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Study of the solar wind-magnetosphere coupling on different time scales

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ABSTRACT

Solar wind-magnetosphere coupling, its causes and consequences have been studied for the last several decades. However, the assessment of continuously changing behaviour of the sun, plasma and field flows in the interplanetary space and their influence on geomagnetic activity is still a subject of intense research. Search for the best possible coupling function is also important for space weather prediction. We utilise four geomagnetic indices (*ap*, *aa*, *AE* and *Dst*) as parameters of geomagnetic activity level in the earth's magnetosphere. In addition to these indices, we utilise various solar wind plasma and field parameters for the corresponding periods. We analyse the geomagnetic activity and plasma/field parameters at yearly, half-yearly, 27-day, daily, 3-hourly, and hourly time resolutions. Regression analysis using geomagnetic and solar wind data of different time resolutions, over a continuous long period, and at different phases of solar activity (increasing including maximum/decreasing including minimum) led us to suggest that two parameters $BV/1000$ (mV m^{-1}) and BV^2 (mV s^{-1}) are highly correlated with the all four geomagnetic activity indices not only at any particular time scale but at different time scales. It probably suggests for some role of the fluctuations/variations in interplanetary electric potential, its spacial variation [i.e., interplanetary electric field BV (mV m^{-1})] and/or time variation [BV^2 (mV s^{-1})], in influencing the reconnection rate.

1. Introduction

In the area of solar-terrestrial physics, one of the key problems is to investigate the mechanism of energy transfer from the solar wind into the magnetosphere. Another related key issue is to investigate the mechanism that excites magnetic disturbances in the geo-magnetosphere. It is generally believed that the basic parameter leading to geomagnetic disturbances is the southward component of the interplanetary magnetic field ($-B_z$) and/or the duskward component of the interplanetary electric field $E_y = -V \times B_z$ (see, e.g., Dungey, 1961; Rostoker and Fälthammar, 1967; Burton et al., 1975; Akasofu, 1981; Badruddin, 1998; Echer et al., 2005; Gopalswamy et al., 2008; Badruddin and Singh, 2009; Alves et al., 2011; Guo et al., 2011; Singh and Badruddin, 2012; Yermolaev et al., 2012 and references therein). With negative B_z, reconnection occurs at the daytime magnetopause between the Earth's magnetic field and southward B_z component of the interplanetary magnetic field (Kane, 2010). The principal manifestation of geomagnetic storms, measured by the index *Dst*, is the increase of ring current intensity, which depends upon the reconnection rate.

Origin of the intense southward magnetic fields are the interplanetary shock/sheath region, coronal mass ejections/magnetic clouds, stream interaction regions etc. (e.g., Lepping et al., 1991; Märcz, 1992; Tsurutani and Gonzalez, 1997; Richardson et al., 2000; Webb et al., 2000; Kudela and Storini, 2005; Kim et al., 2005; Gopalswamy et al., 2007; Singh and Badruddin, 2007; Zhang et al., 2007; Gupta and Badruddin, 2009; Yermolaev et al., 2010; Alves et al., 2011; Mustajab and Badruddin, 2011; Richardson and Cane, 2011; Kudela, 2013) and arrival of these structures leads to changes/fluctuations in various interplanetary plasma and field parameters.

In spite of the success of the so called Dungey mechanism (Arnoldy, 1971; Burton et al., 1975; Holzer and Slavin, 1979; Alves et al., 2011) some effort (e.g., Baker et al., 1981; Clauer et al., 1981; Holzer and Slavin, 1982; Murayama, 1982; Zhang and Burlaga, 1988; Papitashvili et al., 2000; Sabbah, 2000; Gupta and Badruddin, 2009; Dwivedi et al., 2009; Joshi et al., 2011) has gone into looking for other parameters that might correlate better with geomagnetic activity.

Geomagnetic activity being influenced by total interplanetary electric field (Papitashvili et al., 2000; Sabbah, 2000), irregularities in the solar wind and interplanetary magnetic field (Dessler and Fejer, 1963; Garrett et al., 1974; Crooker et al., 1977; Kershengolts et al., 2007), and enhanced dynamic pressure (Murayama, 1982; Srivastava and Venkatakrishnan, 2002; Boudouridis et al., 2005;

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Xie et al., 2008; Ontiveros and Gonzalez-Esparza, 2010; Singh and Badruddin, 2012) have been suggested. However, a unique relationship is still lacking which may ultimately lead to understand the intensity of geomagnetic disturbances.

Most of the earlier efforts to search for better coupling functions, in general used one geomagnetic index or the other, at one time resolution or the other. Further, earlier studies were mainly focused over the durations of moderate to strong geomagnetic disturbances. To the best of our knowledge, none of the previous correlative studies were done over extended periods of several solar cycles using different geomagnetic activity and solar wind parameters at multiple time resolutions. In this work we analyse the continuous data for long periods (~40 years), that contain quiet, weak, moderate as well as strong geomagnetic activity periods. In this paper, we present the results of the analysis using interplanetary plasma and field data and their various derivatives together with various geomagnetic indices of different time resolutions; yearly, half-yearly, 27-day, daily, 3-hourly and hourly resolutions.

2. Results and discussion

In Fig. 1, we have plotted the time variation of 27-day average solar, geomagnetic and interplanetary parameters (http://omniweb.gsfc.nasa.gov) for more than three solar cycles (1970–2011). The parameters plotted in this figure are; sunspot number (SSN)—a solar activity parameter; *ap* index—a parameter of geomagnetic activity; interplanetary plasma and field parameters—solar wind velocity V (km s^{-1}), interplanetary magnetic field B (nT), its north-south component B_z (nT), duskward electric field E_y (mV m^{-1}), 'spacial variation of interplanetary electric potential' i.e., the interplanetary electric field $BV.10^{-3}$ (mV m^{-1}), and two more derivatives that may be referred as 'time variation of the duskward electric potential' B_zV^2 (mV s^{-1}), and the 'time variation of total interplanetary electric potential' BV^2 (mV s^{-1}); although suitability of these latter nomenclatures need to be confirmed. From Fig. 1 alone, it is difficult to infer about interplanetary plasma/field parameter whose time variation best matches with time variation in geomagnetic activity level, it looks, however, as if the time variation of BV^2 is relatively better related to *ap* variations at this (27-day average) time resolution.

In order to understand the response of magnetosphere to varying interplanetary conditions, attempts have been made in the past to search for the parameter(s) that can best explain the occurrence of geomagnetic disturbances, but, efforts are needed to find a relationship that may ultimately lead to unambiguously understand the solar wind-magnetosphere coupling and disturbances in the geo-magnetosphere.

As solar polarity reverses at/near each solar activity maximum, we have divided a complete solar cycle into two parts; (i) increasing including maximum and (ii) decreasing including minimum phases. This division is aimed to look for, if any, the large-scale interplanetary magnetic field (IMF) polarity dependent effects of solar plasma/field parameters on the geomagnetic activity. It is to be mentioned here that large scale IMF–polarity is positive (outward above the heliospheric current sheet and inward below the heliospheric current sheet) during decreasing including minimum phases and negative (inward above the heliospheric current sheet and outward below the heliospheric current sheet) during increasing including maximum phases of even solar cycles (e.g., solar cycles 20 and 22), opposite will be the polarity during similar phases of odd solar cycles (e.g., solar cycles 21 and 23).

We have adopted two approaches, (a) best-fit approach and (b) correlative analysis approach. First, we did the polynomial

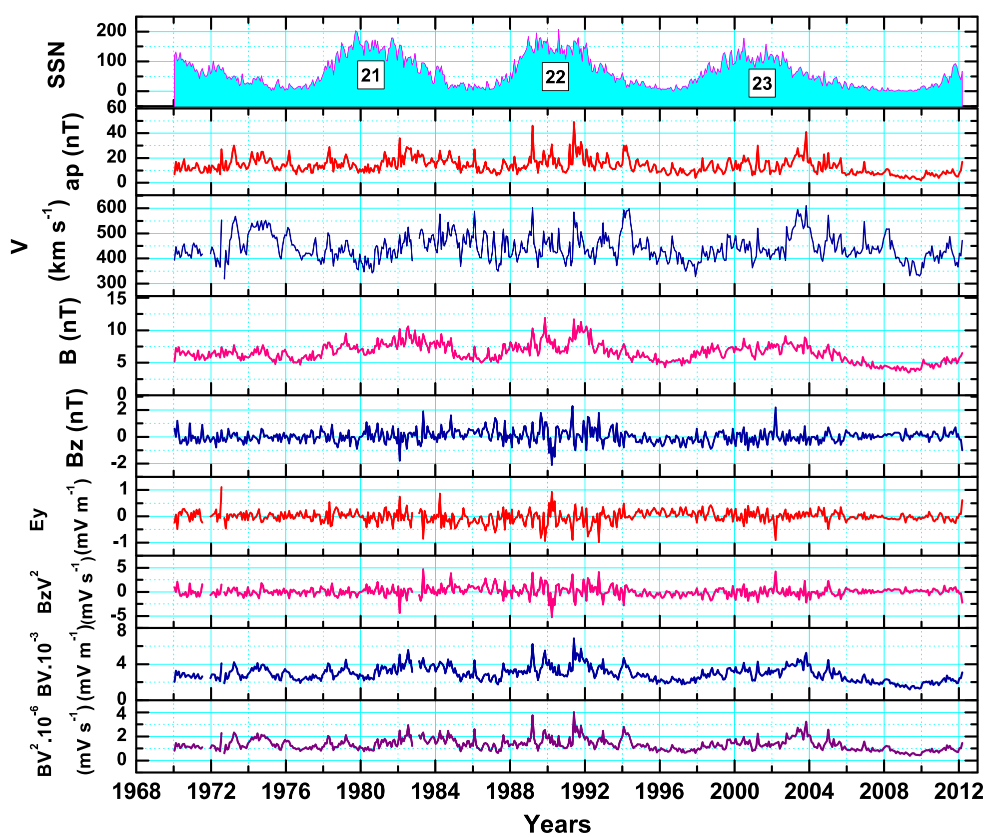

Fig. 1. Time variation of 27-day average solar (SSN), geomagnetic (*ap*), interplanetary plasma/field parameters V (km s^{-1}), B (nT), B_z (nT), E_y (mV m^{-1}), BV (mV m^{-1}), B_zV^2 (mV s^{-1}) and BV^2 (mV s^{-1}).