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LARGE-SCALE STUCTURE OF SOLAR WIND AND APPEARANCE OF SUPERSUBSTORMS

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Abstract. It is carried out the comparative analysis of the space weather conditions for supersubstorms (SSS) appearance. For this purpose, the data of SuperMAG global magnetometers network and the data of IMAGE magnetometers network were used. SSS events, the so-called supersubstorms, are particularly intense substorms (SML< - 2500 nT; AL < -2500 nT). The solar wind and IMF parameters were taken from the OMNI database and the catalog of large-scale solar wind types (*ftp://ftp.iki.rssi.ru/omni/*). Total 131 SSS events were registered for 1998-2016 years at SuperMAG network and 26 SSS events at IMAGE network. It is shown that the SSS substorms were observed mainly during the magnetic cloud (MC) of the solar wind (in 42% of cases) and during plasma compression region before MC or EJECTA (SHEATH) (in 45.2% of cases). Sometimes SSS events were registered during EJECTA (in 8.3% of cases) and during plasma compression region before high-speed streams CIR (in 2.5% of cases). Thus, it is seen that the SSS events were associated only with interplanetary displays of the coronal mass ejections (Sheaths, magnetic clouds and EJECTA) and almost did not observed during high speed streams from coronal holes (FAST). Perhaps, this is happened due to the fact that SSS can occur during super (Dst<-250 nT) and intense (-100 nT> Dst> -250 nT) magnetic storms. On the other hand, it is well known that these storms are usually caused by southward interplanetary magnetic field component Bs during MCs or Sheaths. However, sometimes SSS events were registered during intervals with Dst >-50 nT (in 13.4% of cases). But there are mainly events during storm onset (10.8%) and recovery phase (1.2%) and only two SSS events were registered during non-storm conditions (1.2%). We believe that the most likely space weather conditions for the SSS appearance are associated with enhanced values of the solar wind speed and dynamic pressure, as well as the magnitude of the Interplanetary Magnetic Field (IMF) under the southward direction of the IMF.

Introduction

Subjects of this work are very intense magnetic substorms, the so-called supersubstorms (SSS). The term "supersubstorms" was used by *Tsurutani et al*. [1] to determination of very strong magnetic substorms which were observed by the ground-based observations on the SuperMAG magnetometer network (*http://supermag.jhuapl.edu/*). Supersubstorms (SSS) were called very intense substorms with large values of the SML- or AL–indexes of geomagnetic activity (<- 2500 nT).

Noted, that at the present time the phenomenon of supersubstorms are not explicitly investigated. As far as we know, SSS have been discussed in only a few works [1-3], where only questions about the possible appearance of such intense substorms were considered. In paper [3] the connection of SSS with the polar cap potential and PC-index was investigated. It was shown also that SSS can be observed in any phases of the solar cycle, but the greatest frequency of their occurrence was observed in the phase of the solar cycle decline, while the smallest frequency their appearance was during the solar cycle minimum [2]. According to [1] supersubstorms events are recorded by the long-term southward direction of the interplanetary magnetic field, which is usually associated with magnetic clouds in the solar wind (MC) (46%) or with the region of compressed plasma before the magnetic cloud (SHEATH) (54%). In addition, most of SSS events (77%) were associated with density jumps and pressure pulses in the solar wind.

However, it remains unclear whether SSS always appears during the magnetic clouds or SHEATH regions? Have there been instances of SSS appearance during the other types of the solar wind? The aim of this work is to investigate the relationship between the SSS appearance and the different types of the solar wind, which cover all major types of large-scale solar wind structure.

We will analyze the appearance of SSS depending on the solar wind types during the period from 1998 to 2016, that is, during the 23rd and 24th cycles of solar activity.

Data

We combined the data of the ground-based SuperMAG and IMAGE magnetometer networks, OMNI data base for the interplanetary medium parameters and the solar wind types catalog (*ftp://ftp.iki.rssi.ru/omni/*).

For the analysis we used 6 different types of the solar wind (according to [4]): 1) fast (FAST) streams from coronal holes; 2) slow (SLOW) streams from a belt streamer; 3) magnetic clouds (MC); 4) EJECTA, associated with the manifestations of coronal mass ejections; 5) the plasma compression region at the front of the high speed stream - CIR (before the FAST stream); 6) SHEATH (at the front of the magnetic cloud or EJECTA).

To study the supersubstorms appearance, we used the magnetic data of the SuperMAG (*http://supermag.jhuapl.edu/*) and IMAGE (*http://space.fmi.fi/image/*) magnetometers networks. The SuperMAG network consists of more than 300 magnetometers, detailed descriptions of the SuperMAG project are given in [5-7]. In the present study, supersubstorms were determined from the values of SML and AL indices of geomagnetic activity (<- 2500 nT). During the period 1998-2016, 157 SSS events were found, 131 of them were registered at the SuperMAG magnetometer network and 26 cases were observed at the IMAGE network. Fig. 1 shows an example of the SSS observation by SML- and AL- indexes.

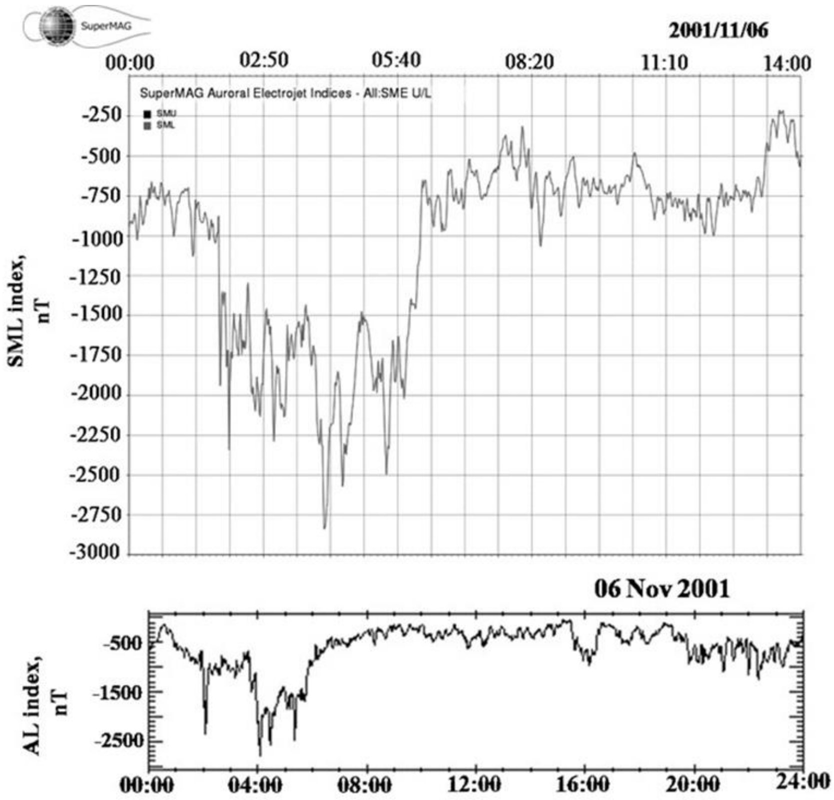

Figure 1. The example of SSS on 06 November 2001 by SML- and AL- indexes.

Results

We compared the supersubstorms (SSS) appearance with the simultaneous observations of the solar wind types. Table 1 shows the number of supersubstorms, which were observed during each type of the solar wind.

It can be seen that supersubstorms were mainly observed during magnetic clouds of the solar wind (MC, 42%), and also during regions of compressed plasma - SHEATH- before magnetic clouds or EJECTA (SHEATH, 45.2%). In addition, sometimes SSS appeared during the manifestations of the interplanetary mass ejections - EJECTA (~ 13%). And very rarely, SSSs can appear during the compressed plasma region before the high speed stream (CIR, 2.5%) or during this high speed steam itself (FAST, 1.7%). Thus, it is seen that the appearance of the SSS is associated with interplanetary manifestations of the coronal mass ejections (SHEATH, MC and EJECTA) and is in fact not associated with high-speed streams from coronal holes.

Type of the solar wind	Number of Supersubstorms (SSS)	Number of solar wind types	Total, %
SHEATH	71	35	45.2
MC	66	27	42.04
EJECTA	13	9	8.3
CIR	4	3	2.55
FAST	3	3	1.91

Table 1. The number of SSS and percentages of the SSS total number for each solar wind type.

We considered the geomagnetic conditions under which supersubstorms were observed. All 157 cases of SSS were divided into two large groups: 1) the cases which were observed during storms (Dst <-50 nT); 2) the cases which were observed in non-storm conditions (Dst> -50 nT). Then non-storm conditions can be conditionally divided into 3 groups: 1) a storm onset (Storm Sudden Commencement - SSC); 2) late recovery phase of the storm; 3) in the absence of a storm. The distribution of SSS cases, depending on the storm and non-storm conditions, is shown in Table 2.

It can be seen that, mainly, supersubstorms were observed during magnetic storms. There are 136 cases, what is 86.6% of their total number. Only 21 cases of SSS were registered in non-storm conditions, what is 13.4% of their total number. However, as can be seen from the Table 2, non-storm conditions mean, most often, the sudden onset of a magnetic storm (SSC). 17 cases from 21 non-storm SSS events were observed during SSC, which is about ~ 11% of the total number. Only 2 SSS events (~ 1.27%) were registered during the late stage of the storm recovery phase, and 2 SSS were recorded in the absence of a storm, which is 1.27% of the total number of SSS.

Geomagnetic conditions	Type of conditions	Number of supersubstorms (SSS)	Total, %	
Storm Dst <-50nT	Storm	136	86.6	
Non-storm conditions Dst >-50nT	Onset of storm, SSC	17	10.82	13.4
	Recovery phase	2	1.27	
	Non storm	2	1.27	

Table 2. The number of SSS that were observed during storm and non-storm conditions and percentages of the total number of SSS for each types of geomagnetic conditions.

Note that SSS by their nature do not differ from the classical substorms, they are only stronger in intensity. Perhaps, a large, abnormal intensity increase of the substorm leads to a certain combination of the parameters of the solar wind and interplanetary magnetic field (IMF). So, magnetic clouds are characterized by a high and regular magnetic field (B> 10 nT), the magnetic pressure prevails over the thermal pressure ($\beta < 0.5$), the dynamic pressure is higher than one in the high speed stream (P > 5 nPa), and for a long time can remain high values of the southward component of the IMF. SHEATHs are characterized by increased density (N > 3 #/cm^3), dynamic pressure (P > 5 nPa), high temperature and magnetic field (B > 5 nT). In addition, before the appearance of SSS, in most cases, there were usually strong jumps in dynamic pressure of the solar wind, which were observed against the background of its high speed. Thus, we believe that the most likely space weather conditions for the SSS appearance are associated with enhanced values of the solar wind speed and dynamic pressure, as well as the magnitude of the Interplanetary Magnetic Field (IMF) under the southward direction of the IMF.

Conclusions

Under certain conditions of space weather, determined by the large-scale structure of the solar wind, supersubstorms (SML <-2500 nT, AL <-2500 nT) are observed on the Earth's surface.

- SSS are observed during interplanetary manifestations of coronal mass ejections, namely SHEATH (45.2%), MC (42%) and EJECTA (8.3%), and are not actually observed during high-speed streams from coronal holes (CIR, FAST).
- Many SSS events are associated with geomagnetic storms (Dst <-50 nT) (86.6%). But sometimes SSS are observed in non-storm conditions (Dst> -50 nT) (13.4%), related to the storm onset (11%) or to the end of the recovery phase (1.27%)

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