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MANIFESTATION OF INTERPLANETARY SHOCK IN GEOMAGNETIC STORMS AND SUBSTORMS

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Abstract. The influence of interplanetary shocks accompanied or not with coronal mass ejections (CME) on geomagnetic storms and substorms generation was investigated. For this aim we have analyzed the data of solar wind parameters and geomagnetic activity (Dst and AE indexes). It was shown that the CME presence after the shock plays a crucial role for the generation of Dst decreasing, i.e. for the geomagnetic storm. While for the substorm disturbances (enhances of AE index) it is important the internal state of the magnetosphere after the shock impact.

1. Introduction

Passage of interplanetary shocks (ISh) is one of the main reasons for the geomagnetic storm generation. This have been noted in a number of papers [*Badruddin*, 1998; *Cho et al.*, 2003; *Manoharan et al.*, 2004; *Wu and Lepping*, 2008]. Owing to [*Echer and Gonzalez*, 2004; *Xu et al.*, 2009] by response in moderate and intense storms (Dst < -50 нТ) geoeffectiveness only about 50% of the ISh. Magnetic clouds have an important role in the magnetic storm generation, and 81% geoeffective ISh associated with interplanetary mass ejections (ICME). In paper [*Yermolaev and Yermolaev*, 2003] there was analyzed 464 geomagnetic storms and it was shown, that the most geoeffective solar wind structures are magnetic clouds (MC) (~61%), three times less geoeffective (~ 20-21%) are events of corotating interplanetary regions (CIR) and Ejecta with Sheath and the least geoeffective (~ 8%) are events of Ejecta without Sheath. Response to the passage of ISh in substorm disturbances was considered in papers [*Zhou and Tsurutani*, 2001; *Hong et al.*, 2001; *Meurant et al.*, 2005; *Nikolaeva et al.*, 2011]. It was noted that ISh and associated solar wind dynamic pressure increases and ICME lead to compression of the magnetosphere and can trigger a substorm. Thus, it is important the presence of negative IMF Bz [*Solovyev et al.*, 2006].

The purpose of this work is to evaluate the effectiveness of ISh by Dst index decreases (geomagnetic storms) and substorm disturbances (AE index increases) depending on the ICME presence.

2. Data analysis

Data on ISh were obtained from the Internet, the data ACE list (*http://www.ssg.sr.unh.edu/mag/ace/ACElists/obs_list.html*), data on CME from the catalog of the paper [*Richardson and Cane*, 2010] (*http://www.srl.caltech.edu/ACE/ASC/DATA/level3/icmetable2.htm*), sudden storm commencements SSC – from bulletin IAGA Bull, (*ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SUDDEN_COMMENCEMENTS/*), geomagnetic indices Dst and AE from *http://wdc.kugi.kyoto-u.ac.jp/*.

The analysis of these data on the growth phase of the 23rd solar cycle was fulfilled. The minimum of the cycle was observed in 1996 (average annual number of sunspots W=8,6), maximum was in 2000 (W=119,6). In the analyzed time period from September 1997 to December 1999 according to the using catalogs has been registered 80 ISh, 27 ICME, 60 geomagnetic storms, 26 of them were sporadic and 34 recurrent. Time of the geomagnetic storm beginning was determined by main phase of the storm – a sharp decrease of Dst-index on more than 30 nT (weak storms), more then 60 nT (moderate storms) and more then 100 nT (intense storms). As a beginning of the substorm was taken an hour, when the AE index increased more than 200 nT duration more 10 hours. For the analyze we selected isolated events with the absence of repeated disturbances for 1 day. As a result, there were formed three groups of the events:

1. There was ICME behind the ISh and geomagnetic storm was observed on the Earth – (Shock + CME + Dst) = 17 events, including 9 intense, 5 – moderate, 3 – weak storms
2. There was no ICME behind the ISh and geomagnetic storm was observed on the Earth – (Shock – CME + Dst) = 27 events, including 7 intense, 5 – moderate, 15 – weak storms.
3. There was no ICME behind the ISh and no geomagnetic storm on the Earth – (Shock – CME – Dst) = 20 events.

3. Discussions

In all groups the passage of ISh was accompanied by intensification of substorm activity (AE index increasing) and in the most cases there were SSCs. The absence of SSC were in 3 cases from 17 for the 1st group, in 7 cases from 27 for the 2nd group, in 8 cases from 20 for the 3rd group.

For the events (Shock + CME + Dst) a number of intense of storms dominated (9 – intense, 5 – moderate, 3 – weak), but for the events without ICME (Shock – CME + Dst) more often were weak storms (7 – intense, 5 – moderate, 15 – weak). Average amplitude of the storm for the 1st group of the events was 100 nT, for the 2nd group – 74 nT.

Average duration of substorm disturbances was 21.8 hours for the 1st group (Shock + CME + Dst), 15,4 hours for the 2nd group (Shock – CME + Dst) and 13,6 hours for the 3rd group (Shock – CME – Dst). The duration of the intervals between the registration time of ISh, SSC, the beginning of ICME, Dst decreasing and AE increasing are shown in the table.

Table

Group	Number of the events	CME	SSC		Dst		AE	
		Shock	Shock	Dst	Shock	CME	Shock	CME
Shock + CME + Dst	17	7,1	0,6	-2,5	3,2	-3,9	1,4	-5,7
Shock – CME + Dst	27	-	0,1	-3,4	1,9	-	1,3	-
Shock – CME – Dst	20	-	0,6	-	-	-	-3,4	

As one can see from the table, on the average CME was delayed relative to ISh on 7,1 hours, SSC was observed during an hour after ISh registration and before 2-3 hours the storm decreasing. A storm on the average began after 2-3 hours ISh and ahead the start of CME registration quiet 4 hours. Substorm (AE index) began an hour or two after the ISh when the storm was observed. Growth of AE index began 3,4 hours before the ISh and 5,7 hours before ICME when storm disturbances were absent.

For illustration, Fig. 1 shows the curves of Dst and AE indices together with the solar wind parameters for three particular events of the selected groups for 5 days starting from the day preceding the registration of ISh. For comparison we selected moderate storms with amplitude of Dst index decreasing 64 and 52 nT. The red line marks time of registration of ISh.

Fig. 1a: (Shock + CME + Dst), 12-16 June 1998: ISh was registered June 13 at 18:56, SSC at 20 hour, CME began June, 14 at 05 hours, storm Dst decrease began June 14 at 04 hour, substorm AE increase began June 13 at 24 hour.

Fig. 1b: (Shock – CME + Dst), 22-26 April 1998: ISh was registered April 23 at 17:28, SSC at 19 hour, CME absent, storm Dst decrease began April 23 at 23 hour, substorm AE increase began April 23 at 20 hour.

Fig. 1c: (Shock – CME – Dst), 01-05 July 1999: ISh was registered July 02 at 00:30, SSC at 01 hour, CME and Dst decrease absent, substorm AE increase began July 02 at 06 hour.

In all three cases this time coincides with the start of increasing of module IMF, proton density and the leading edge of the solar wind velocity. Module IMF increased in all three events but in 3rd group (Fig. 1c) it keeps the increased value only 1,5 days whereas in the 1st and 2nd groups – more than 2 days. The behavior of Bz component is similar in the first two events too: behind the shock front Bz smoothly changes direction from north to south, which is typical of magnetic clouds. In the event from 3rd group Bz changes its direction from (+) to (-) 4 times: before the ISh and three times after, i.e. changes are more chaotic. The vector IMF variability increases right behind the ISh in all three events, but in the 1st group, the change is much smaller and shorter. Those. in the events of the 2nd and 3rd groups IMF is more turbulent than the 1st group.

The increase in proton density is different for the events: for the event from 1st group Np increases to 20 cm^{-3}, held extended almost a day and then increases again during a day to more than 10 cm^{-3}. For the event of the 2nd group there is short, about 8 hours a splash of Np to value about 50 cm^{-3}. For the event of the 3rd group Np slowly increased to 8 cm^{-3} during a day and than slowly falls. Speed has a sharp front edge with a jump of more than 50 km/s for the events of 1st and 3rd groups and increased to 150 km/sec during 8 hours (as density burst interval) for 2nd group. Velocity is kept increased during three days after the ISh for the events of the 1st and 2nd groups, and decreases monotonically day later the ISh for the event of the 3rd group.

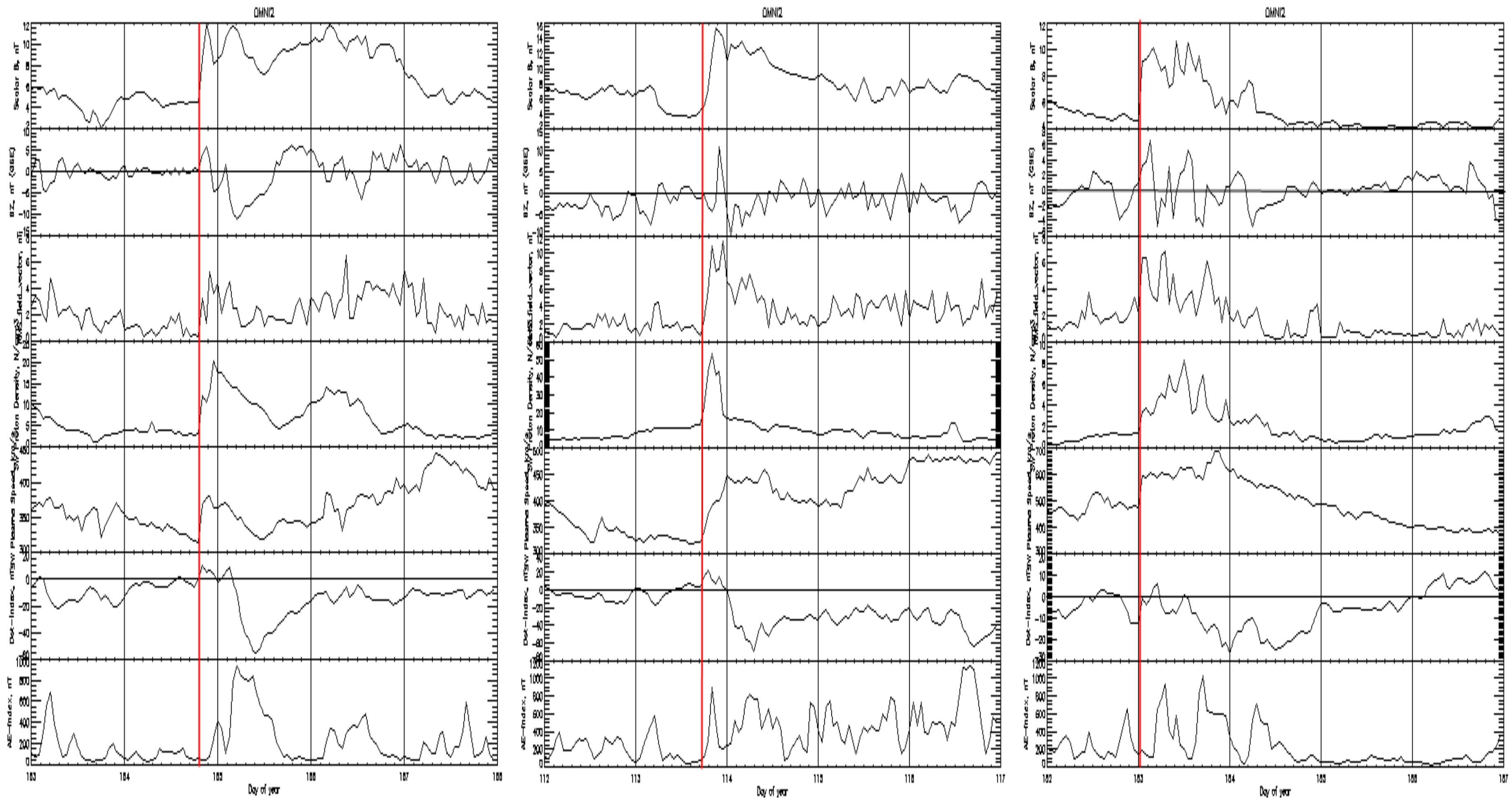
Changes of Dst index is typical storm-time decrease and slow recovery phase for the events of the 1st and 2nd groups, and small nonstorm Dst decrease ~ 20 nT for the 3rd one. AE index substorm changes are also different: for the event of the 1st group, there are three substorms: the first one lasts about a day immediately after the ISh, and there are two small substorm enhances on the 2nd and 3rd days, during the magnetic storm recovery phase. For the event of 2nd group substorm disturbance begins after the ISh and lasts during all observation period, with a slight weakening and strengthening. For the event of 3rd group there were 4 short substorm intensifications – for 6 hours before the ISh and three times after the passage of the ISh.

Thereby:

1. it was confirmed that SSC is related to the passage of ISh;

2 for the geomagnetic storm generation it is not necessarily the presence of the ICME behind the ISh;

3. in the presence of ICME behind the ISh the probability of the observation of high-intensity storm increases, but in the absence of ICME the weak storms are observed more often. That is, for the generation of geomagnetic storms it is very important the configuration of the interplanetary magnetic field, the presence of southward Bz component of the IMF in the magnetic cloud behind ISh;



a) Shock + CME + Dst **b)** Shock – CME + Dst **c)** Shock – CME – Dst

Figure 1. Solar wind parameters (top to bottom – module B and Bz component of IMF, variability σBv of IMF vector, proton density Np and solar wind speed V) and geomagnetic indices Dst and AE. For the illustration there were selected one event of every three group.
a) June 12-16, 1998, (163-167 days). Shock June 13 at 18:56;
b) April 21-25, 1998 (112-116 days). Shock April 22 at 17:28;
c) July 01-05, 1999 (182-186 days). Shock July 02 at 00:30.

4. growth of substorm activity owing to the ISh passage in the absence of storm disturbances and substorm beginning before the ISh registration at the Earth orbit can be explained by assuming [*Shadrina and Starodubtsev*, 1998] that the cause of substorm activity is the MHD turbulence which is generated in front of the ISh due to the acceleration of energetic particles (Ep ~ 1 MeV) on the front of quasi-parallel ISh. This turbulence by means of magnetic reconnection can penetrate into the magnetosphere and actuate the relevant intermagnetospheric processes.

4. Conclusions

The analysis of the solar wind parameters, IMF and geomagnetic Dst and AE indices during solar activity growth phase of the 23rd solar cycle, from September 1997 to December 1999 was fulfilled. On the basis of performed study of 80 ISh, 27 ICMEs and, 60 geomagnetic storms it was found that passage of interplanetary shock:

1. in 70% generates the geomagnetic storms, both in the presence of ICME and in their absence. In the first case more intense storms are observed;
2. in more than 80% accompanied by the registration of SSC;
3. almost always causes substorm disturbances. Mostly, the substorm increasing of AE index starts with the beginning of the main phase of the storm, but in the absence of the storm they often start before the shock arrival. This apparently means that their cause is intermagnetospheric processes that are started before the arrival of ISh at Earth orbit. Perhaps these processes are generated by turbulent region ahead of the shock front.

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