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27-day variation in solar-terrestrial parameters: Global characteristics and an origin based approach of the signals

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Abstract

The Earth and the near interplanetary medium are affected by the Sun in different ways. Those processes generated in the Sun that induce perturbations into the Magnetosphere-Ionosphere system are called geoeffective processes and show a wide range of temporal variations, like the 11-year solar cycle (long term variations), the variation of ~27 days (recurrent variations), solar storms enduring for some days, particle acceleration events lasting for some hours, etc.

In this article, the periodicity of ~27 days associated with the solar synodic rotation period is investigated. The work is mainly focused on studying the resulting 27-day periodic signal in the magnetic activity, by the analysis of the horizontal component of the magnetic field registered on a set of 103 magnetic observatories distributed around the world. For this a new method to isolate the periodicity of interest has been developed consisting of two main steps: the first one consists of removing the linear trend corresponding to every calendar year from the data series, and the second one of removing from the resulting series a smoothed version of it obtained by applying a 30-day moving average. The result at the end of this process is a data series in which all the signal with periods larger than 30 days are canceled.

The most important characteristics observed in the resulting signals are two main amplitude modulations: the first and most prominent related to the 11-year solar cycle and the second one with a semiannual pattern. In addition, the amplitude of the signal shows a dependence on the geomagnetic latitude of the observatory with a significant discontinuity at approx. ±60°.

The processing scheme was also applied to other parameters that are widely used to characterize the energy transfer from the Sun to the Earth: F10.7 and Mg II indices and the ionospheric vertical total electron content (vTEC) were considered for radiative interactions; and the solar wind velocity for the non-radiative interactions between the solar wind and the magnetosphere. The 27-day signal obtained in the magnetic activity was compared with the signals found in the other parameters resulting in a series of cross-correlations curves with maximum correlation between 3 and 5 days of delays for the radiative and between 0 and 1 days of delay for the non-radiative parameters. This result supports the idea that the physical process responsible for the 27-day signal in the magnetic activity is related to the solar wind and not to the solar electromagnetic radiation.

Keywords: 27-day variation; Solar wind; Solar radiation; Cross-correlation

1. Introduction

The gaseous plasma composition of the Sun induces an un-uniform rotation around its axis with a dependence on the heliographic latitude. The rotation rate is observed to be fastest at the equator and decreases toward the poles. The sidereal rotation period according to the Carrington definition is of ~ 25.3 days at a latitude of 26°. This period should not be confused with the synodic rotation period of ~ 27.2 days which is the time for a fixed point on the Sun to rotate to the same apparent position as viewed from Earth (Beck, 2000).

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The effects of the synodic rotation period can be detected in many parameters measured on the Earth and can be roughly classified by their origin in two groups: (i) signals generated by phenomena related to the entrance of charged solar wind particles into the magnetosphere and (ii) signals generated by phenomena related to the solar radiation.

In the first group, the most important physical parameters to detect a 27-day signal are the usual variables that characterize the solar wind: density, velocity and interplanetary magnetic field (IMF) intensity, which at the orbit of the Earth have mean values of 4 cm^{-3}, 400–500 km s^{-1} and 5 nT respectively (see (Prölss, 2004), Ch. 6). The variability of the magnetic field observed near the Earth is primarily driven by the magnetic reconnection between the IMF and the geomagnetic field. The fact that the geomagnetic dipole is approximately perpendicular to the ecliptic plane makes the reconnection rate dependent on the southward component of the IMF, and proportional to the Y component of the motional electric field ($\mathbf{E} = -\mathbf{v}_{sw} \times \mathbf{B}_{IMF}$) of the solar wind (Vasyliunas, 1975). Hence, coherent solar wind structures containing southward magnetic field components and high velocities are thus most efficient drivers in the transference of energy into the magnetosphere. Among these coherent structures are high-speed streams (HSS) emanated from near-equatorial coronal holes and corotating interaction regions (CIR) arising from the interaction of the rotating HSS with the upstream slower-speed stream. Both can generate temperate geomagnetic activity with a 27-day recurrence (Tsurutani et al., 2006).

The 27-day variation in the magnetic activity has been studied by many authors. Its existence is well documented in classic works like (Fraser-Smith, 1972; Sargent, 1986; Shapiro and Ward, 1966 and Ward, 1960). One of the preferred techniques to studying it was the signal spectrum calculation of several magnetic indices. The spectrum of the geomagnetic activity is quite complex for periods around 27 days. In fact, this complexity led some authors to investigate subsidiary peaks near the frequency associated to the 27-day period and interpreted them as modulations. The subsidiary peaks contain information about other periodicities like the semiannual, annual or the 11-year (solar cycle) variation (see for example (Clúa de Gonzalez et al., 1993) or (Střeštík, 1998)). Besides the fact that several different phenomena can contribute to periodicities around 27 days, there is an intrinsic temporal variation in the period (it is not constant in time) that could make Fourier analyses not adequate to study this variation in long data sequences, as suggested by Schreiber (1998).

In the second group, the 27-day signals are produced by the solar radiation in a process that can be simplified as follows: while the Sun rotates around its axis, the Earth projection over the solar disc is affected by different radiative regions that are distributed in-homogeneously around the disc, resulting in a change of the radiation flux that reaches the upper layers of the terrestrial atmosphere. The radiation corresponding to the extreme ultra-violet (EUV) and X bands ionizes the neutral elements of the atmosphere and then generates the ionosphere. Therefore, there exist a close connection between the temporal variations in the solar radiation and in the generation and destruction of ions in the ionosphere-thermosphere system. The 27-day variation resulted from this process has been studied by different authors, including global analyses where the periodicities in variables like total electron content and the electron density are considered in the ionosphere at a global scale (Afraimovich et al., 2006; Hocke, 2008), or even localized analyses focused on specific ionospheric layers like the articles of Min et al. (2009) and Reuveni and Price (2009).

The study of the 27-day signal combining different Sun-Earth parameters has also served to study other less known phenomena like the 22-year cycle in the magnetic activity (Apostolov et al., 2004; Cliver et al., 1996). According to these references, the 22-year variation is the result of an asymmetry between the Northern and the Southern Hemispheres of the Sun.

In this work, the 27-day pattern that the synodic period produces over a variety of solar-terrestrial measurements was investigated. The study was focused in the magnetic data utilizing the horizontal component (H) of the magnetic field measured at several geomagnetic observatories and the main goal was to characterize the global aspects of this variation. The same methodology was applied to other solar terrestrial measurements for the purposes of comparing results. These parameters are: the solar radiative proxies F10.7 and Mg II, ionospheric vTEC and solar wind speed (v_{sw}). All the analyses were done by means of less restrictive statistical techniques like the calculation of auto-correlation and cross-correlation parameters, moving averages and standard deviations.

The article is structured as follows: Sections 2 and 3 explain in detail the data that were utilized and the processing sequence that was applied to it. In Sections 4 and 6 the results of the different correlation studies are presented while the characterization of the 27-day signal of each quantity investigated is analyzed in Section 5.

2. The data

This section describes the data that were utilized on this work. All the cited websites were publicly available at the moment of the elaboration of this paper, approximately in April 2017.

2.1. Magnetic data - H

As it was mentioned in Section 1, the focus of this work is the magnetic activity. Specifically, the analysis was based on the horizontal component of the Earth's magnetic field (H) observed at several magnetic observatories/stations

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