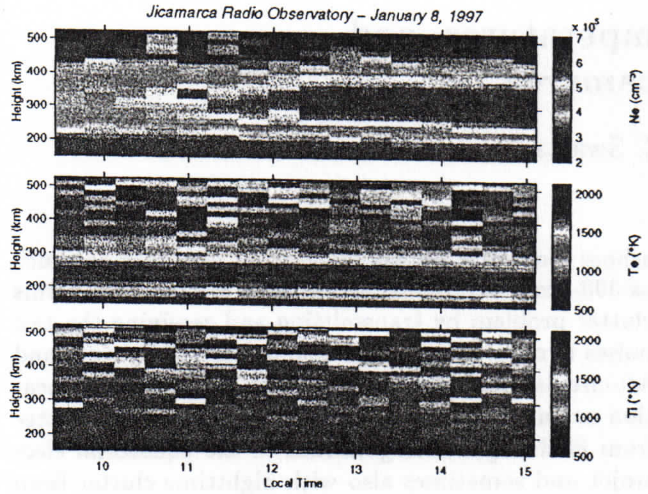

Figure 2. Electron density, electron temperature, and ion temperature time history.

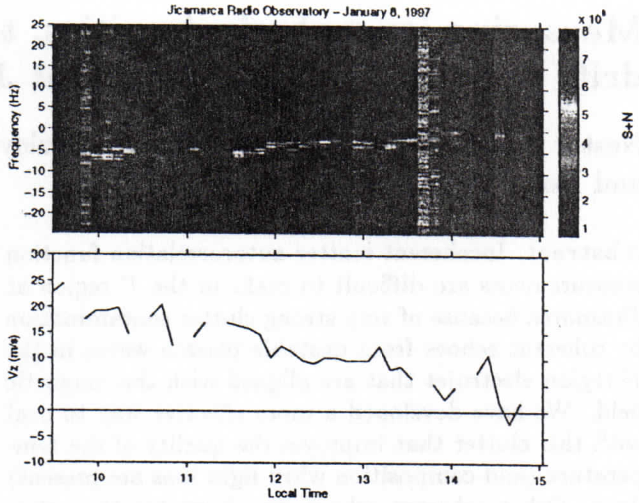

Figure 4. Time variation of the 150 km echo spectra and the deduced vertical velocity.

clutter problem has always existed at Jicamarca and, in the past, the analysis procedure has been to calculate the lags that should be affected at each altitude and ignore these in the fitting process. But the fact that the filters have a finite time response and the electrojet echoes vary in strength and in the altitude they come from, makes this an inexact procedure, and we now realize that bad data points were often not excluded from the fitting. One might think that this clutter would simply make the results noisier, but the distortion is subtle and more systematic than expected. The net effect of the distortion, when present and unaccounted for, is that the ACF usually appears to represent an electron-to-ion temperature ratio that is too low (sometimes as low as 0.8). For some F-region altitudes one or more lags in the ACF can be affected. As described further below, we have recently adopted new procedures, made possible in part by advances in computer technology, that do a much better job of coping with the clutter effects.

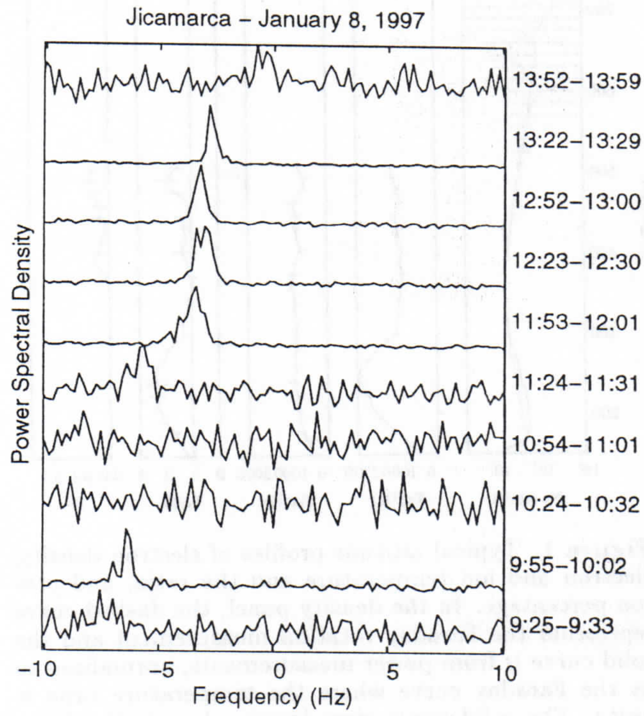

Figure 3. Self normalized power spectra of the 150 km echo acquired with the Faraday/Double Pulse experiment. Each is an average over the time intervals listed along the right side of the figure. Only one fourth of the spectral data is plotted.

In contrast to the electrojet clutter, some signals leaking in through the antenna sidelobes turn out to be useful. The "150 km" echoes, first investigated in detail by *Kudeki and Fawcett*, [1993], come from field-aligned irregularities at altitudes of 140–170 km. *Woodman and Villanueva* [1995] have shown that the Doppler shifts of these echoes give an excellent measure of the vertical drift of ionization (and hence the zonal electric field) in the F region, at least at times when there is little altitude gradient (the usual case). This paper presents the first results from explicitly sampling the 150 km coherent echoes concurrently with the regular Faraday/Double Pulse observations.

These drift measurements are similar to, but different from, the "standard" drift observations that have been made at Jicamarca throughout the F-region for many years [*Woodman and Hagfors*, 1969; *Fejer*, 1991; *Fejer et al.*, 1991]. The standard measurements are made with the beam pointed perpendicular to the magnetic field and produce radial velocities with very small uncertainties (typically less than 1 m/s) using integration times of only a minute or so. However, this beam pointing direction is incompatible with the Faraday/Double Pulse mode.

Some special experiments have split the antenna into two parts with one directed perpendicular to the magnetic field for the vertical drift experiment and the other directed off perpendicular for the Faraday/Double Pulse [*Woodman et al.*, 1972; *Sterling et al.*, 1972]. Unfortunately, this halving of both the antenna size and transmitter power reduces the signal-to-noise ratio for both measurements by a factor of 4 and increases the integration time by a factor of 16. It is not practical to switch the full antenna back and forth repeatedly between these two modes because the manual rephasing of the antenna array takes a minimum of two hours.

2. Experimental setup and results

The basic Faraday measurement is done as described by *Farley* [1969a], except that many of the analog compensation and error correcting schemes discussed there are now done digitally. Pulses are transmitted simultaneously in both magneto-ionic modes (the quasi-longitudinal approximation is still valid even though the beam is nearly perpendicular to the magnetic field) and then received separately. Cross multiplying the complex voltage samples gives a phase angle which changes with altitude because of Faraday rotation. The rate of change with altitude determines the electron density.

The double-pulse ACF measurement is very similar, except that the two pulses are separated by a delay of up to 2 ms. Cross multiplying the appropriate samples then gives the autocorrelation function at that delay, or lag, multiplied by the Faraday rotation phase factor. Cycling through a series of lags gives the full autocorrelation function. The standard program that performs on-line averaging of the lagged products uses 8 lags at 0, 0.2, 0.4, 1.0, 1.2, 1.4, 1.8, and 2.0 ms. A new program used recently, in which all the processing is done off-line, uses 11 lags equally spaced from 0 to 2 ms at 200 μs intervals. The measured ACFs are used to determine the electron and ion temperatures and the ion composition via least square fitting to theoretical ACFs [*Swartz*, 1978].

Numerical compensation schemes are used to reduce the inevitable cross talk between the "orthogonal" polarizations as much as possible, but these cannot deal with very strong clutter from the electrojet, as discussed in the introduction, or with ground clutter and receiver blanking for long lags in the lower F-region. Samples that are corrupted by the electrojet and other clutter sources are identified by their anomalously large powers, and the corresponding lag products are then simply ignored in the temperature and composition analysis. We can apply this procedure to both the old on-line integrated data as well as the new (where the raw samples are recorded directly to tape). The new data with a greater number of lags has the advantage, however, that the lost lags have less impact, especially at the heights where the 1 or 1.2-ms lags must be discarded.

The off-line analysis of the new raw data mode allows us great flexibility and, furthermore, permits us to analyze echoes from the 140–170 km altitude range in a totally different manner. These daytime echoes from field-aligned irregularities that enter through the antenna sidelobes are much weaker than the electrojet echoes, but they are stronger than incoherent scatter and so are easily detected. (These echoes do not, fortunately, generate clutter affecting F-region measurements. The polarization isolation reduces them to well below the cosmic noise level, in contrast to the case for the vastly stronger electrojet echoes.) We measure the power spectrum of the 150 km echoes by simply Fourier transforming successive voltage samples from 150 km. The natural bandwidth of the scattering process (inverse of the correlation time) is less than 1 Hz (= 3 m/s of radial velocity), and so sampling at intervals of the interpulse period (IPP), which is typically 10 ms, is more than adequate and gives accurate drift velocities. We use only the first of each pulse pair for this measurement. This yields uniformly spaced samples, but two out of every eleven samples are corrupted by clutter from the second pulse of the pair—from the electrojet for a lag of 0.4 ms and from the ground and/or the receiver blanking when the lag is 1.0 ms. These regular spikes in the time series produce very sharp spectral spikes, which we suppress. There are certainly more sophisticated ways to process this data, but our present simple scheme works adequately.

Examples of parameter profiles obtained from one 22-minute integration are shown in Figure 1, and results from a few hours of observation are shown in Figure 2.

We should note that there was a peculiar hardware problem during these observations that caused half the data (from every other IPP) to be lost, so the 22-minute integrations have the quality that would normally be obtained in 11 minutes.

The sharp increase in power at the very lowest height (see Figure 1) is due to the clutter echoes from 140–170 km. These were analyzed as just discussed above to form the spectra shown in Figure 3. Each spectrum corresponds to an integration period of about 7 minutes. The figure shows only one fourth of the spectra. The Doppler shift of the narrow peak that appears in many of the spectra determines the vertical drift velocity. The 150 km echo comes and goes and so several intervals show only noise. Figure 4 shows the time variation of the vertical velocity over about five hours of local time. This variation is typical for this season and low solar activity [*Fejer*, 1991; *Fejer et al.*, 1991]. Unfortunately, these echoes are present only during the daytime and so cannot give us information about the important early evening pre-reversal enhancement of the zonal electric field.

3. Conclusions

We have improved the ACF measurements at Jicamarca and have eliminated most of the long standing problems with the distortion of the electron-to-ion temperature ratio caused by electrojet clutter. We have also taken advantage of echoes from daytime (only) field-aligned irregularities in the 140–170 km height region to measure vertical drifts and hence zonal electric fields. These new measurements currently require us to record the raw receiver voltage samples and do all the data processing off-line. This is undesirable for routine synoptic studies, and we are working towards implementing on-line procedures.

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