Scale Analysis of Pre- and Post-Midnight ESF Bubbles at Storm Time and Quiet Time

K. Y. Chen[1], S.Y. Su[2], H. C. Yeh[2] and C.H. Liu[2]

[1]The Department of Electronic Engineering, Huafan University, Taipei Hsien, Taiwan

[2]Institute of Space Science, National Central University, Chung Li, Taiwan

Abstract

This paper adopts a scale analysis technique to investigate the properties of intermediate scale plasma structures observed by ROCSAT-1 in the equatorial F region. A procedure of scale analysis that developed via the empirical mode decomposition (EMD) method of Hilbert-Huang transform (HHT) technique allows the mutually correlated components in velocity, density and relative density gradient to be identified and extracted. Comparing the three parameters, good match in wave form is found for density and velocity in scales between kilometers and hundred meters (few kilometers ~ 300 m). It implies that there are electric fields proportional to density fluctuation $-\delta n/n$ in the form similar to what expected for the generalized Rayleigh Taylor instability. We find such a one-to-one match holds for various pre- and post-midnight ESF bubbles at storm time and quiet time. It therefore means that spatial structures of electric field in the intermediate scale (few kilometers ~300m) will correlate to the density structures in a manner of $\delta E \propto -\delta n/n$ not necessary depending on the driving mechanism of ESF bubbles, although it is known that ESF bubbles can be driven by different mechanisms under different space weather conditions. In smaller scales (300 m ~ 50m), fluctuation patterns of density and velocity don't correlate to each other any more, the good match is then found in density gradient $\nabla_x n/n$ and velocity. It is known as the manifestation of the Boltzmann relation. We note that the GRT instability related relationship $\delta V_z \propto -\delta n/n$ for irregularities in scale of kilometers holds only for ESF bubbles occur within ±5 dip latitude, while the Boltzmann relation (δV_z proportional to $\delta \ln N$) holds for small scale irregularities without such a limitation.

Introduction

Plasma instability phenomena occurring in the equatorial F-region ionosphere are grouped under generic name equatorial spread F (ESF). In general, the ESF irregularities in large scale are thought to be driven by gravitational Rayleigh-Taylor (GRT) instability [Dungey, 1956] and developing to smaller scales under the work of some mechanisms. In conventional, the features of ESF irregularities were mainly studied in frequency (wavenumber) domain by examining the Fourier spectra of the density and the electric field fluctuations in spite of the fact that the data are usually non-stationary (non-homogeneous). For ESF irregularities in kilometer scales, the fluctuations of electric filed E and that of density n should obeys $|\delta E|^2 \propto |\delta n/n|^2$ in spectrum to consist with RT instability that states

$$\delta E_x = -\frac{gB}{\upsilon_{in}}\frac{\delta n}{n}. \qquad (1)$$

While for scales between few hundred meters and few tens meters, the Boltzmann relationship holds.

$$|\delta E|^2 \propto k^2 |\delta n/n|^2 \qquad (2)$$

i.e. $|E| \propto |\nabla n/n|$

Figure 1 illustrates the spectrum relationship between the $E_x x B_y$ induced velocity fluctuation V_z and density fluctuation, a spectrum break occurred around 500m is noted, thereafter a difference of 1.6 (close to 2) in power law is realized as a manifestation of Boltzmann relation. In an indirect way, the in situ measured ion drift velocity V_z reflects the features of electric field.

Contrary to traditional Fourier based method; HHT [Huang et al. 1998] provides a great opportunity for us to study ESF irregularity structures directly in space domain by applying the EMD method, an adoptive mode decomposition technique, to decompose the data into a finite number of intrinsic mode functions (IMF) which admit well-behaved Hilbert transform. Chen et al. [2001] firstly shown the application of HHT on analyzing ESF irregularity structures, they utilized EMD and show the scale analysis in their study. In this paper, we have pre- and post-midnight ESF bubbles at storm time and quiet time for such a scale analysis. The components of ESF irregularity fluctuations in scales corresponding to GRT instability and Boltzmann relation are then extracted. The comparisons between those scale analyses reveal some interesting properties of ESF irregularities. In the paper, we show the comparison between pre- and post-midnight bubbles at storm time; the comparison of pre-midnight ESF bubbles at storm time and quiet time; also the studies on the events occurred not on equator. A summary on the analyses is given on the table, and then the discussion and conclusion follow.

Discussion and summary on the analyses

There are some other ESF events in our scale analysis. Table 1 list all the events for comparison and discussion, the one-to-one match holds or not are shown in the last two columns. Our analyses include pre-midnight and post-midnight ESF bubbles. The activity of magnetic storm is also considered. Bubbles locate away from magnetic equator are studied also. Check on the table we find that the good correlation between velocity and density ($\delta V_z \propto -\delta n/n$) holds for events occur on magnetic equator. Although it is known that ESF bubbles can be driven by different mechanisms under different space weather conditions, our analyses show that one-to-one match between V_z and $-\delta n/n$ can be find in both pre- and post-midnight cases. It therefore means that spatial structures of electric field in the scales between few kilometers and 300m will always correlate to the density structures in a manner of $\delta E \propto -\delta n/n$ not necessary depending on the driving mechanism of ESF bubbles. Also we note that the one-to-one match between velocity V_z and relative density gradient $\nabla_x n/n$ holds in all cases. The match between V_z and $\nabla_x n/n$ is known as the manifestation of the Boltzmann relation [Chet et al. 20001]. This feature exists without depending on conditions pre- or post- midnight, storm or quiet time, on equator or not. The small-scale irregularities in an upward drift active ESF bubble will exhibit one-to-one match between fluctuations of V_z and $\nabla_x n/n$. We note that the relationship $\delta V_z \propto -\delta n/n$ for irregularities in scale of kilometers holds only for ESF bubbles occur within ±5 dip latitude, while the Boltzmann relation (δV_z proportional to $\delta\, ln N$) holds for small scale irregularities without such a limitation.

Reference:

Chen K. Y., H. C. Yeh, S. Y. Su, C. H. Liu, and N. E. Huang, Anatomy of plasma structures in an equatorial spread F event, *Geophys. Res. Lett.*, Vol. 28, No. 16, 3107-3110, Aug.15, 2001

Dungey, J. W., Convective diffusion in the equatorial F-region, *J. Atmos. Terr. Phys.*9, 304, 1956.

Huang N. E., Z. Shen, S. R. Long, M. L. Wu, and H. H. Shih, The Empirical Mode Decomposition and Hilbert Spectrum for nonlinear and nonstationary time series analysis. Proc. R. Soc. London Ser. A454:903-995, 1998.

Yeh H. C., S. Y. Su, Y. C. Yeh, J. M. Wu, R. A. Heelis, and B. T. Holt, Scientific mission of the IPEI payload on board ROCSAT 1, *TAO supplementary issue*, 19-42, 1999

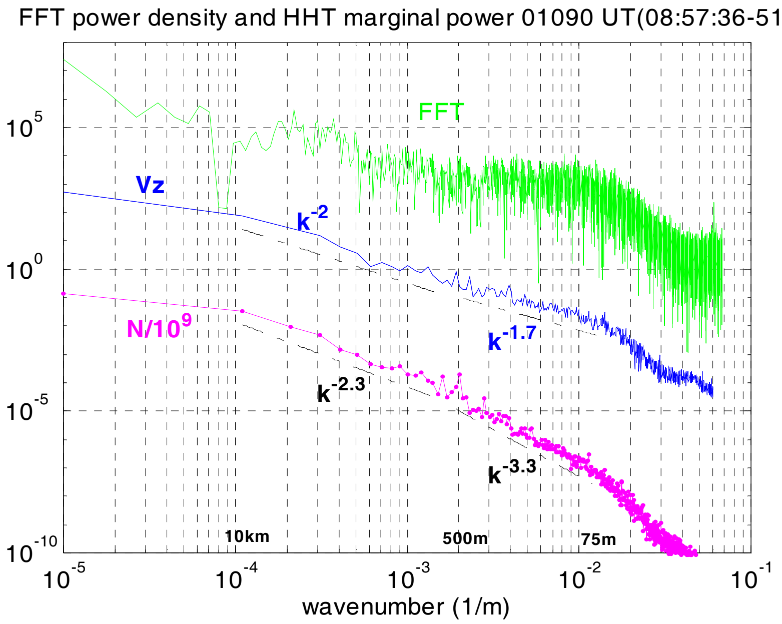

Figure 1. The marginal power spectra for V_z and relative density gradient $\nabla_x n/n$ as well as density fluctuation N for the entire data set. The conventional Fourier spectrum for V_z is also shown on the top. Background power level for V_z in HHT spectrum is around 10^{-4}. The spectra indices derived from HHT marginal power are also included.

	(Glat, Mlat)	On Equator	Storm Time	Pre-Mid	Post-Mid	δVz~δLogN	δv~∇n/n
99295	(15.9, 4.1)	v	v	v		v	v
01090a	(16.9, 5.3)	v	v		v	v	v
00084	(9.9, 2.0)	v		v		v	v
01090b	(27.3, 26)		v	v			v
00085a	(0.37, -6.5)	v		v		v	v
00085b	(-1.8, -10.1)			v			v
01108 a,b,c			v	v			v

Table 1 ESF events for pre- and post- midnight, storm and quiet time, on and off equator. The events are 99295 on 22 October 1999; 01090a on 31 March, 2001; 01090b on 31 March, 2001; 00084 on 24 March, 2000; 00085 on 24 March, 2000; and 01108 on 18 April, 2001