International Beacon Satellite Symposium BSS-2016
Trieste, Italy

Coherent backscatter interferometric radar images of equatorial spread F structures using Capon's method

Fabiano S. Rodrigues*[1], Gebreab K. Zewdie[1], and Eurico R. de Paula[2]

[1] W. B. Hanson Center for Space Sciences, UT Dallas, Richardson, TX, USA.
(E-mail: fabiano@utdallas.edu)

[2] Instituto Nacional de Pesquisas Espacais - INPE, Sao Jose dos Campos, SP, Brazil.

ABSTRACT

We present and discuss results of the application of Capon's spectral method for estimation of in-beam images of ionospheric scattering structures observed by a small, low-power coherent backscatter radar interferometer. We also present results of numerical simulations used to evaluate the performance of the Capon method for typical F-region measurements. The numerical simulations show that, despite the short baselines of the radar, the Capon technique is capable of distinguishing features with km scale sizes (in the zonal direction) at F-region heights. We use the imaging technique to investigate the morphology of scattering structures and better understand the development of equatorial spread F events in the light of current instability theories.

Key words: equatorial ionosphere, ionospheric irregularities, radar imaging.

1. INTRODUCTION

Equatorial spread F (ESF) refers to a wide range of electron density irregularities occurring in the equatorial F-region ionosphere. ESF is associated with interchange plasma instabilities, which can create larger scale sizes plasma density perturbations. Secondary plasma instabilities then create smaller scale irregularities. While the overall features of ESF are well-understood, we still seek a better understanding of the processes leading to the variability in the generation, development and decay of ESF events. In addition to the scientific aspect of studying instabilities in space plasmas, investigation of ESF is also motivated by its impact on the propagation of trans-ionospheric radio waves such as those used for remote sensing, navigation, and communication

Coherent backscatter radar imaging has been used for investigations of equatorial spread F. Palmer et al. [1998] and [Yu et al., 2000] proposed that the Capon spectral method can be used to create interferometric images of scattering structures producing coherent scatter echoes. Implementation of the method is simple, not computationally intensive, and produces images of the scattering regions with much higher spatial resolution than those created by the conventional Fourier method. Despite encouraging initial results, limited efforts have been made to use the Capon method in ionospheric studies.

In the present study, we revisit the Capon method and investigate its performance when applied to measurements made by a small, low-power coherent backscatter radar interferometer located in the equatorial site of Sao Luis.

2. MEASUREMENTS AND ANALYSES

The measurements available for this study were made by a 30 MHz coherent backscatter radar interferometer. The radar was installed in the equatorial site of Sao Luis, Brazil (2.59°S, 44.21°W, -2.66° dip latitude). The Sao Luis radar is a low-power radar system that has been used for studies of equatorial ionospheric irregularities in the E and F regions. The radar is equipped with four independent antenna sets connected to four receivers. Each antenna set is formed by an array of 4x4 Yagi antennas. The arrays have been placed non-uniformly in the magnetic zonal direction for radar imaging studies of scattering layers. The longest baseline is 150 m, that is 15 λ, where the λ is the wavelength of the 30 MHz radar signal. Two 4-kW transmitters are available for observations and are normally used for F-region measurements. For F -region measurements, we used 28-bit coded pulses, with a 9.33 ms inter-pulse period (IPP). The baud length and sampling were 2.5 km. A total of 250 samples were collected per IPP. This observation setup allowed us to make measurements of the F-region from 200 to 825 km altitude with a range resolution 2.5 km.

3. ANALYSES

Palmer et al. [1998] proposed a new technique to obtain images with higher angular resolution than those provided by the Fourier method. The technique is based on the Capon spectral analysis approach. The method is based on a set of weights that will not only provide a high-resolution spectrum, but will also suppress the effects of interfering signals. The set of weights is obtained by setting the search for the brightness distribution as a constrained optimization problem. The Capon weights are such that they minimize the brightness in all directions, except in the direction of interest. A detailed description of the derivation of the Capon method is given by [Palmer et al., 1998; Yu et al., 2000].

4. RESULTS

Figure 1 shows an example of our imaging results. It shows a sequence of images created using the Capon method for measurements made between 01:13 and 01:26 UT on March 14 when bottomside and topside echoes were observed. The sequence serves to illustrate the ability of the Capon method to produce images that provide important information about the dynamics of ESF irregularities. The images show, initially, the tilted scattering structure, which produces the bottom-type layer in the RTI map (top panel). Then, a narrow channel of irregularities starts to develop, from the top of the tilted structure and to the west of the radar site. It is possible to see that while the new irregularities become stronger they also drift to the east, following the expected direction of equatorial plasma motion around evening hours. Other results of our imaging can identify favorable conditions for the collisional shear instability and drift instability, which are thought to be responsible for equatorial spread F events.

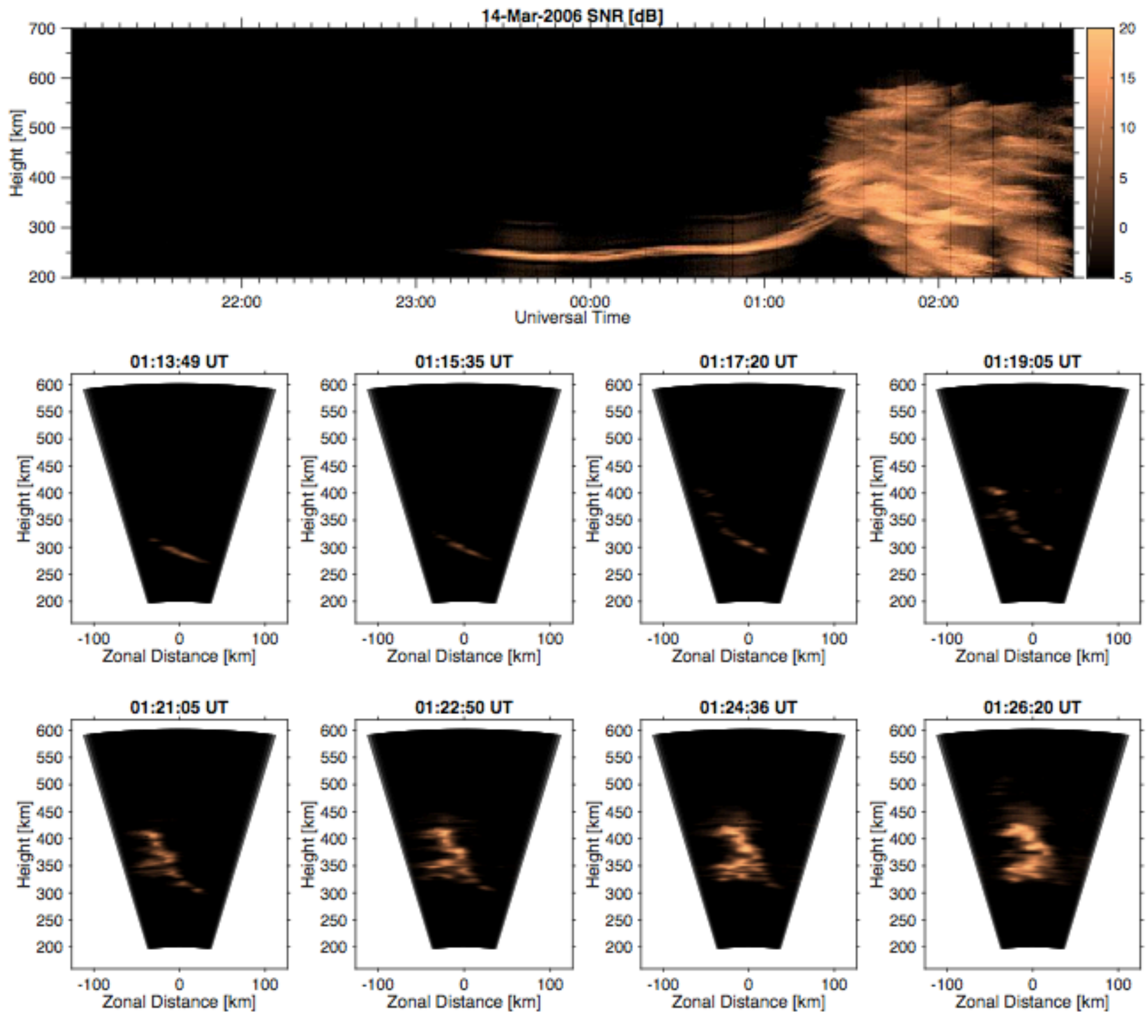

Figure 1 – Example of Capon imaging results for measurements made on March 14/15, 2006.

REFERENCES

[1] Palmer, R. D., S. Gopalam, T.-Y. Yu, and S. Fukao (1998), Coherent radar imaging using Capon's method, Radio Sci., 33(6), 15851598, doi:10.1029/98RS02200.

[2] Yu, T.-Y., R. D. Palmer, and D. L. Hysell (2000), A simulation study of coherent radar imaging, Radio Sci., 35(5), 11291141, doi:10.1029/1999RS002236.

[3] Rodrigues, F. S., A. O. Moraes, and E. R. de Paula (2012), Imaging equatorial spread F irregularities with the Sao Luis coherent backscatter radar interferometer, Radio Sci., 47, RS0L03, doi:10.1029/2011RS004929.

Acknowledgements: This work was supported by NSF (AGS-1303658) and AFOSR (FA9550-13-1-0095)