Perpendicular and Off-Perpendicular to B Observations of 150-km Echoes: Evidence of Meridional Modulation and Structure

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Introduction

Although discovered more than 40 years ago [Balsley, 1964], there is still no physical mechanism that explains the occurrence of coherent echoes from altitudes around 150 kms (the so called 150-km echoes). East-West oblique beam [Fawcett, 1999] as well as wide beam imaging observations at Jicamarca, indicates that temporal variability of 150-km echoes (the pearls in the necklace) is not due to structuring and/or modulation in the zonal direction. These results point to a meridional modulation [E. Kudeki, personal communication]. Recently Chau [2004] reported the observations of echoes from 150-km region coming from off-perpendicular to B angles, implying that the aspect sensitivity (i.e., the North-South angular brightness) is not a narrow Gaussian as originally thought. Moreover, the spectrum of these echoes was very wide. Motivated by these new results, interferometric, multi-beam and faraday experiments were conducted at Jicamarca in December, 2004, and bistatic and interferometric experiments were conducted in March, 2008. Figure 1 shows a sketch of both experiments.

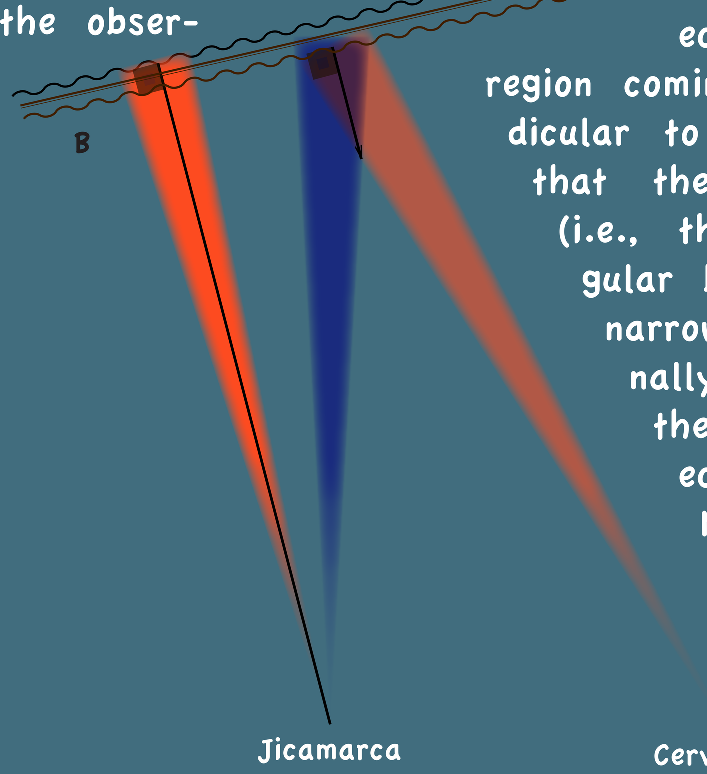


Figure 1. Multi-beam (Dec-2004) and bistatic (Mar-2008) radar configurations for 150-km experiments.

The preliminary results of the Dec-2004 experiments, presented by Woodman and Chau [2005], are:

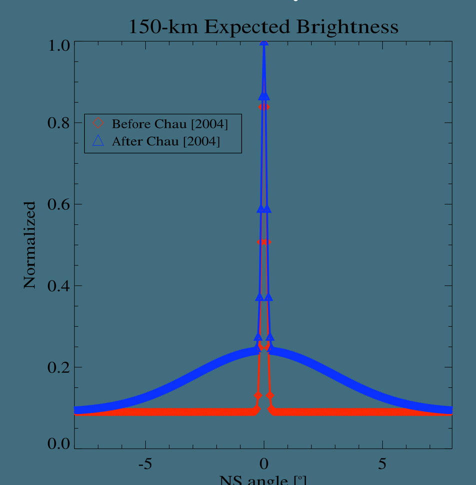


Figure 2. Expected 150-km brightness based on multi-beam experiments: narrow Gaussian (red), and narrow and wide Gaussian (blue).

1. The angular brightness of 150-km echoes is not a narrow Gaussian function, instead it is a composition of a narrow and wide (with less amplitude) Gaussian functions (see Figure 2).

2. The spectra of Oblique echoes resemble the Incoherent scatter radar (ISR) spectrum expected for these altitudes. In Figure 3, we show the expected ISR spectrum for (a) Perpendicular beam, (b) Oblique beam (~1.8°S) assuming the same electron density. In both cases we have considered a finite radar beam of ~1° width.

3. There is a high correlation between Oblique and Perpendicular echoes above 155 kms and below 145 kms (see SNR in Figures 4 and 5).

4. Using Faraday rotation [Farley, 1969], the enhanced echoes are not due to enhanced densities in the region. Moreover, density depletions were observed above and/or below the enhanced 150-km coherent echoes.

In the next sections, we present new results obtained from the December 2004 and preliminary results of the recent bistatic experiment. As indicated in Table 1, the main characteristics of the December 2004 experiments are: (a) Two concurrent beams were used: Oblique (on-axis position) and Perpendicular to B. The NS separation of the two beams at 150 kms is ~5 kms; (b) For each beam a NS interferometer was used on reception; and (c) the Oblique spectra are not aliased but there is range aliasing.

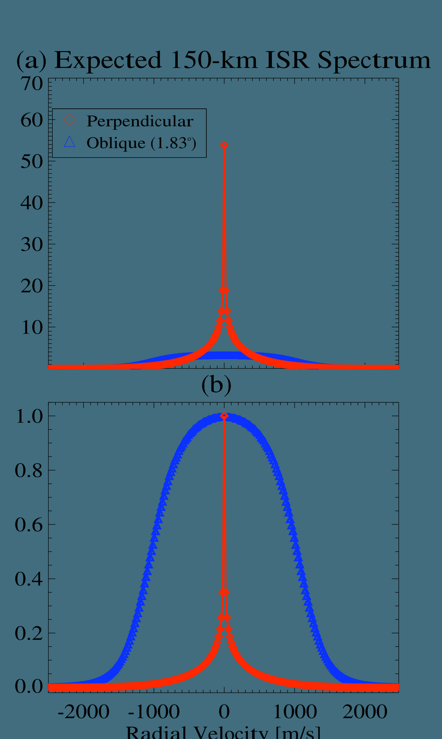


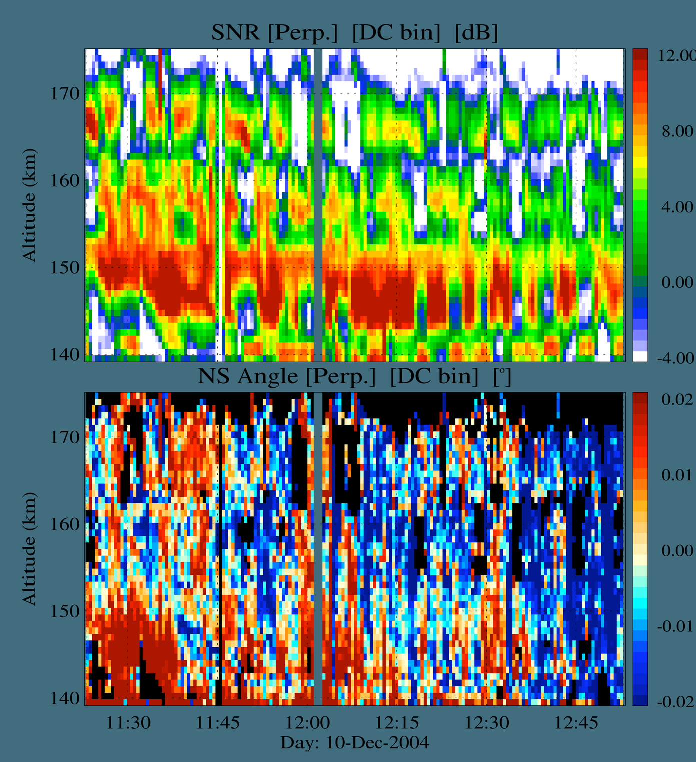
Figura 3. Expected ISR spectrum around 150 kms: perpendicular to B (red), and 1.83° off (blue) [Bottom: Normalized to their peak values].

For the March 2008 experiment, the main characteristics are: (a) the same volume was observed with Oblique and Perp. beams. The latter is accomplished with a bistatic configuration were the receiver station (Cervatel) is located ~9km south of Jicamarca. (b) For the Oblique beam, a NS interferometer was used on reception.

Parameters	Dec-2004	Mar-2008
Configuration	Two-beam	Bistatic
Nyquist	±2040 m/s	±1200 m/s
Interferometry	NS Perp & Oblique	NS Oblique
FFT points	32	8000
Beams	Perp & Oblique	Perp. & Oblique
IPP	110 km	187.5 km
Tx. Power	2 MW	2 MW
Resolution	0.75 km	0.75 km
Code	Barker 7	Barker 13

Table 1. Main Parameters/Characteristics

Two beam and Interferometry [December 2004)



Figures 4 and 5 show the SNR and NS angle for the Perpendicular and Oblique observations, respectively. The Perpendicular results have been obtained by processing the low frequency components (±30 m/s) using coherent integration. For the Oblique results, all frequency bins have been considered after a 3 point median filter was applied to remove possible Perpendicular echoes coming from sidelobes. Note that the angular range for the Perpendicular/Oblique results is ±0.02°/0.25°. For the Perpendicular results 0° represents the position of the locus of perpendicularity. In the case of the Oblique results, it represents the center of the illuminated volume at 150 kms.

Figure 4. SNR (top) and NS angle (bottom) for Perp. beam echoes, considering only "DC" frequency bins.

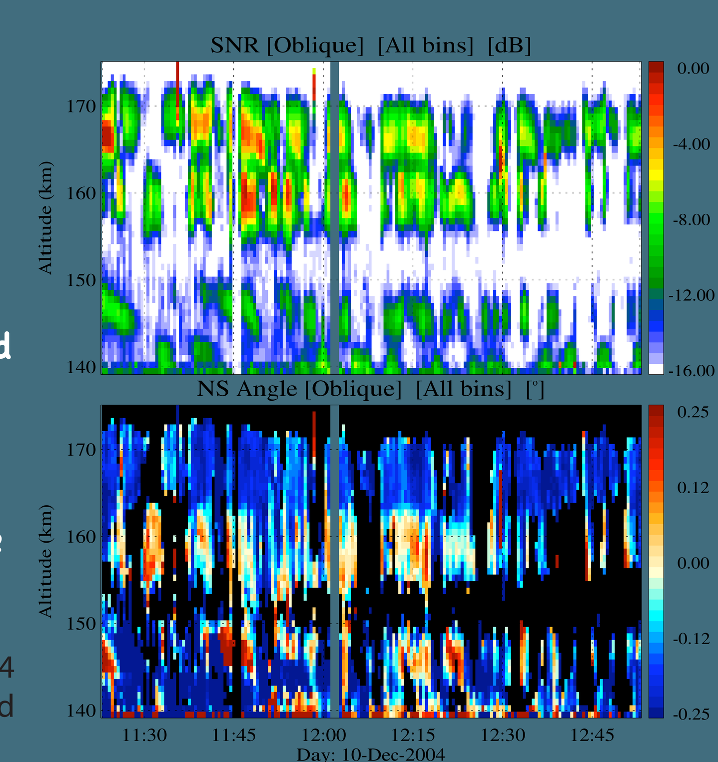
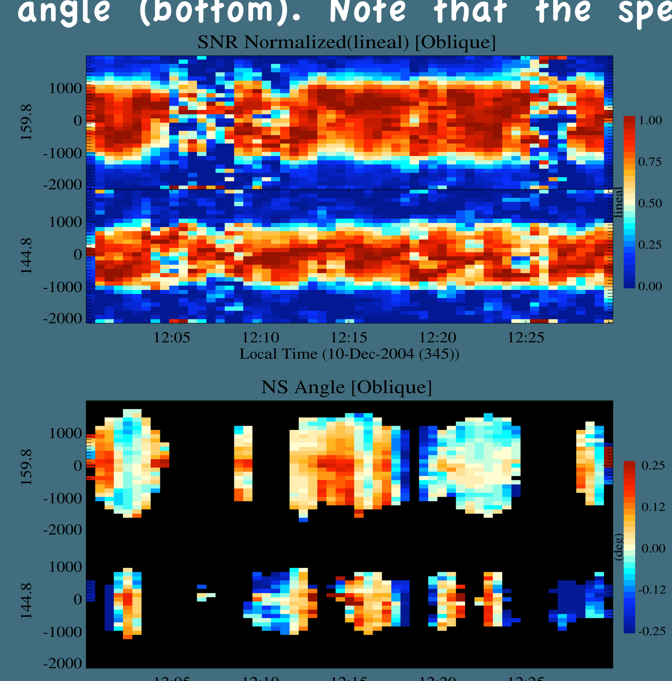


Figure 5. Same as Figure 4 but for Oblique echoes and all frequency bins.

NS and Frequency Structure

The Perpendicular NS angle results (Figure 4) shows that although small, there are angular deviations from the expected perpendicularity condition. However the Oblique NS angle Oblique (Figure 5) show significant variability, indicating that the scattering center changes inside the illuminated volume. For example, Oblique echoes above 165 km come from negative angles, while echoes around 160 km oscillate in time between positive and negative angles. Such large variability is also observed in the March 2008 results, moreover the coherence values show that the scattering volume is most of the time smaller than the illuminated volume [See Figure 11].

Besides meridional structure, we have also observed frequency structure in the Oblique spectra. In Figure 6, we show Oblique spectrograms of normalized self spectra and NS angle as function of Doppler velocity for two selected altitudes (144.8 and 159.8 kms). In both altitudes we can observe changes of peak velocity as function of time (e.g., sawtooth-type of structures in the lower altitude). Such velocity changes appear to be associated to changes in NS angle (bottom). Note that the spectra is narrower in the lower altitude.



The periodicity observed in the NS angle spectrograms is between 5 to 8 minutes. What is the cause of the Doppler and NS angle variability?

Figure 6. Oblique spectrograms for two selected altitudes (144.8 km and 159.8 km): normalized self-spectra (top) and NS angle (bottom).

Conclusions

1. The NS brightness distribution of 150-km echoes varies as a function of altitude. The central region (third band) are very aspect sensitive (coming from "pure" field-aligned irregularities). For the other regions, the NS brightness is like the blue function in Figure 2, with varying amplitude ratios, indicating that the irregularities are elongated in the NS direction but with corrugations of the order of 100 to 500 meters (see sketch in Figure 1).

2. The pure FAI echoes present narrower spectral width, and higher coherence (not shown) than echoes at other bands. The echo characteristics of this region might due to a much higher concentration of long-lived metallic ions as compared to the expected short-lived molecular ions.

3. The average spectra shape of Oblique 150-km enhanced echoes resemble the expected ISR spectra at these altitudes. These echoes could be used to get temperature measurements of this region.

4. There is a clear evidence that there is a significant structure/modulation in the meridional direction that could be associated to the meridional wind, atmospheric gravity waves, and/or the coupling with the E region [e.g., Tsunoda, 1994].

Bistatic and Interferometric [March 2008]

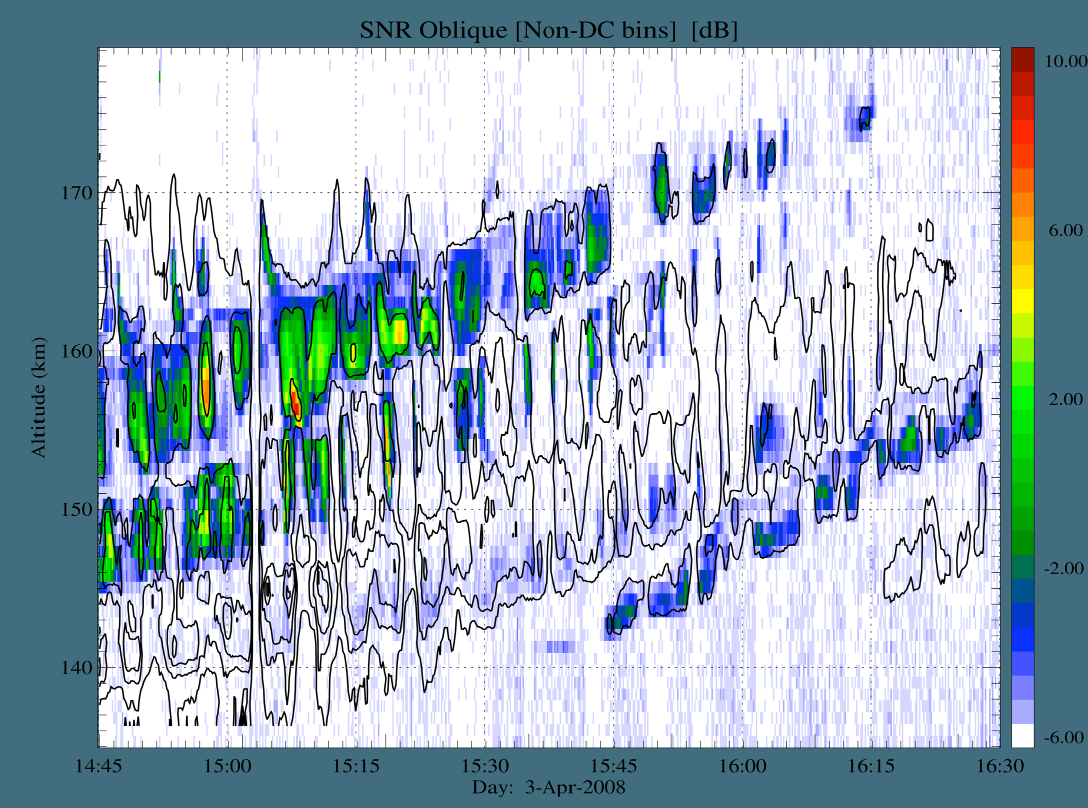
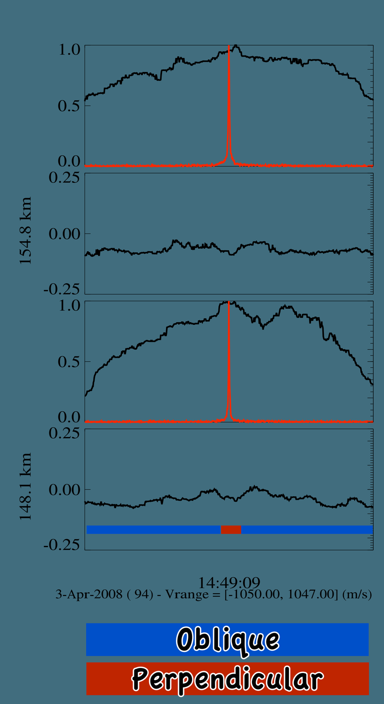


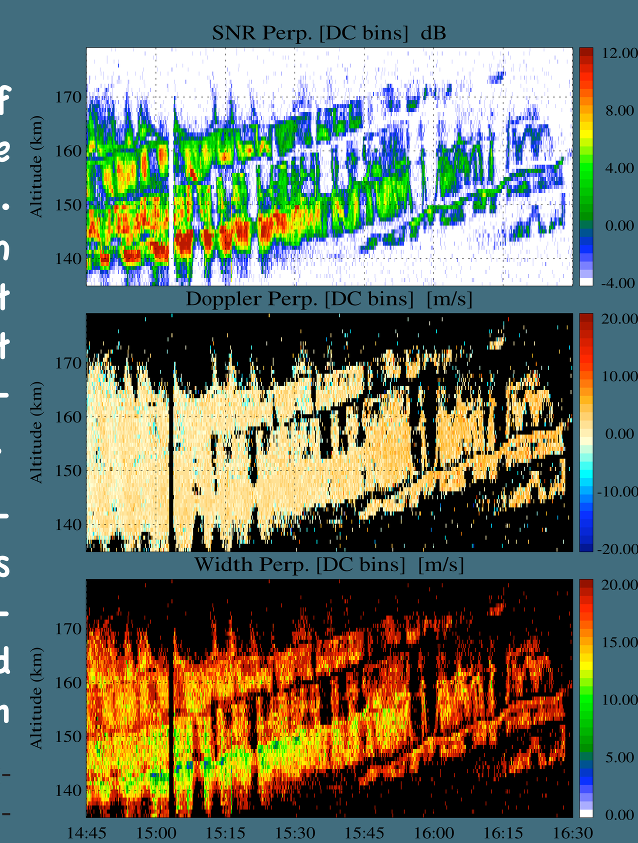
Figure 7. SNR map for Oblique observations during a bistatic experiment. The concurrent observations of Perpendicular SNR are shown in black contour lines.



The SNR comparison between Oblique and Perpendicular Mar-2008 observations in Figure 7, shows that there is a high correspondence (altitude and time) between Oblique and Perpendicular echoes occurring in the first, second and fourth altitude bands (starting from above). However, the correlation is very weak for the strong Perp. echoes occurring in the third band (see Perpendicular SNR values in Figure 9).

Figure 8. Normalized oblique spectra and NS angle for selected altitudes and time (black). The concurrent normalized Perp. spectra is indicated in red.

The example spectra of Figure 8 shows that the wide spectra is aliased. We are indicating with blue/red the bins that have been used to get the Oblique/Perpendicular results, respectively.



The spectral width results in Figure 9 shows that Perpendicular spectra of the "third" band region are narrower than the spectra at other altitudes (Why?). Figure 10 shows that the Oblique spectra gets wider as altitude increases, as expected from ISR spectra at these altitudes (temperature?). However the regions of equal width decreases in altitude as time increases. The Oblique SNR does not show evidence of the "fifth" band observed in the Perpendicular results around 1615 LT (sensitivity).

Figure 9. SNR, Doppler, and spectral width for Perpendicular observations.

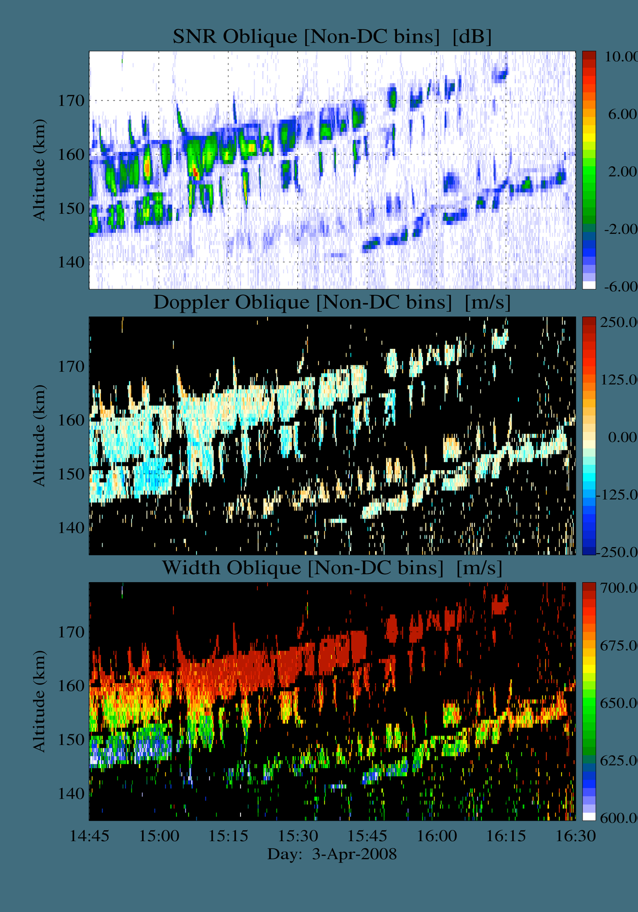


Figure 10. Same as Figure 10, but for Oblique observations.

The Doppler velocity of Perpendicular echoes are good proxy measurements for the F region ExB drifts [Chau and Woodman, 2004]. In the case of the Oblique mean Doppler results, they appear to be associated to the NS angle results shown in Figure 11. Again, the scattering center of the Oblique echoes occur North and South of the mean beam position. The coherence values of Figure 11 shows the Oblique echoes are coming from scattering volumes smaller than the illuminated volumes (coherence > 0.5), except for those times and altitudes where the coherence is less than 0.5 (blue values).

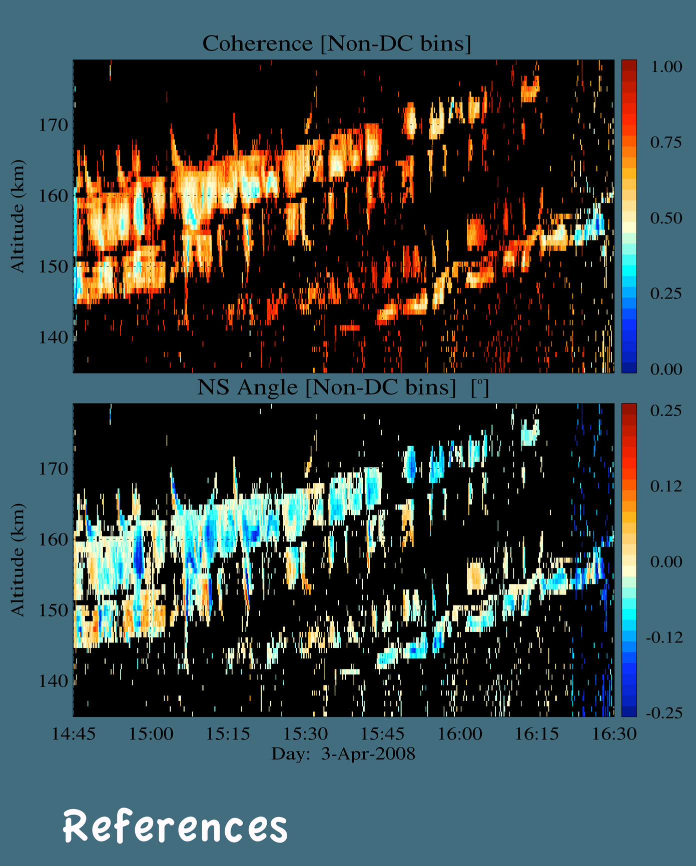


Figure 11. NS coherence and NS angle for oblique observations.

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