Unexpected spectral characteristics of VHF radar signals from 150-km region over Jicamarca

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[1] The physical mechanisms that cause daytime 150-km echoes at equatorial latitudes are still puzzling. However, there is a general consensus that the radar signals coming from this altitude region should present a narrow spectra (<20 m s^{-1}). Moreover 150-km echoes are believed to come from field-aligned irregularities, and to be very aspect sensitive, i.e., they come from regions where the radar line of sight is perpendicular to the magnetic field (**B**). In this letter, we present evidence of a surprising result: radar signals around 150 km altitudes are also obtained when the radar points few degrees off-perpendicular to **B**, and more importantly, their spectra are very wide (>1000 m s^{-1}). On the other hand, the time and altitudinal characteristics of these off-perpendicular observations are the same as those presented by the so-called 150-km echoes. Moreover, the off-perpendicular echo strengths are several orders of magnitude weaker than perpendicular echoes. Our preliminary interpretation of these results suggests that the spectra of these signals are controlled by ion (electron) dynamics when they are observed off-perpendicular (perpendicular) to **B**. *INDEX TERMS:* 2415 Ionosphere: Equatorial ionosphere; 2419 Ionosphere: Ion chemistry and composition (0335); 2411 Ionosphere: Electric fields (2712); 2439 Ionosphere: Ionospheric irregularities; 2772 Magnetospheric Physics: Plasma waves and instabilities. **Citation:** Chau, J. L. (2004), Unexpected spectral characteristics of VHF radar signals from 150-km region over Jicamarca, *Geophys. Res. Lett.*, *31*, L23803, doi:10.1029/2004GL021620.

1. Introduction

[2] Equatorial radar signals around 150-km altitude region were first observed in the early 1960's over the Jicamarca Radio Observatory [*Balsley*, 1964]. Since then, they have been observed at Jicamarca on a campaign basis by pointing the antenna perpendicular to the magnetic field **B** [e.g., *Røyrvik and Miller*, 1981; *Kudeki and Fawcett*, 1993; *Fawcett*, 1999]. Perpendicular to **B** 150-km echoes have been observed at other equatorial longitudes [e.g., *Kudeki et al.*, 1998; *Blanc et al.*, 1996; *de Paula and Hysell*, 2004]. These latter observations, have been obtained using relatively small and inexpensive radar systems.

[3] Briefly, we can summarize the following properties from the radar observations of the so-called 150-km echoes from perpendicular to **B** observations: (1) They are confined to the daytime at equatorial magnetic latitudes; (2) occur at upper *E* region altitudes, between 140 and 170 km; (3) present narrow spectral widths (<15 m s^{-1}), (4) present aspect widths of $\sim 0.1^\circ$, i.e., smaller than those from the equatorial electrojet (EEJ) and larger than those of equatorial spread *F* (ESF) [e.g., *Fawcett*, 1999]. In addition, their vertical velocities represent the *F*-region $\mathbf{E} \times \mathbf{B}$ vertical drift [*Kudeki and Fawcett*, 1993; *Chau and Woodman*, 2004a].

[4] As mentioned above, 150-km echoes were previously observed only when the radars were pointed perpendicular to **B**. When other pointing directions (hereinafter oblique beams) were used for incoherent scatter radar (ISR) observations at Jicamarca, echoes from 150-km region were assumed to come from antenna sidelobes pointing perpendicular to **B**. In fact, these "sidelobe" echoes have been used by *Aponte et al.* [1997] to get simultaneously *F*-region density, temperatures and composition, as well as $\mathbf{E} \times \mathbf{B}$ vertical drifts during the daytime over Jicamarca when oblique beams were used.

[5] Although a large number of observations now exist, the physical mechanisms that cause them are still puzzling. In this letter we present new and unexpected characteristics of signals coming from this altitude region. These new observations have been possible due to recent improvements to the Jicamarca acquisition system. In addition to these improvements, serendipity took place. While we were performing a meteor experiment with an oblique beam, we decided to get samples also from the 150-km region in order to measure the $\mathbf{E} \times \mathbf{B}$ vertical drifts as was done by *Aponte et al.* [1997] using oblique beams. We obtained signals from the expected regions, but to our surprise we did not observe the expected narrow spectral width, instead we observed very wide spectra. Our observations present, basically, two new characteristics of 150-km echoes: they are also observed few degrees off-perpendicular to **B**, and they present a very wide spectral width (>1000 m s^{-1}).

2. Experimental Setup

[6] The observations have been made using a meteor observing configuration [e.g., *Chau and Woodman*, 2004b]. Namely, the large Jicamarca array ($\sim$300 m $\times$ $\sim$300 m) was used for transmission, and each of the four quarter sections for reception ($\sim$75 m $\times$ $\sim$75 m). The same linear polarization has been used in both modes. The antennas were phased to point on-axis ($\sim 2^\circ$ off-perpendicular to **B** at 150 km altitude at the time of the experiment). Complex voltages (raw data) were recorded for all four channels, however, only the information of one channel has been used for this work. Our findings have been possible due to recent improvements to the Jicamarca acquisition system. Previously, due to throughput limitations, we could sample only few ranges around the expected meteor altitude (80–

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Table 1. Radar Parameters for the 150-km Oblique Observations of September 8, 2004

Parameter	Value	Units
Inter pulse period (IPP)	200	km
Pulse width	9.75	km
Barker code	13	
Sampling rate	0.75	km
Initial range	60	km
Number of samples	162	
Number of complex channels	4	
Transmitter peak power	2	MW

130 km); with the new system we have been able to include more altitude ranges during a meteor observing mode (60–180 km).

[7] The main radar parameters for this observing program are summarized in Table 1. We have used the full duty cycle available (5%) and a reasonably high range resolution by using a 13-bit Barker code with 0.75 km baud.

3. Radar Observations

[8] In Figure 1 we present a typical spectrogram (range vs radial velocity) of returns from the 60–180 km range, along with the mean signal-to-noise ratio (SNR) profile, after a 7 minute integration. Given the large dynamic range of the signals, we use two different color scales in the spectrograms. Signals below (above) 120 km are represented with numbers without (between) parenthesis on the color bar. Starting from the lowest altitude, we can observe narrow spectra from mesospheric echoes (65–80 km), EEJ spectra (90–115 km) coming from a sidelobe pointing perpendicular to **B**, weak range-aliased *F*-region spectra (above 120 km), and thin layers of enhanced SNR with wide spectral width between 140 and 170 km. The narrow spectra above 170 km represent type 1 EEJ echoes coming from an antenna sidelobe pointing at a relatively large east-west (EW) zenith angle (~53°E). Note that there is weak spectral line of RF interference at ~−500 m s^{-1}. It is important to mention that the strongest calculated antenna sidelobe pointing perpendicular to **B** is ~36 dB weaker than the main beam.

[9] In this work we will concentrate on the signals coming from the 130–180 km region; however, we have shown on purpose the signals of other regions as evidence that the radar system was working properly. In Figure 2 we show the spectrum at four different ranges indicated by the arrows in the right panel of Figure 1, i.e., 165, 150, 131 and 179 km. On each spectrum the noise level is indicated by the horizontal dashed line. The noise has been estimated from the lower ranges, where *F* region ISR clutter is not expected for this time of the day.

[10] The spectra shown in Figure 2 are from the same date and time and have the following characteristics:

[11] • First panel. It shows the typical spectrum of the enhanced 150-km layers using an oblique beam. Note that the spectrum is very wide, it is aliased (the sampling interval is 1.33 ms, the interpulse period) and its shape cannot be uniquely determined with the current observing mode. The signal increase at high Doppler velocities is due to frequency aliasing of the true colored spectra. We have simulated typical ISR spectra and obtained similar results by using a sampling interval between the first and the second zero crossing of the autocorrelation function.

[12] • Second panel. This spectrum shows a strong narrow spectrum from signals coming from perpendicular to **B**.

[13] • Third panel. This shows the spectrum of range aliased *F*-region ISR signals. This signal is coming from a region around the *F*-region peak (i.e., ~330 km).

[14] • Fourth panel. This spectrum shows the typical type 1 EEJ spectrum, i.e., centered around the ion acoustic speed and very narrow. This signal comes via an antenna sidelobe pointing east and perpendicular to **B** at an elevation angle of ~37°. Note that type 1 EEJ echoes are stronger when observed at large EW zenith angles [e.g., *Farley*, 1985]. There is no evidence of signals coming from the west. This effect might be because the diagonal of the JRO antenna is ~6° off the current magnetic declination, i.e., the antenna sidelobes are not symmetrical respect to the **B**.

[15] These observations were made for few hours on September 8, 2004. Figure 3 shows the range-time distributions of SNR (top) and spectral width (bottom) for signals coming between 130 and 180 km. In this case, each parameter has been obtained every 1 minute. The transmitter was off starting around 1150 and 1235 LT.

[16] The range-time SNR characteristics are the same as the well known characteristics of 150-km echoes [e.g., *Kudeki and Fawcett*, 1993], i.e., necklace shape, quasi-periodic modulation, and layering. The sporadic points and vertical lines correspond to meteor echoes. On the other hand, most of the spectra are very wide (black color in Figure 3 representing widths greater than 60 m s^{-1}). There are a few events that present narrower widths shown in light gray coming from perpendicular to **B**.

4. Discussion

[17] Our observations present, basically, two new characteristics of 150-km echoes: they are also observed few degrees off-perpendicular to **B**, and they present a very

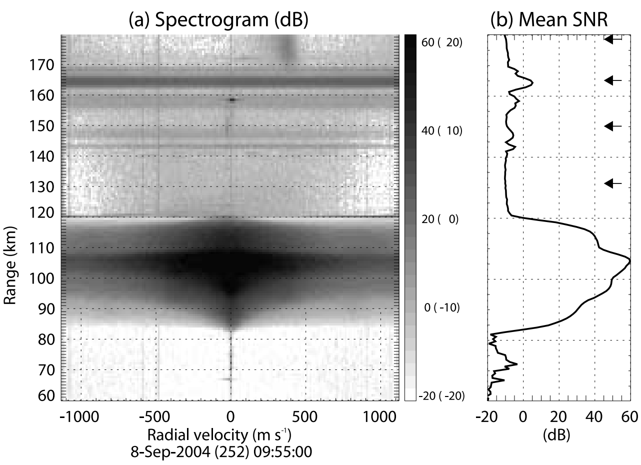

Figure 1. (a) Range vs. radial velocity spectrogram of radar echoes between 60 and 180 km, (b) Signal-to-noise ratio (SNR) profile. The arrows in Figure 1b indicate the ranges for the spectra shown in Figure 2. The color-coded scale for altitudes below (above) 120 km is indicated with numbers without (between) parenthesis.

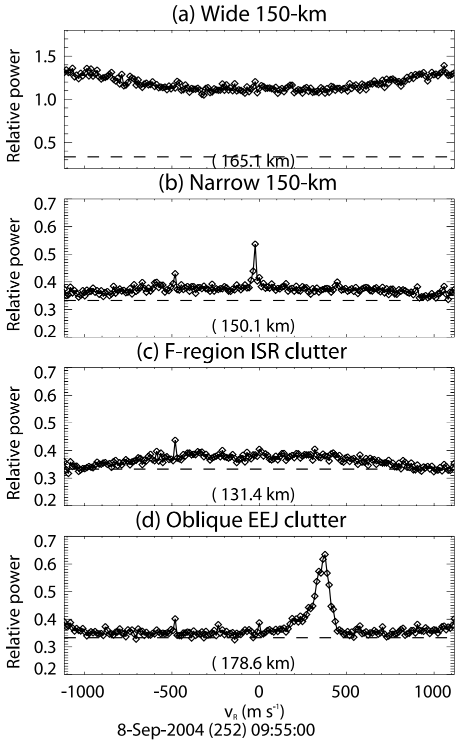

Figure 2. Spectra cuts for the following cases (a) wide 150-km, (b) narrow 150-km, (c) range-aliased *F*-region incoherent scatter, and (d) oblique type 1 EEJ echo. The horizontal dashed lines indicate the noise level.

wide spectral width (>1000 m s^{-1}). It is surprising to see that these features have not been observed before, but as mentioned in the introduction, until now it has been thought that, when oblique beams were used, those echoes were coming from perpendicular to **B** sidelobes. The previous oblique ISR observations have been done with long pulses or analyzed with correlation techniques, making the detection of the features we are reporting very difficult. Indeed, there are a few events that come from the almost 36 dB weaker sidelobe, but those events are not too frequent and are comparable in signal strength to the oblique observations.

[18] The range-time characteristics of these oblique observations are the same as those reported using perpendicular to **B** beams. Therefore, we think both observations are related, and the spectra are controlled by the ion (electron) dynamics when off-perpendicular (perpendicular) to **B** beams are used.

[19] Based on our limited data where both wide and narrow spectral widths were observed, it appears that the perpendicular to **B** echoes are 2–3 orders of magnitude stronger than the oblique echoes. Moreover, the power of signals coming from the 150-km region with oblique beams is a few dB stronger than incoherent scatter from the *F*-region peak. In conventional oblique ISR measurements, those powers are comparable [e.g., *Aponte et al.*, 1997, Figure 1], using wider transmitter pulses. However, 150-km echoes come from narrow layers (thinner than the long pulse widths used).

[20] The spectra of the enhanced 150-km echoes observed at any of these two angles taken one at the time are easy to understand. The very narrow spectra from perpendicular to **B** can be explained, as in the case of incoherent scattering (IS), because of the electron control irregularity dynamics. The electrons gyrate very tightly around the field lines and any scattering fluctuations take a long time to diffuse (long life times are equivalent to narrow spectra). At 2° off perpendicular to **B** the ions take control and the correlation time is defined by the thermal ion velocities, again, just as in the IS case [e.g., *Woodman*, 2004, and references therein]. It is not understood why the signal power is enhanced, however, at either angle.

[21] We can think of two possible mechanisms to explain this problem:

[22] • (A) The echoes come from an incoherent scattering mechanism away from perpendicularity, being unstable only at angles very close to perpendicularity. This hypothesis is hard to accept, since it will require narrow layers (less than 5 kms) of very high electron concentrations (higher than the *F* region peak). The features we are speculating have not been observed by ionosondes. Before excluding this possibility, we plan to look carefully at existing ionograms and to study what an ionosonde would see if narrow layers of high density are present around 150 km.

[23] • (B) Both perpendicular and oblique observations could be caused by the same unstable process. This process would have to have a very narrow brightness distribution, ∼0.1° to the half-power points [*Fawcett*, 1999], but at the same time be wide enough to be non-trivial at 2°-off its maximum. A Gaussian-looking shape will definitely not work.

[24] In the near future we plan to perform new experiments in order to improve the characterization of these new oblique features. For example, we plan to perform radar observations with beams pointing simultaneously perpendicular and at several off-perpendicular angles, in order to validate the one-to-one correspondence we expect and to quantify the difference in signal strength at different angles (i.e., to get a coarse brightness distribution). In addition, we plan to perform a double pulse measurement [*Farley*, 1969] to get a better estimate of the spectral shape of the oblique observations.

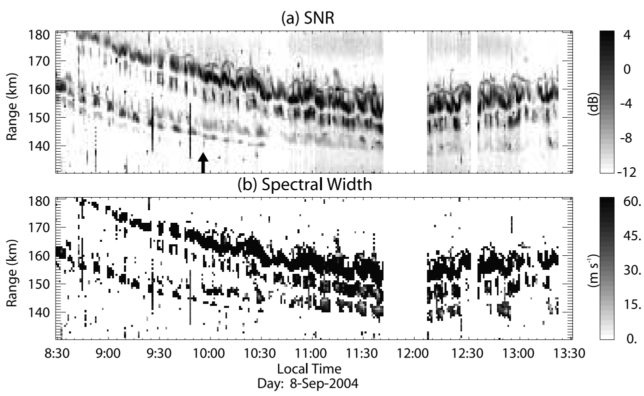

Figure 3. Range-time distribution of (a) SNR, and (b) spectral width, for the observations performed on September 8, 2004. Only spectral widths were the SNR is greater than −8 dB are shown. The arrow in the top panel indicates the time of the results shown in Figures 1 and 2.

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