EGU2020-4981

Dynamical Complexity of Magnetic Storms at Swarm Altitudes Using Entropy Measures

C. Papadimitriou[1,2], G. Balasis[1], A. Z. Boutsi[1,3], O. Giannakis[1], A. Anastasiadis[1], I. A. Daglis[3,1], P. De Michelis[4], G. Consolini[5]

(1) IAASARS – National Observatory of Athens

(2) Space Applications & Research Consultancy

(3) National & Kapodistrian University of Athens

(4) Istituto Nazionale di Geofisica e Vulcanologia

(5) Istituto Nazionale di Astrofisica

EGU General Assembly
Online | 4–8 May 2020

Motivation

- **Dynamical complexity detection** for output time series of complex systems is one of the foremost problems in physics, biology, engineering, and economic sciences.

- Especially in geomagnetism and magnetospheric physics, accurate detection of the dissimilarity between **normal and abnormal states** (e.g. pre-storm activity and magnetic storms) can vastly improve space weather diagnosis and, consequently, the mitigation of space weather hazards.

- The data sets obtained from most space physics studies are usually **nonstationary, rather short, and noisy**.

- One of our objectives is to find an **effective complexity measure** that requires short data sets for statistically significant results, provides the ability to make fast and robust calculations, and can be used to analyze nonstationary and noisy data, which is convenient for the analysis of geomagnetic and magnetospheric time series.

IAASARS

ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

iaps

inTeRnS

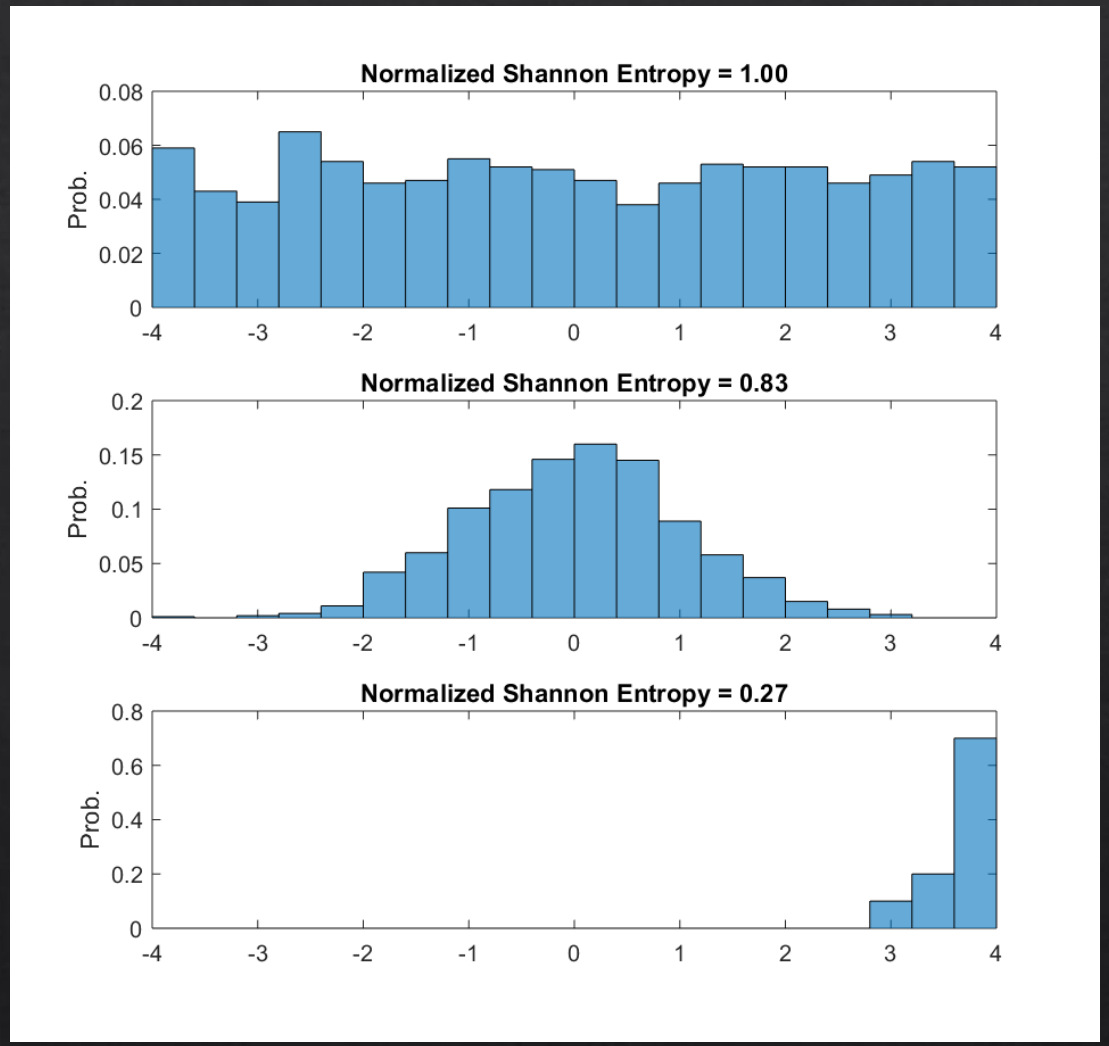
Shannon Entropy

Given p_i the probability of a telecom. system being in a cell 'i' of its phase space, Shannon defined the information produced by it by means of the Boltzmann H theorem, as the entropy

$$H = -\sum_i p_i \cdot \log_b p_i$$

Continuous variables can be "digitized" in order to define these "cells" of the phase space.

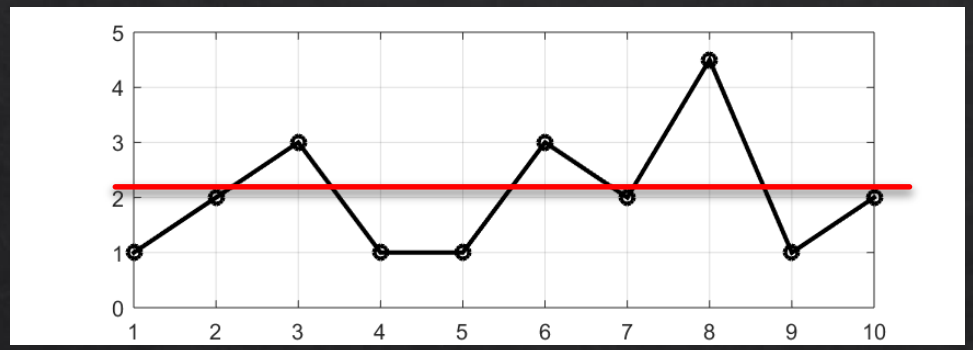
This in essence becomes a "histogram entropy" and loses all sense of temporal information.



EGU General Assembly
Online | 4–8 May 2020

Symbolic Dynamics & Block Entropies

Digitization of continuous time series (as an easy example consider the binary case, performed by a simple mean-value thresholding)



0, 0, 1, 0, 0, 1, 0, 1, 0, 0

Parsing the symbolic series in blocks of length ‘m’, e.g. for m=3

Gliding/Sliding Method (overlapping)

Lumping Method (non - overlapping)

0, 0, 1, 0, 0, 1, 0, 1, 0, 0, 0, 1, 0, 0, 1, 0, 1, 0,

0, 0, 1, 0, 0, 1, 0, 1, 0, 0, 0, 1, 0, 0, 1, 0, 1, 0,

0, 0, 1, 0, 0, 1, 0, 1, 0, 0, 0, 1, 0, 0, 1, 0, 1, 0,

In both cases, count the probability of appearance of each “block of length m” and compute the block entropy H(m).

The entropy of the source is given by $h = H(m+1) - H(m)$, for $m \to \infty$
[Karamanos & Nicolis, 1999]

EGU General Assembly
Online | 4–8 May 2020

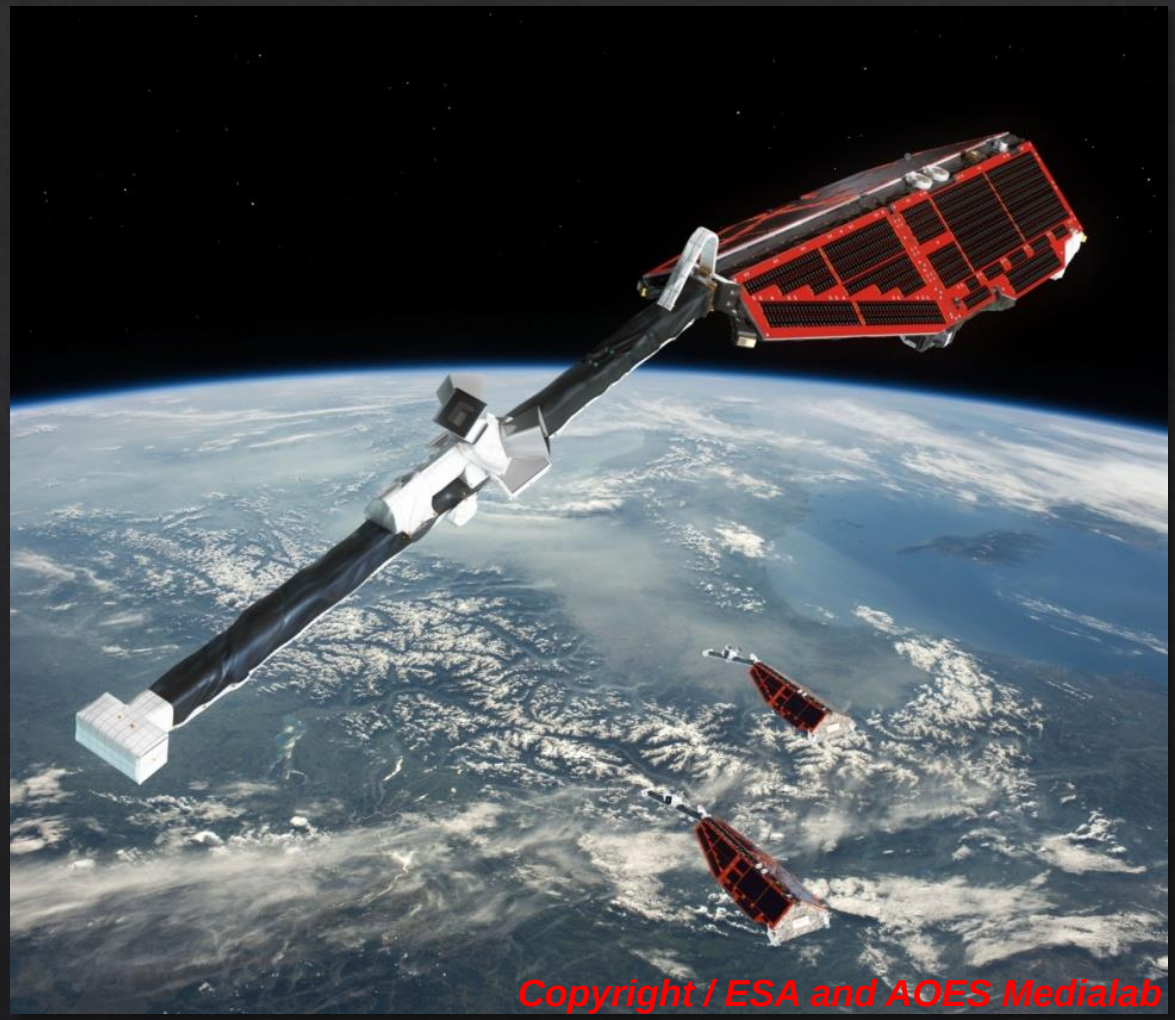
ESA Swarm Mission

Each satellite is measuring:

- ✓ Strength and direction of the magnetic field
- ✓ Plasma conditions and characteristics
- ✓ Position, orientation & acceleration

The Constellation:

- ✓ 3 identical satellites:
  - 2 side-by-side in low orbit (<460km)
  - 1 in higher orbit
  - (< 530km)
- ✓ three orbital planes for optimal coverage in space and time
- ✓ **Launch: 22 November 2013**



IAASARS

ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

iaps

inTeinS

Case Study: March 2015 Storm

Swarm-A, Total Magnetic Field, after subtraction of CHAOS-6 model, 1 Hz sampling rate (data from the VFM instrument)

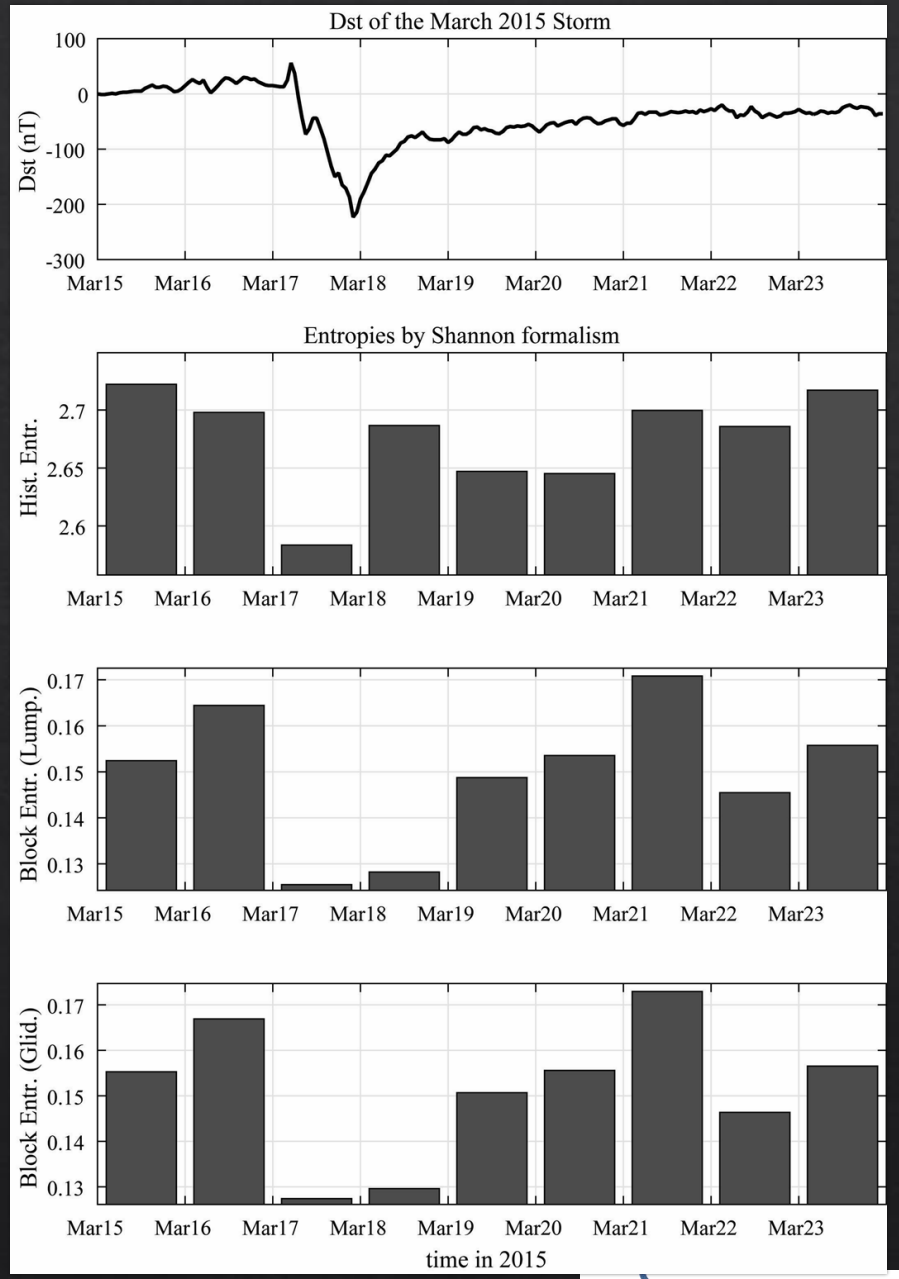
Keeping only measurements between ±50° Mag. Lat. creates equatorial segments of approx. 1400 points (23.3 min)

Filter each segment by removing a 2-min moving average

Histogram Entropy computed in 20 bins, while Block Entropies computed with a binary digitization up to Block Length = 3

Final values: Mean Entropy of all segments for every day

[Papadimitriou et al., *Entropy* under review]



IAASARS

ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

iaps

EGU General Assembly
Online | 4–8 May 2020

inTeNS

Summary

- One can utilize different concepts
  - Histogram
  - Block Entropies on Symbolic Series
  - Non-symbolic Measures based on ApEn

  … as well as different entropy definitions

  to capture the changes in the dynamics of a Complex System.
- Lower entropy values are associated with a higher degree of complexity or level of self-organization, which is characteristic of critical phenomena.
- Such tools can be used to assess the pre-conditioning of the magnetosphere for enhanced prediction & monitoring capabilities.

EGU General Assembly
Online | 4–8 May 2020