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Space Weather Conditions and Non-Storm Supersubstorms Observations

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Abstract

It is known that very intense substorms, so-called "supersubstorms" (SSSs: SML < −2500 nT) usually occur in the main phase of the magnetic storms. At the same time, it was found that such intense events are observed not only during very strong storms (superstorm with Dst<-250 nT), but also during intense or moderate magnetic storms (-100 nT >Dst>-250 nT; -50 nT >Dst>-100 nT). The aim of this work is to study the supersubstorms observed during non-storm conditions by the OMNI data base and global magnetometer networks SuperMAG, INTERMAGNET and IMAGE. For this purpose, we selected the SSS events observed by SYM/H>-50 nT. We found 18 such SSS events in the period 1998-2017. Among them, several typical events can be distinguished: (1) – the events near the magnetic storm commencements SC, (2) - the events observed in the distant recovery phase of the storm, (3) – the events observed outside of a magnetic storm. Besides, we discussed some special conditions in the solar wind and interplanetary magnetic field (IMF) under which such events have been observed.

Keywords: solar wind, magnetic cloud, high-speed streams, supersubstorm, magnetic storm

Introduction

For the first time the term "supersubstorms" was introduced by investigations of intense magnetic substorms based on the data of the SuperMag magnetometers network, the events with high negative values of SML index (< - 2500 nT) were called "supersubstorms" [Tsurutani et al. 2015]. Until now, there are several works where the statistical studies of the conditions for the occurrence of supersubstorms have been carried out, their dependence on solar activity, on conditions in the IMF and solar wind, and on the presence of magnetic storms [Haira et al., 2016; Despirak et al., 2019], the energy of supersubstorms [Tsurutani, Haira, 2023] and a detailed study of some individual events. Detailed studies of SSS development have been performed only for a few events: September 7-8, 2017; March 9, 2012; April 5, 2010 and May 28, 2011. On the Figure 1 shown the SML-index development during these four events as examples of supersubstorm determination.

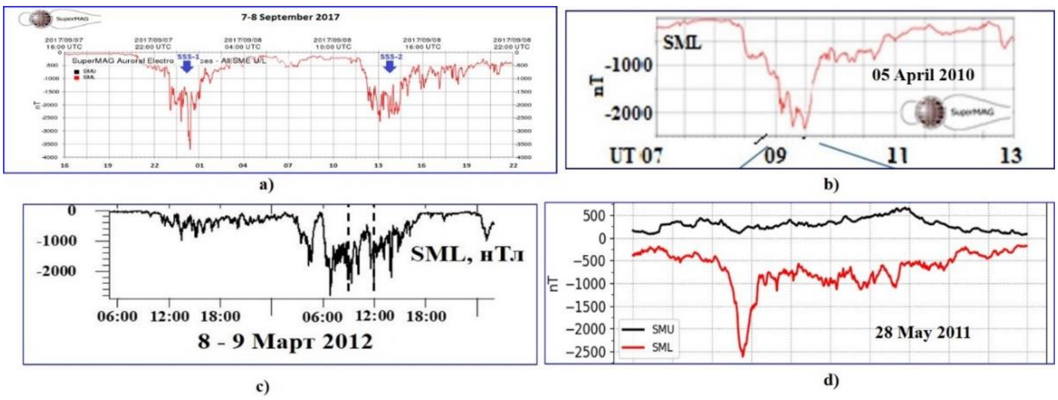

***Figure 1**. Variations of the SML-index during SSS: a) on 7-8 September 2017; b)- on 05 April 2010; c) – 8-9 March 2012; d) – 28 May 2011*

Note that an analysis of these SSS events showed that the supersubstorm was characterized by some special features: an extremely intense magnetic reconnection, an unusually large dipolization, intense fast plasma streams directed towards the Earth, an unusual spatial pattern of the development of auroras and auroral electrojets: eastward and westward electrojets developed globally and surround the polar cap from different sides to reach the day side [Haira et al., 2018; Nishimura et al., 2020; Zong et al., 2021; Despirak et al., 2020, 2021, 2022a, 2022b]. It was shown also that SSS usually are connected with the development of large magnetic storms, but they can sometimes also be observed during moderate magnetic storms and under nonstorm conditions. The result presented on the Figure 2.

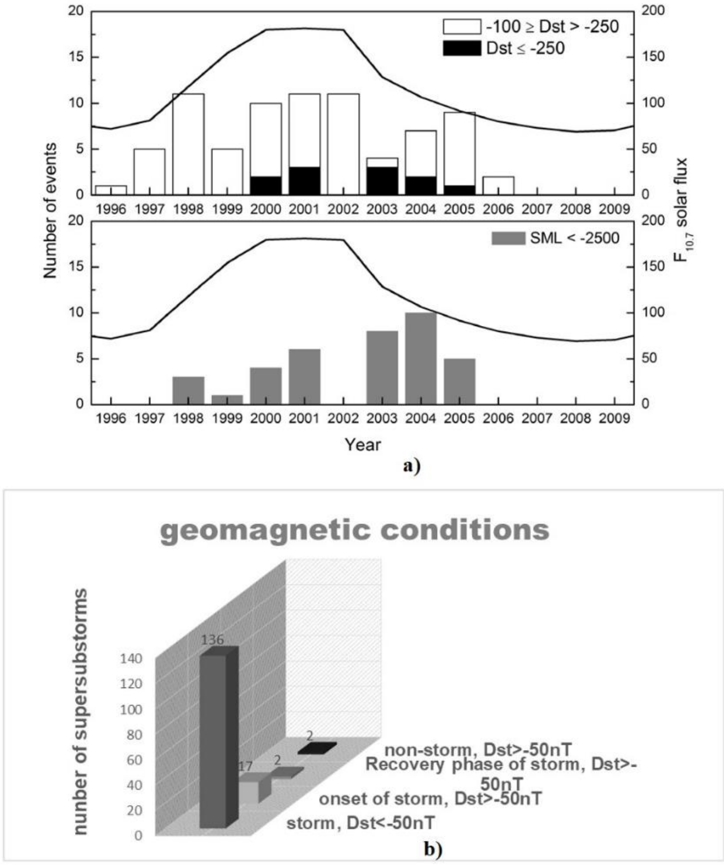

Figure 2*. Distributions of SSS on the intensity of magnetic storms, the pictures were taken from work of Tsurutani et al., 2015 (a) and from work Despirak et al., 2019 (b)*

The purpose of our work is study of supersubstorm events observed during non-storm conditions. We selected all supersubstorm events for 2010-2020 period observed during non-storm conditions, i.e. by SYM/H- index > -50 nT. Three examples of typical supersubstorm development under nonstorm conditions are presented below.

Data

The solar wind and interplanetary magnetic field (IMF) parameters are taken from OMNI database https://cdaweb.gsfc.nasa.gov/ and the catalog of large-scale solar wind types ftp://ftp.iki.rssi.ru/pub/omni/catalog. Global magnetometer networks SuperMAG and IMAGE data were used for determination of the substorm development as at the midlatitudes well as at auroral latitudes. The IMAGE magnetometer data are taken from http://space.fmi.fi/image/. The global spatial distribution of electrojets was determined from the maps of magnetic field vectors obtained on the SuperMAG network. SML- index is taken from http://supermag.jhuapl.edu/.

Results

1) SSS event registered out of the magnetic storm

We selected the event on April 22, 2017 as the example of SSS observation during non-storm condition. Solar wind and IMF conditions for period on April 21-26, 2017 shown in the Figure 3. It is seen that the features of recurrent high-speed stream from coronal holes are observed in this time period.

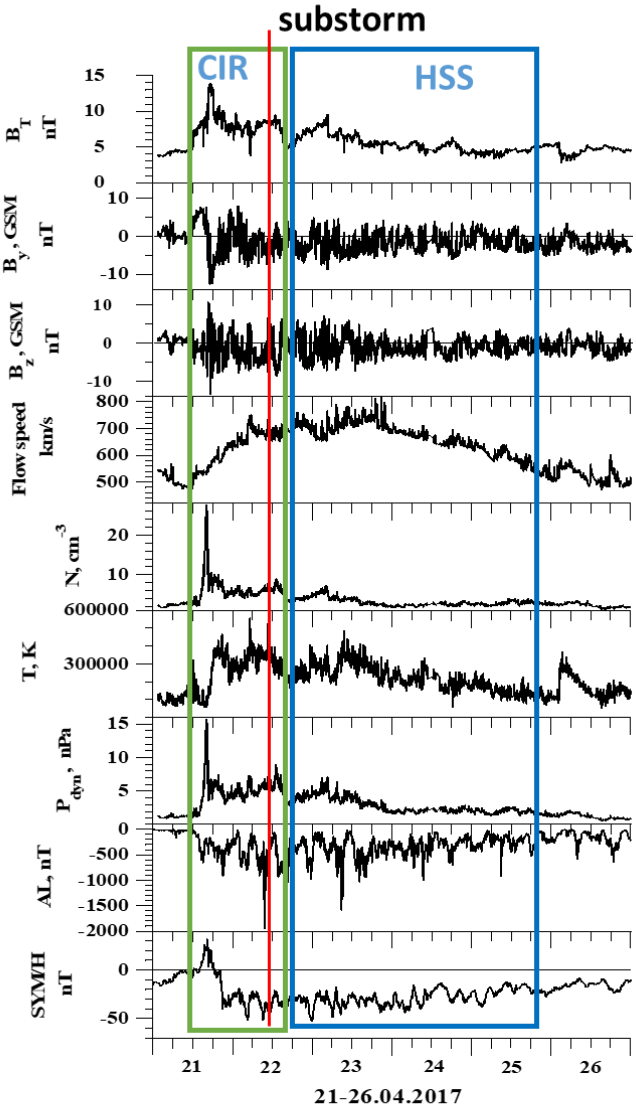

Figure 3*. Solar wind and IMF parameters on April 21-26, 2017, from top to bottom: IMF magnitude (B_T), the IMF Y- and Z- components (B_Y, B_Z), the flow velocity (V), the dynamic pressure (P). and geomagnetic indexes SYM/H and AL.*

At the front of the HSS the region of compresed plasma – the CIR- was registered. CIR and HSS boundaries are marked by the green and blue rectangles, respectively. The CIR contains the intervals of negative values of the IMF Bz, but magnetic storm not developed (SYM/H~-40 nT). Against the background of CIR, at ~09:30 UT one intense substorm (SML ~-2100 nT) began to develop. The moment of the substorm onset is shown by the vertical red line. Ground-based magnetic disturbances and Field Aligned Currents (FAC) distribution during this SSS are described in detail in our work Despirak et al., 2022c.

2) SSS registered during SC or at the onset of the magnetic storm

As the example of SSS observation during SC or onset of the magnetic storm was selected the event on April 11, 2001 Solar wind and IMF conditions for period on April 21-26, 2017 are shown in the Figure 4. Two consecutive structures in the solar wind were observed: SHEATH with EJECTA. As result, there was the magnetic storm on 11 April 2001 with SYM/H ~300 nT. Note, there were two events of SSS (SSS-1 and SSS-2, which were marked in the picture by the vertical dotted blue lines,) at this day observed during Sheath region of the solar wind. But we considered in our work only first SSS event (SSS-1) registered at the onset of storm (SYM/H ~-10 nT).

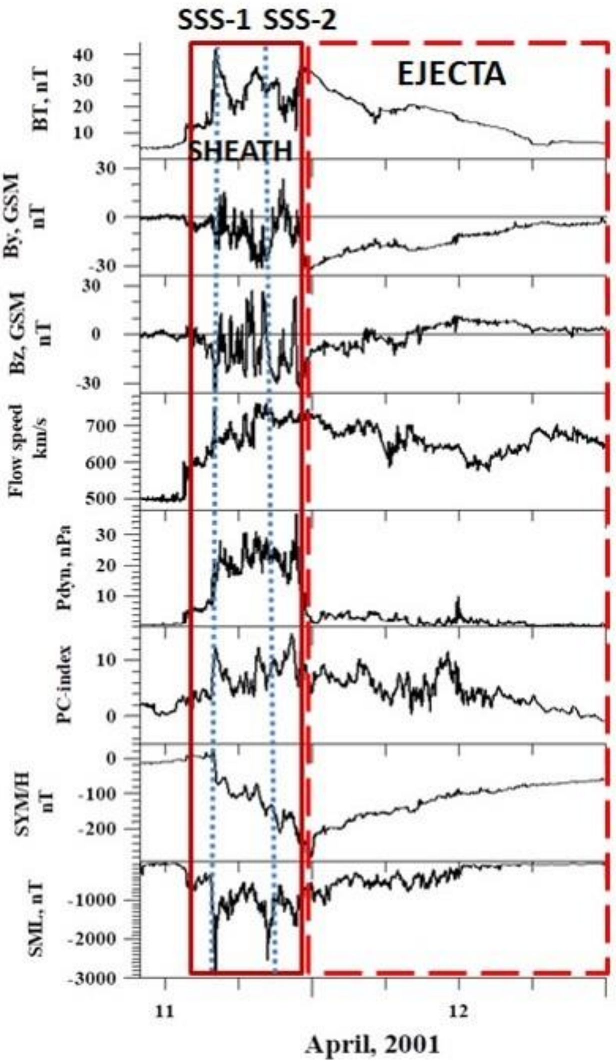

Figure 4. *Solar wind and IMF parameters on April 11-12, 2001, from top to bottom: IMF magnitude (B_T), the IMF Y- and Z- components (B_Y, B_Z), the flow velocity (V), the dynamic pressure (P). and geomagnetic indexes PC, SYM/H and SML.*

It is seen that before SSS-1 occurrence the solar wind dynamic pressure was ~ 20 nPa, the solar wind velocity shows very high values (~ 600-650 km/s), the magnitude of the IMF for SSSs was ~ 25-35 nT.

3) SSS in the distant recovery phase of the magnetic storm

As the example of SSS observation during the distant recovery phase of the magnetic storm was selected the event on September 12, 2011 Solar wind and IMF conditions for period at 16 UT on 10 September to 10 UT on 14 September are shown in the Figure 5. It is seen that the features of recurrent high-speed stream from coronal holes are observed in this time period.

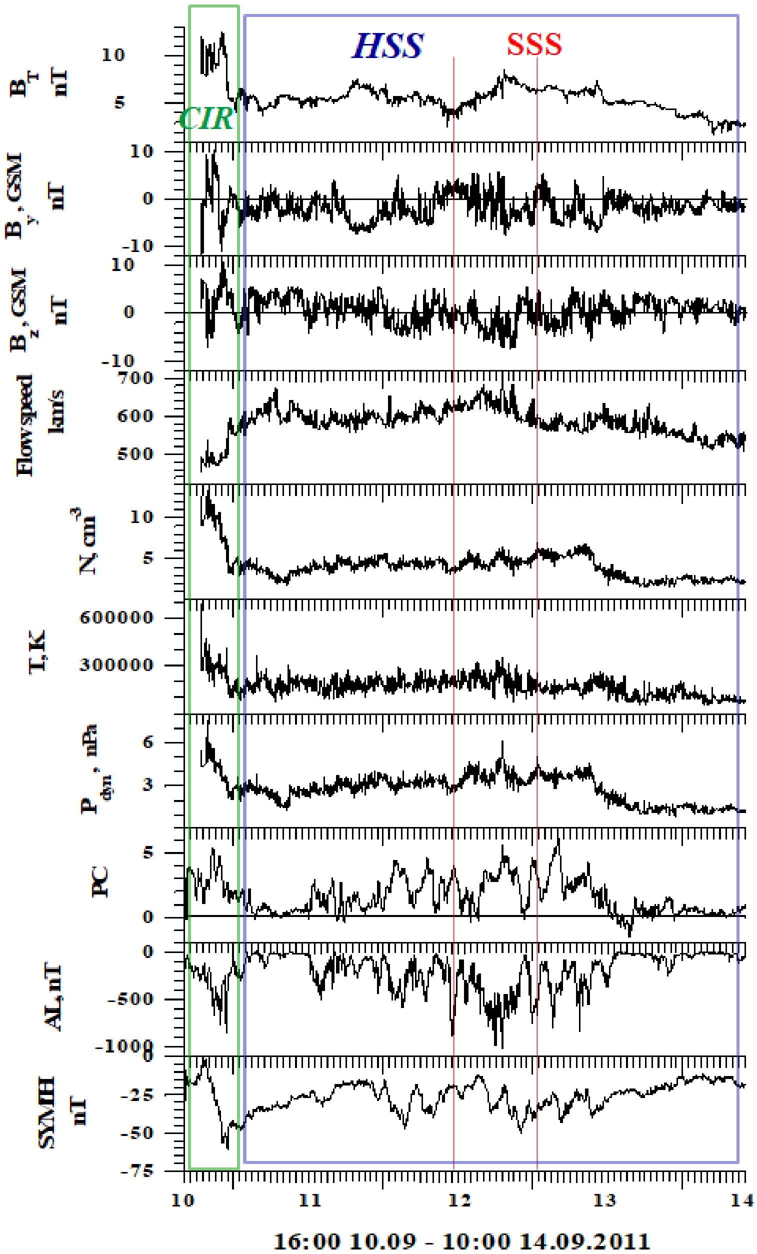

Figure5. *Solar wind and IMF parameters on September 10-14, 2011, from top to bottom: IMF magnitude (B_T), the IMF Y- and Z- components (B_Y, B_Z), the flow velocity (V), the dynamic pressure (P). and geomagnetic indexes PC, AL and SYM/H.*

CIR and HSS boundaries are marked by the green and blue rectangles, respectively. It can be seen that the CIR region included a negative Bz component, which may have been the source of a moderate magnetic storm with SYM/H~-60 nT. The storm lasted almost 3 days, from 11 to ~ 14 September 2011. Two supersubstorms were observed in the distant recovery phase of this magnetic storm. The moment of the SSS onset shown by the vertical red line.

It is seen that before SSSs, the Bz-component was small negative, but the solar wind velocity shows high values (~ 600 km/s), SSSs observed during the high-speed stream (HSS).

Summary

It is shown that non-storm SSS events (by SYM/H>-50 nT) were mainly registered:

1) during small CIR- storms development
2) during the late recovery phase of CIR-storms.
3) at the beginning of a magnetic storm caused by MC/ SHEATH;
4) moreover, the solar wind velocity for these events shows very high values (~ 600- 700 km/s)

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