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Substorm activity during the main phase of magnetic storms induced by the CIR and ICME events

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Abstract

In this work, the relation of high-latitude indices of geomagnetic activity (AE, Kp) with the rate of storm development and a solar wind electric field during the main phase of magnetic storm induced by the CIR and ICME events is investigated. 72 magnetic storms induced by CIR and ICME events have been selected. It is shown that for the CIR and ICME events the increase of average value of the Kp index (Kp_{aver}) is observed with the growth of rate of storm development. The value of Kp_{aver} index correlates with the magnitude of minimum value of Dst index ($|Dst_{min}|$) only for the ICME events. The analysis of average values of AE and Kp indices during the main phase of magnetic storm depending on the SW electric field has shown that for the CIR events, unlike the ICME events, the value of AE_{aver} increases with the growth of average value of the electric field (Esw_{aver}). The value of Kp_{aver} correlates with the Esw_{aver} only for the ICME events. The relation between geomagnetic indices and the maximum value of SW electric field (Esw_{max}) is weak. However, for the ICME events Kp_{aver} correlates with Esw_{max}.

Keywords: Magnetic storm; Substorm; Solar wind; Electric field; Geomagnetic indices; Interplanetary magnetic field

1. Introduction

It is known that during periods of a prolonged southward Bz component of the interplanetary magnetic field (IMF) in the Earth's magnetosphere together with substorm disturbances there occur magnetic storms. The special attention is given to investigations of intense substorm disturbances during the main phase of magnetic storm, when the effects of interaction of the solar wind (SW) and the Earth's magnetosphere are most strongly manifested. The southward IMF Bz is main geoeffective parameter of SW, whose efficiency is connected with the influence of SW electric field ($Esw = V \times Bz$) (Burton et al., 1975; Gonzalez et al., 1994; Kane, 2005). To estimate a substorm activity a high-latitude AE index is used (Davis and Sugiura, 1966).

In early researches Akasofu and Chapman (1961) and McIlwain (1974) believed that the sequence of intense substorm disturbances leads to development of a magnetic storm. According to the opinion of supporters of this hypothesis, during a substorm there occurs an injection of energetic particles from a magnetosphere's tail into a ring current. Amplification of the ring current causes a decrease of the Earth's magnetic field, and, correspondingly, a decrease of Dst index. The first doubts in a correctness of this hypothesis appeared after paper by Burton et al. (1975) in which it was shown that the decrease of Dst index is obviously connected with the southward IMF Bz. The time of response of Dst to the southward IMF Bz is much less than a characteristic time of development of a substorm. Further, it was proved in works (Iyemori, 1994; Iyemori and Rao, 1996; Tsurutani et al.,

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2004). Thus, the mentioned results allow to make a conclusion that the magnetic storm and substorm are processes which are not connected between each other having a common reason of occurrence of the southward IMF Bz i.e. the SW electric field. Therefore, during the periods of magnetic storm the high-latitude (AE) and low-latitude (Dst) indices defining the intensity of the auroral zone current and ring current, correlate between each other. However, the relation of these indices has a more complex character. Observed variations/fluctuations of AE, Dst indices are related to changes of SW/IMF and also to a complex and nonlinear dynamics of the Earth's magnetosphere (Consolini and De Michelis, 2011; De Michelis et al., 2015; Alberti et al., 2017). In the paper by Alberti et al. (2017) it was shown that the magnetospheric short-timescale fluctuations ($\tau < 200$ min) seem to be not directly related to the same timescale fluctuations in the SW/IMF. This indicates that internal processes strongly affect the magnetospheric response at timescales lower than 200 min. On the contrary, the SW/IMF fluctuations at long timescales ($\tau > 200$ min) play a primary role into the variations of geomagnetic indices. Thus, the Earth's magnetosphere response consists of both external and internal processes.

The results of statistical and morphological investigations show that the intensity of magnetospheric-ionospheric disturbances (magnetic storms and substorms) also depends on a type of SW (see, for example, papers by Gonzalez et al. (1999), Plotnikov and Barkova (2007), Yermolaev et al. (2010) and references therein)). There exist the following types of SW: interplanetary manifestations of coronal mass ejections (ICME) including magnetic clouds (MC) and Ejecta, corotating interaction regions (CIR), and sheath regions before ICMEs. The analysis between SW parameters for different types of currents and indices of geomagnetic activity has shown (Plotnikov and Barkova, 2007; Yermolaev et al, 2010; Guo et al, 2011; Yermolaev et al, 2012; Cramer et al, 2013) that during magnetic storms the magnitude of minimum value of Dst index increases with the growth of SW electric field for all types of SW but for events of ICME (MC + Ejecta) the value of $|Dst_{min}|$ will not increase at high values of Esw. The nonlinear dependence of AE (Kp) index on Esw is observed only in the events of MC (Plotnikov and Barkova, 2007; Yermolaev et al, 2012).

It should be noted that the Dst index variation is defined by the intensity of not only a ring current, but also a current on the magnetopause, current systems of a magnetosphere tail part and high-latitude magnetospheric-ionospheric currents (Feldstein et al., 2005). Using the high-latitude geomagnetic index (AE) one can consider the contribution of magnetospheric-ionospheric current systems into the Dst variation. However, because of different temporal scales of the development of substorm and storm disturbances, the high-latitude index give the approximate representation about a role of magnetospheric-ionospheric current systems in a magnetic storm. Besides, during the magnetic storms both the intensity of auroral currents and their shift to the low latitudes as a result of expanding of the auroral oval during the magnetic storms, define the value of AE index. Therefore, it is also necessary to consider a mid-latitude Kp index, besides the AE index. A joint analysis of AE and Kp indices allow one to understand a picture of development of the substorm disturbances during periods of a magnetic storm more precisely.

The purpose of this work is to investigate the relationship between the substorm activity and variation of Dst index during the main phase of magnetic storm, and also their dependence on the electric field (Esw) for various types of the SW.

2. Experimental data and results

In order to analyze a substorm activity at midlatitudes during the main phase of magnetic storm we use the events that have been considered in paper by Boroyev (2016). In the work a moderate and a strong magnetic storms have been considered (72 events). 72 magnetic storms were induced by CIR and ICME (ICMEs without sheaths) events. The procedure of identification of solar wind types and their relation to storms was carried out in the paper by Yermolaev et al. (2009). Because of different temporal scales of development of the substorm and storm disturbances, the rate of storm development during the main phase ($|\Delta Dst|/\Delta T$), average values of the AE ($\Sigma AE/\Delta T$) index during the main phase (where ΣAE are summary values of the AE index during the main phase of magnetic storm) for each event have been calculated in the paper by Boroyev (2016). The duration of main phase (ΔT) have been determined as the temporal interval from the moment of sharp decrease of the Dst index (Dst_0) up to the minimum value of Dst (Dst_{min}). The value of $|\Delta Dst|$ has been calculated using the following formula: $|\Delta Dst| = |Dst_{min} - Dst_0|$.

To estimate a substorm activity in the present work the mid-latitude (Kp) index has been considered. The average values of Kp ($\Sigma Kp/\Delta T$) index during the main phase (where ΣKp are summary values of Kp index during the main phase of magnetic storm) for each event have been calculated. The values of Kp index of geomagnetic activity have been taken from the following website: http://swdcwww.kugi.kyoto-u.ac.jp/index.html. To take into account the SW parameters by hourly average data (http://www.omniweb.com/) the maximum value of SW electric field has been determined, as well as the average value of SW electric field during the main phase of magnetic storm has been calculated.

In the paper by Boroyev (2016) the relationship of the rate of storm development to the average value of AE index ($\Sigma AE/\Delta T$) during the main phase has been investigated. In the present work, using the experimental data set (Boroyev, 2016) the analysis of substorm activity with the account of mid-latitude index (Kp) has been carried out.