

Solar wind density effect on the night-side geomagnetic activity (*AL* index)

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Abstract

The role of solar wind density in driving of geomagnetic activity is now again in the focus of attention of magnetospheric scientists. We analyze 20 years of hourly *AL* and OMNI solar wind data to reveal the basic solar wind flow influence on the magnitude of night-side geomagnetic activity and magnetotail dynamics. In such a data set trigger-related specifics of substorm onsets are averaged out. The more pronounced effects of the solar wind speed and interplanetary magnetic field on *AL* need to be eliminated before the analysis of the smaller density role. With an iterative method we determine the best formula, accounting for the velocity and magnetic field contribution: $E = V\sqrt{B_y^2/2 + B_z^2 \sin^4(\theta/2)} + \alpha V^2 \sin^{0.5}(\theta/2)$. Average *AL* proved to be not sensitive to density changes, when density was above $\sim 5 \text{ cm}^{-3}$, and average $|AL|$ dropped by $\sim 30\%$, when density decreased from 5 to 1 cm^{-3} .

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1. Introduction

Primary role of the interplanetary medium in generation of geomagnetic activity has been clearly established in the early years of space research. Among various forms of magnetospheric activity we will concentrate here on the magnetotail dynamics, revealing itself on the ground as the night-side auroral-zone geomagnetic variations (e.g., Baker et al., 1996). The Earth's magnetosphere is shaped by the solar wind hydrodynamic flow, but its internal dynamics is mainly controlled by the interplanetary electric field $E_y = VB_s$ (Dungey, 1961). Here B_s is southward component of interplanetary magnetic

field (IMF), V is solar wind speed (hereafter all vectors are in GSM frame of reference). IMF B_y and solar wind density are also considered as geoeffective, but less important interplanetary factors.

Recently the topic of solar wind density influence on substorms and magnetotail dynamics again appeared in the focus of interest of magnetospheric scientists. Case studies (e.g., Boudouridis et al., 2004) suggested that pressure jumps can modify magnetotail reconnection dynamics (substorm development), while several statistical investigations revealed increase of night-side auroral magnetic variations (Shue and Kamide, 2001) and auroral power (Shue et al., 2002) with increase of density, when IMF was southward. In a number of numerical modelling studies the positive correlation

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of ionospheric Joule heating and solar wind dynamic pressure was discovered (Palmroth et al., 2004; Lopez et al., 2004).

Since solar wind density values range almost two orders of magnitude, even a weak dependency on the density (if any) should be observable in a sufficiently large statistical material. The main difficulty in such an analysis is density and speed anticorrelation in the solar wind. Since solar wind speed is one of primary factors in geomagnetic driving, while density is of the lower importance, the speed dependence in the data set should be fully compensated before any density analysis can be done. In this paper, this task is performed with the iterative selection of the driving function.

2. The data set

Our investigation of the solar wind density effect on geomagnetic activity is based on hourly *AL* data and OMNI-2 solar wind data for years 1966–1974 and 1977–1988 (*AL* for 1975 and 1976 is missing). Only index samples with available simultaneous and two preceding solar wind and IMF measurements were considered (just over 80,000 samples, while the total number is 192,840 for 1966–1988). Preceding solar wind values proved to be necessary to account for the input history.

The *AL* index is the only routinely available global auroral night-side activity characteristic, suitable for a long-period statistical study. However, it is frequently argued, that localized magnetotail geomagnetic activity might be missed by a sparse set of *AE* stations. In particular, so called contracted-oval (weak) substorms, associated with low interplanetary electric field, occur on geomagnetic latitudes higher, than that of the *AE* stations (Petrukovich et al., 2000). Also, storm-time auroral oval shifts equatorward from *AE* stations. However, in the latter case magnitudes of magnetic variations are only (moderately) underestimated in *AL*, since the night-side activity encompasses a rather broad range of latitudes during substorm development (Kauristie et al., 1996).

Additional error in correlations might be introduced by the solar wind variability, resulting in differences between solar wind, measured at some distant spacecraft location, and actually hitting the Earth's magnetosphere. However, for moderately and strongly geoeffective solar wind inputs, these differences are rather low (Petrukovich et al., 2001; Petrukovich and Klimov, 2000).

Usage of the relatively coarse 1-h averages is optimal to concentrate on the energy aspects of the solar wind forcing. Auroral geomagnetic variations on a finer time scale are dominated by peculiarities of magnetospheric response such as substorm onsets, localized transient activations, solar wind and IMF triggering, etc., investigation of which is beyond the scope of this study. It is also important, that the OMNI data set covers several solar cycles and includes a wide variety of combinations of solar wind and IMF parameters.

A standard approach to analysis of solar wind geoeffectiveness is to determine a function, relating geomagnetic index value (output) to concurrent solar wind measurements (input). With linear filtering, artificial neural network or similar formalistic approach (Bargatze et al., 1985; Gleisner and Lundstedt, 1997), this function can be determined with a comprehensive mathematical optimization algorithm as a rather formal (polynomial, matrix operator, etc.) combination of individual input parameters.

The alternative method is to approximate an index with a simple combination of solar wind and IMF characteristics (driving or coupling function), based on some physical arguments. VB_s is the simplest driving function. Among other suggested expressions are, e.g., V^2B_s and $\varepsilon \sim VB^2 \sin^4 \theta/2$ (θ is the IMF clock angle $\tan(\theta) = B_y/B_z$) (Perreault and Akasofu, 1978). Moderate solar wind density or dynamic pressure effect was sometimes included in the driving function as $\sim(NV^2)^{-1/3}$, $\sim(NV^2)^{1/2}$, $\sim(NV^2)^{1/6}$ (review of Gonzalez et al., 1994).

Since solar wind density is usually assumed to be less important solar wind driver, than the primary B_z and V , it is important first to determine B_z and V input in *AL*. Otherwise, density dependence of *AL* might be dominated by the latent influence on, e.g., speed: for density $> 20 \text{ cm}^{-3}$ mean solar wind speed was 390 km/s, while for densities $< 1.5 \text{ cm}^{-3}$ – 520 km/s.

In the previous investigations usually only general quality of a driving function was tested as a correlation coefficient between input and output. We used the alternative iterative method of driving function selection (Petrukovich and Rusanov, 2005). The algorithm is easy to understand, considering the first example (Fig. 1).

3. Primary driver determination

Fig. 1a presents average *AL* for logarithmically spaced bins of the driving function $E = VB_s$ values

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