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Ionospheric Structure Diagnostic for Satellite Communication, Navigation, and Surveillance System Performance Evaluation

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Abstract

An empirical mode decomposition (EMD) procedure was developed by Norden Huang. However, EMD has several issues including instability and convergence. An improved procedure, which has been implemented as a complement to widely used wavelet and FFT algorithms [2],[3] generates a set of position-dependent modes. This talk will summarize an ongoing study comparing segmented spectral density function (SDF) estimation and fast iterative filtering (FIF). FIF has been recently proposed as an efficient, stable and convergent alternative to EMD for the decomposition of non-linear, non-stationary signals into functions oscillating around zero, known as Intrinsic Mode Functions (IMFs).

1 Introduction

Ionospheric structure in the intermediate-scale range from tens of kilometers to hundreds of meters is characterized by two-component power-law DFs. Although the structure is three dimensional, stochastic variation is defined by intersections of field-aligned *striations* with two-dimensional planes. Diagnostic measurements are either point scans through structured regions or integrations along propagation paths sweeping through structured regions. Either way, diagnostic measurements are formally non-stationary time series with structure characteristics defined by the scan orientation and motion relative to the magnetic field direction. A local coordinate system and region-of-interest are implied. We developed a procedure for generating power-law structure realizations as summations of collections of striations[1]. The results verify that diagnostic measurements are one-dimensional time series with power-law parameters determined by the defining three-dimensional power-law parameters and the scan velocity.

Power-law processes have been studied extensively. They admit a fractal-like self-scaling property, which underlies the configuration-space realization procedure. The most extensively used statical measure is the aforementioned SDF, which is the intensity of the Fourier transform of the diagnostic structure. However, the removed Fourier component phase determines the configuration of the structure. Diagnostic procedures that measure both frequency and spatial-distribution include wavelets. The underlying concept is that correlation with a scalable support provides scale-dependent position information.

2 SDF-IMF Comparisons

Here we show comparisons of SDF and FIF diagnostics. The upper frame of Figure 1 summarizes an analysis of developed high-resolution simulated equatorial plasma bubble (EPB) structure at 550 km. From a standard spectral density function (SDF) estimate an automated procedure is applied to estimate the power-law parameters. The SDF with the estimated two-component power-law spectrum overlaid is shown in the lower right hand frame. The lower frame shows a configuration space realization to which the same parameter estimation procedure has been applied. The SDFs are identical, which illustrates the need for complementary configuration-space diagnostics.

Figure 2 shows two FIF examples. The left frame show an FIF analysis of the EPB simulation shown in Figure 1. The summary shows the scale of the peak FIF mode at each altitude. The development at the lower altitudes where the EPB is just beginning to structure is confined to the westward wall. The simulated structure is moving westward at 125 mps, whereby the enhancement is expected. The example illustrates the utility of structure location. The example on the right shows the FIF modes derived from TEC structure extracted from an equatorial GPS satellite pass. The relation of IMF modes and ESF structure is under investigation.

References

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[2] A. Cicone and H. Zhou, "Numerical analysis for iterative filtering with new efficient implementations

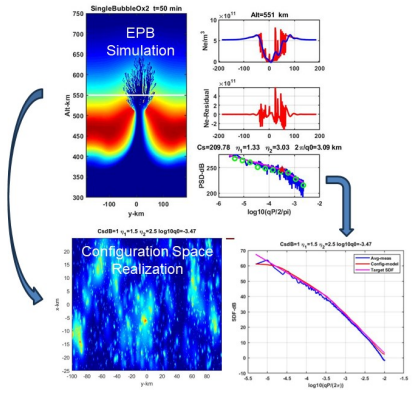

Figure 1. Upper frame show spectral analysis of simulated ESF structure at 550 km. Lower frame shows spectral analysis of configuration space realization. The estimated SDFs are identical

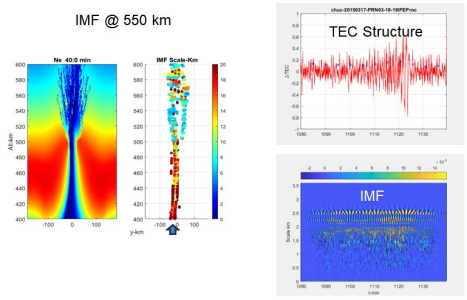

Figure 2. Left frame shows iterative mode scales of from IMF peak. Right frame shows IMF derived from measured GPS equatorial TEC structure.

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[3] Angela Stallone, Antonio C icone and Massimo Materassi, "New insights and best practices for the successful use of Empirical Mode Decomposition, Iterative Filtering and derived algorithms," *Scientific Reports*, **51**, 10, 2020, pp. 1516, doi.org/10.1038/s41598-020-72193-2