Wavelet spectral analysis of the ENIGMA magnetometer array time series and solar wind conditions around the strongest magnetic storms of solar cycle 24

Adamantia-Zoe Boutsi, Georgios Balasis

Magnetic storms are undoubtedly among the most important phenomena in space physics and also a central subject of space weather. Here we study the Earth's magnetic field time variations measured by ENIGMA for 2015, when the three strongest magnetic storms of solar cycle 24 occurred in March, June and December, along with the corresponding solar wind parameters and geomagnetic activity indices. We apply spectral analysis techniques based on wavelet transforms and calculate the Hurst exponent of these time series.

The HellENIc GeoMagnetic Array (ENIGMA) is a network of 4 ground-based magnetometer stations in the areas of Trikala, Attica, Lakonia and Lasithi in Greece that provides measurements for the study of geomagnetic pulsations, resulting from the solar wind - magnetosphere coupling. ENIGMA is a SuperMAG contributor that enables effective remote sensing of geospace dynamics and the study of space weather effects on the ground (i.e. Geomagnetically Induced Currents - GIC).

The wavelet transform identifies the temporal evolution of the signal's spectral content, i.e. various frequencies, and thus should in principle be capable of separating the various field source contributions. For the analysis we used the algorithm developed by Torrence and Compo (1998). The geomagnetic activity index used as a proxy is the SYM-H. The solar wind parameters were obtained from the OMNIweb database.

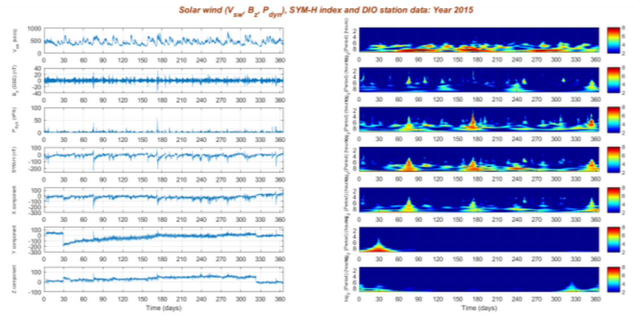

Figure 1: (From top to bottom) Depiction of the time series and respective wavelet power spectra of the solar wind parameters (Plasma Velocity, Dynamic Pressure, IMF's Bz component), the SYM-H index and the x, y and z components of the Earth's magnetic field as measured by the ENIGMA Dionysos (DIO) station.

The comparative Fig. 1 shows that the intensity of the three major storms of 2015 is clearly depicted in the SYM-H, Pdyn and the x-component of the Earth's magnetic field panels. The spectral analysis on the By and Bz components reveals a strong dependence on "steps" in the time series, for which special attention must be given.

Next, we calculate the Hurst exponent, H, for the time series presented in Fig. 1. We note that when 0<H<0.5 the time series has anti-persistent properties, which means that if the fluctuations increase with time, it is likely to decrease in the interval immediately following and vice versa. Physically, this implies that fluctuations tend to induce stability within the system (negative feedback mechanism). If H takes values in the interval (0.5 1) the signal exhibits persistent properties, which means that if the amplitude of the fluctuations increases with time, it is likely to continue increasing in the immediately next interval. Namely, the underlying dynamics is governed by a positive feedback mechanism [Balasis et al., 2006].

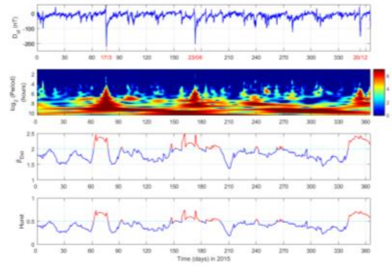

Figure 2: (From top to bottom) Depiction of the Dst index time series, its wavelet transform, the β exponent and the linearly correlated to it Hurst exponent. Blue color corresponds to values less than 0.5 and red color to values above 0.5.

In Fig. 2 we present the calculated Hurst values for the Dst geomagnetic activity index. Our results show the existence of two different patterns: (i) a pattern associated with the intense magnetic storms, which is characterized by higher Hurst values; (ii) a pattern associated with the quiet-time magnetosphere, which is characterized by lower Hurst values.

References:

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Authors:
Z. Boutsi[1,2] G. Balasis[1]
1) Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing, National Observatory of Athens, Greece
2) Section of Astrophysics, Astronomy and Mechanics, Department of Physics, National and Kapodistrian University of Athens, Greece

Corresponding author:
Zoe Boutsi
Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing, National Observatory of Athens
Metaxa & Vas. Pavlou, Penteli, 15236 Athens, Greece
Tel.: (+30) 210 8109183, e-mail: zboutsi@noa.gr