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Geomagnetic activity driven by solar wind turbulence

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Abstract. The solar wind - magnetosphere relationship has been widely studied in the presence of intense perturbations in the solar wind, causing geomagnetic storms and substorms, by means of the so-called coupling parameters. However, remarkable variations in the geomagnetic field occur even in absence of such perturbations. We suggest that, in those conditions, solar wind MHD turbulence might have a role. Recent results have shown that solar wind turbulence can be described as a mixture of inward and outward stochastic Alfvénic fluctuations, including also convected structures, dominated by an excess of magnetic energy. The present study focuses on the relationship between solar wind MHD turbulence and geomagnetic activity at high latitudes as measured by the AE index, for different phases of the solar cycle, and finds that at solar minimum Alfvénic turbulence drives the geomagnetic response.

Key words. Solar wind: turbulence – Solar wind: Alfvénic fluctuations – Magnetosphere: auroral activity

1. Introduction

Recent works suggested that MHD turbulence might play a key role in the nonlinear coupling between solar wind and Earth's magnetosphere. In fact, it is well-known that the solar wind is a turbulent plasma (Bruno & Carbone 2005). Moreover, evidences of scale-invariant dynamics and multifractal behaviour (Consolini et al. 1996) of the magnetosphere have been found in analyzing the impulsive character of the magnetotail dynamics in terms of the study of the auroral electrojet (AE) indices (Davis & Sugiura 1966) that are a rough estimate of the energy release by the magnetosphere into the ionosphere during the magnetospheric activity.

In the present paper, we focus on the role played by Alfvénic fluctuations and structures convected by the wind in the solar wind - magnetosphere coupled system considering the geomagnetic response as monitored by the AE indices.

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2. Solar wind MHD turbulence

Solar wind MHD turbulence has a strong Alfvénic character due to the fact that Alfvénic modes have a longer lifetime than other MHD modes. It must be noted that more Alfvénic periods are found at solar minimum as polar coronal holes, from which fast wind streams orig-

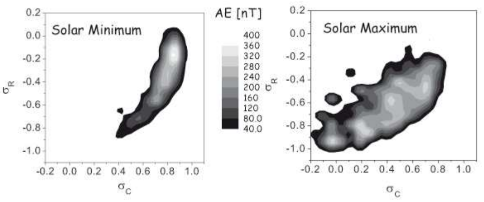

Fig. 1. Average AE values computed for every square bin $\Delta\sigma_C$-$\Delta\sigma_R$ at solar minimum (left) and maximum (right), adapted from D'Amicis et al. (2008).

inate, considerably widen up reaching low solar latitudes. This new configuration produces an alternation of fast and slow wind streams in the ecliptic plane, the plane where most of the spacecraft operate and record data. While approaching solar activity maximum, coronal holes are limited to small and not well defined regions around the poles, so that the presence of slow wind is predominant in the ecliptic.

In order to highlight the role of the Alfvénic fluctuations, Tu & Marsch (1995) introduced the following normalized parameters to characterize the state of turbulence: $\sigma_C = (e^+ - e^-)/(e^+ + e^-)$ and $\sigma_R = (e^v - e^b)/(e^v + e^b)$, the normalized cross-helicity and the normalized residual energy, respectively. In the previous equations, e^v and e^b are the kinetic and magnetic energy (per unit mass), respectively, while $e^\pm$ is the energy (per unit mass) associated to $z^\pm$ modes, where z^+ and z^- represent Alfvén modes propagating in opposite directions along the ambient magnetic field. In particular, σ_C indicates how much a mode (either inward or outward) is dominant with respect to the other, while σ_R measures the excess of kinetic energy on magnetic energy or viceversa according to the sign. For an ideal Alfvén wave, $\sigma_C = \pm 1$ (where +1 indicates fluctuations that propagate away from the Sun while -1 modes towards the Sun) and $\sigma_R = 0$ (condition indicating equipartition between kinetic and magnetic energy).

3. Alfvénic turbulence and auroral activity

To evaluate the role played by MHD turbulence in driving the auroral activity in the absence of large perturbations in the solar wind, D'Amicis et al. (2007, 2008) computed average values of AE in correspondence of every square bin $\Delta\sigma_C$–$\Delta\sigma_R$.

D'Amicis et al. (2007) (and references therein) found that both at solar minimum and maximum, σ_C–σ_R distributions indicate predominantly outward fluctuations ($\sigma_C > 0$) showing some magnetic excess ($\sigma_R < 0$). By averaging AE values for every bin σ_C–σ_R, the same authors found that at solar minimum, the AE peak is located in the Alfvénic region ($\sigma_C \simeq 1$ and $\sigma_R \simeq 0$). This result represents a clear evidence of the relationship between Alfvénic fluctuations and AE index activity, as shown in Fig. 1. On the contrary, at solar maximum, this correspondence is largely depleted since AE maximum value is not well defined, not being localized around particular σ_C and σ_R values.

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