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Scaling features of cosmic rays, solar, heliospheric and geomagnetic data

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Abstract

Hurst exponent states one of the time series descriptors, allowing for the quantitative consideration of the state of the randomness, persistence or anti-persistence mode. This parameter has been used, in various types of real dynamical systems e.g., in financial analyses, solar physics or astrophysical processes. In our work we apply Hurst exponent to the revealing of the scaling features of cosmic ray intensity and anisotropy measurements over the solar cycle 24 (years 2007-2019). More precisely, using two different approaches: structure function and detrended fluctuation analysis methods we perform systematic calculation of Hurst exponent for selected physical parameters. Additionally solar, heliospheric and geomagnetic data are considered. Conducted analysis allows to identify periods with randomness and to obtain more complete picture of cosmic rays transport in the heliosphere and Earth magnetosphere throughout the solar cycle.

Keywords: scaling properties of time series, Hurst exponent, structure function, detrended fluctuation analysis

Introduction

The concept of Hurst exponent has its origins in hydrology (Hurst, 1951), and from that time it has been increasingly used in other disciplines: in finances (e.g., Di Matteo, 2007), in biomedical time series (e.g., Ihlen, 2012), or space weather studies (e.g., Takalo and Timonen, 1998; Wanliss, 2004; De Michelis et al., 2021; Alberti et al., 2021), as well as in solar activity predictions (e.g., Singh and Bhargawa, 2017). Moreover, using Hurst exponent (e.g., Ruzmaikin et al., 1994), revealed the stochastic character of the solar activity time profile. The Hurst exponent properties were used in the analysis of compound diffusion properties, i.e., when the particles are closely connected to the magnetic field lines and the perpendicular transport origins in the random walk (Kota and Jokipii, 2000).

There are several techniques for the determination of H exponent from experimental data. In this paper, we use two approaches for establishing the Hurst exponent: the structure function and detrended fluctuation analysis methods.

Here we apply the scaling techniques to analyze the Hurst exponents of the daily cosmic ray count rates data from neutron monitor stations around the world, amplitude and phase of the diurnal (24-hours) variation of cosmic rays intensity, solar, heliospheric and geomagnetic data.

Results

The Hurst exponent is evolving with the 11-year solar activity cycle with significant variability for different cosmic ray parameters, as well as solar, heliospheric and geomagnetic data. Time series of the cosmic ray diurnal amplitude and phase evolve from the more persistent structure in and near the solar minimum to the more random character in and near the solar maximum. It is seen a transition from a weakly correlated structure near the solar minimum to uncorrelated near the solar maximum of solar cycle of heliospheric dynamics represented by cosmic ray diurnal variation. It is in agreement with the general configuration of the heliosphere, being more regular-structured near the solar minimum with the established heliospheric magnetic field and more turbulent near the solar maximum.

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