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Certain Space Weather Conditions for a Supersubstorm Appearance

Despirak I.V.[1], Lubchich A.A.[1], Kleimenova N.G.[2]

[1]Polar Geophysical Institute, Apatity, Russia
[2]Schmidt Institute of the Earth Physics RAS, Moscow, Russia

E-mail: despirak@gmail.com

Abstract

Analysis of the space weather periods associated with five events of the supersubstorms (SSS) was carried out. Two magnetic storms, on 8 September 2017 and 09 March 2012, have been studied. During these two storms, there were registered 5 supersubstorms. It was shown that the onsets of the SSS events were preceded by strong jumps in the dynamic pressure and density of the solar wind, which were observed against the background of a high solar wind speed. Besides, the high values of the Interplanetary Magnetic Field (IMF B_T > 10 nT) and high values of the southern B_Z component of the IMF were also observed before the SSS occurrence. In additional, the values of the B_Y component of the IMF were small positive or turned from negative to positive values.

Introduction

In the last 5 years there has been a rapid increase in interest in research of extremely intense substorms [*Tsurutani et al*., 2015; *Haira and Tsurutani*, 2018; *Despirak et al.*, 2019, 2020a, 2020b; *Nishimura et al*., 2020]. The new type of very strong magnetic disturbances named as supersubstorms (SSS for shorthand) was first seen in the study by [*Tsurutani et al*., 2015, *Haira et al.*, 2016] using the ground-based data from the SuperMAG magnetometers network. The supersubstorms were determined as very intense magnetic substorms with very large negative values of SML index (≤ -2500 nT). This index is similar to the widely used AL-index, but derived from the 88 auroral SuperMAG stations [*Gjerloev et al.*, 2012]. However, in our opinion, this definition of the SSS intensity (SML index threshold ≤ -2500 nT) should be extended, at least, up to SML values ≤ -2000 nT [*Despirak et al*., 2020b], because this threshold proposed in the paper [*Tsurutani et al*., 2015] was an arbitrary one.

The SSS events as well as the classical substorms are typically observed during the main phase of a strong magnetic storm. However, the question arises whether the nature of the SSSs differs from classical substorms or not.

We found [*Despirak et al*., 2020a, 2020b] that in some SSS cases, the spatio-temporal development of the westward electrojet has a specific feature showing an almost global distribution in longitude from the evening to noon sector surrounding the Earth. The largest intensity of these SSS events was observed in the post-midnight sector. This activity was accompanied by the bay-like disturbances at dayside polar latitudes with the significantly reduced magnitude. The initial case studies of auroral disturbances during the SSS events showed that the development of the visible auroras is also nonstandard; the intense auroras were registered in the pre-midnight and morning sectors of magnetic local time (MLT) [*Haira and Tsurutani*, 2018].

Two examples of the SSS events are shown in Fig.1 as the time variations of the SML index on 11-12 April 2005, the moments of SSSs are pointed by the blue arrows. It is seen, that the SSSs were registered at 16:09 UT on 11 April (SML ~ -2920 nT) and at 20:24 UT on 12 April 2001 (SML ~ -2450 nT).

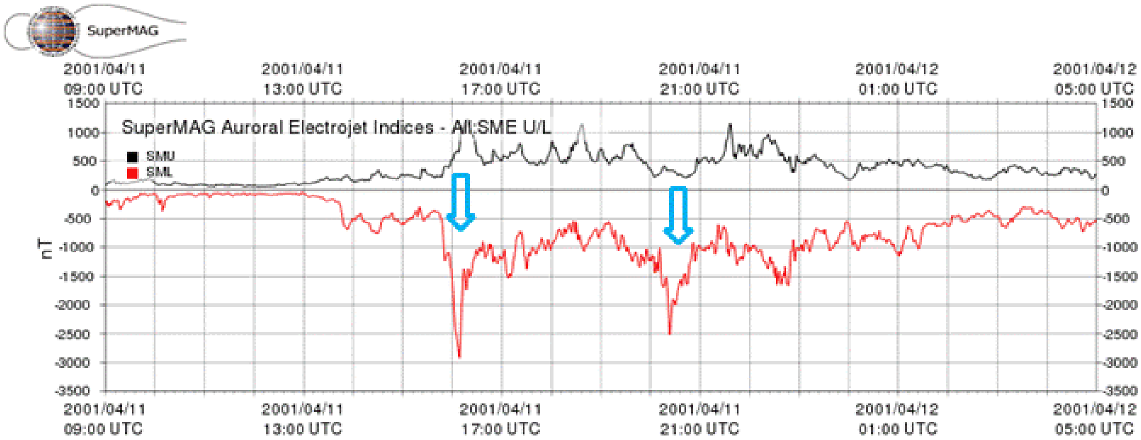

Fig.1. Variations of the indexes of geomagnetic activity from 09 UT on 11 April to 05 UT on 12 April 2001 by SuperMAG data are presented. The SMU index is shown at the top panel by the black line, SML index - at the bottom panel by the red line. Two moments of SSS observations are shown by the blue arrows.

Recently it was shown [*Despirak et al.*, 2019] that SSSs occur during the certain types of the large-scale solar wind streams, namely, the SSSs are mainly observed during the approach to the Earth's magnetosphere of the solar wind magnetic clouds (MC) and SHEATH plasma compression regions. Thus, the SSS events are caused by interplanetary coronal mass ejections and are, in fact, unassociated with high-speed streams from coronal holes. Considering the solar wind types have a fairy long duration, there is a question if there are local drivers for supersubstorms.

The aim of our work is the search of the solar wind and interplanetary magnetic field (IMF) drivers of SSSs during two strong magnetic storms with SYM/H ~ 150 nT. In our study, we considered the local behavior of the solar wind and IMF before the onset of the SSSs. For this purpose, the data of SuperMAG network and CDAWeb database were combined.

Data

We used the OMNI data base and the catalog of large-scale solar wind phenomena for determination of the solar wind types [*Yermolaev et al.*, 2009]. These parameters were taken from the 1-min sampled OMNI data base of the CDAWeb (http://cdaweb.gsfc.nasa.gov/cgi-bin/eval2.cgi).

Extremely intense substorms (SSS) were determined by the SML index, based on the data from the magnetic ground-based stations of the SuperMAG network (http://supermag.jhuapl.edu/) and Scandinavian IMAGE network (http://space.fmi.fi/image/). Supersubstorms are defined as those events with the SML (AL) peak < -2000 nT.

Observation results

Here we present some results of our study of the magnetic storms on 8 September 2017 and 9 March 2012.

a) Solar wind and IMF conditions for SSSs on 8 September 2017

Figure 2 shows the several solar wind and IMF parameters: magnitude of magnetic field (B_T), B_Y- and B_Z- components of IMF, the flow speed and the dynamic pressure of the solar wind, SYM/H and SML indexes of geomagnetic activity. From the left panel of Fig. 2, it is seen that two consecutive structures in the solar wind were observed: SHEATH with EJECTA and SHEATH with Magnetic Cloud (MC). As result, there were two severe magnetic storms on 7 and 8 September 2017. The main phase of the first magnetic storm began with the arriving of the second SHEATH with the strong negative values of the IMF B_Z. The second magnetic storm was caused by MC with the negative IMF B_Z component. Against the background of these two storms, two SSSs were registered, which were marked in Fig. 2 by the vertical~~,~~ dotted blue lines. The first SSS (~ 3500 nT) was observed during second SHEATH, and the second SSS (~ 2500 nT) was registered during MC. In the right panel of Fig. 2 shows the behavior of the solar wind parameters in more detail. It is seen that before both SSS occurrence, the local jump of the dynamic pressure was observed. The By component of the IMF was turned from the negative to positive values in the moment of the SSS occurrence. Besides, the high values of the southern B_Z component of the IMF and the total magnetic field were also registered before the SSSs onsets.

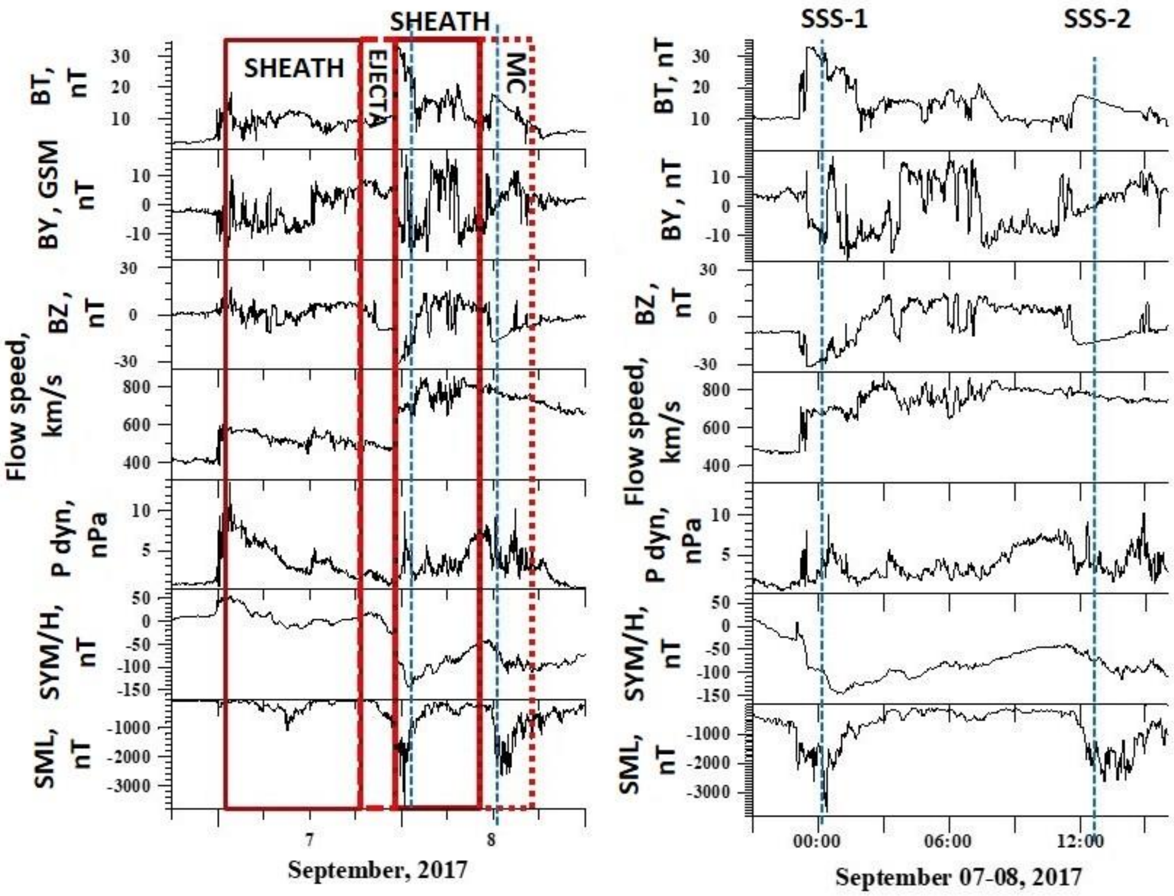

Fig.2. Variations of the solar wind and IMF parameters for two time periods: from 18 UT on 6 September to 24 UT on 8 September 2017 (a) and from 21 UT on 7 September to 16 UT on 8 September 2017 (b). The boundaries of the solar wind types are marked by the red rectangles: SHEATH – by the solid lines, MC and EJECTA – by the dotted lines. The moments of the SSS are shown by the vertical dotted blue lines.

b) Solar wind and IMF conditions for SSSs on 9 March 2012

Figure 3 shows the several solar wind and IMF parameters during the time period of 8 - 9 March 2012. The format of Fig. 3 is the same as Fig. 2. The boundaries of the magnetic cloud (MC) and the region of the compressed plasma (SHEATH) are indicated by the red rectangles: SHEATH - by the solid lines, MC– by the dotted lines.

It can be seen that at the beginning of MC, an increase in the southward IMF component (-14 nT) was observed, which occurred against the background of the high solar wind speed (700-750 km/s), which led to the development of a magnetic storm. The intensity peak of this storm (SYM/H ~ -140 nT) was recorded at ~ 08 UT on 9 March. At the main phase of the magnetic storm, at ~ 06-16 UT, a sharp increase in the module of the SML index was observed in the form of a sequence of substorms, it was the complex pattern of the disturbances from which it is difficult to distinguish an individual substorm. In Fig. 3, at least 4 minima in the SML index are seen: ~ -2800 nT, ~ -2500 nT, ~ -2370 nT, and ~ -2200 nT, three of them will be considered in this work as SSS events: at 06:55 UT (SSS-1), at 09:19 UT (SSS-2) and at 11:57 UT (SSS-3). In Fig. 3 these events are marked by the vertical blue dashed lines and designated as SSS-1, 2, 3. It is seen that all these SSS events were observed during MC, in the main phase of the magnetic storm, closely to the minimum of the SYM/H index.

In Fig. 3b, the behavior of the solar wind parameters shows in more details. It is seen that before occurrence of each SSS event, there was registered a local jump of the solar wind dynamic pressure. Note, that these jumps often occurred under the high values of the solar wind speed. In additional, before the SSS-1, the B_Y component of the IMF was turned from the negative to positive values and the values of this component were small positive before both the SSS-2 and SSS-3. Besides, the high values of the southern B_Z component of the IMF and the total magnetic field were also registered before each of the SSS onsets.

Discussion

Thus, our analysis of the space weather conditions before and during the occurrence of five SSS events during two strong magnetic storms (on 8 September 2017 and 9 March 2012) showed that there were the specific conditions in the solar wind and IMF leading the generation of huge intensity substorms (so called supersubstorms) with the magnitudes higher 2000 nT.

We found that all five SSS events under consideration were observed during the main phases of the magnetic storms, four of the SSS events were observed during the magnetic storm associated with MC, and one SSS event was observed during the magnetic storm associated with SHEATH. All five studied SSS events were observed under high values of the solar wind velocity (Vsw ~ 700 km/s) and strong total magnetic field (B_T > 10 nT).

Moreover, all SSS events were generated only after the occurrence of the very strong values of the southern B_Z component of the IMF (up to -30 nT). That fact indicates a huge input solar wind energy into the magnetosphere which is proportional to the product of Vsw by B_T IMF or $Vsw*(BzIMF^2 + ByIMF^2)^{1/2}$ [*Kan and Lee,* 1979; *Troshichev et al.*, 2014].

We found also that before each of the SSS events, there was observed a jump of the solar wind dynamic pressure. This jump was strong in the magnetic storm on 8 September 2017 reaching ~10 nPa and much smaller in the magnetic storm on 9 March 2012. We suppose that the sudden compression of the magnetosphere by a sharp jump of the solar wind dynamic pressure could be local driver of a supersubstorm generation. The substorm onset triggering by interplanetary shocks was previously discussed in the paper [*Zhou and Tsurutani,* 2001].

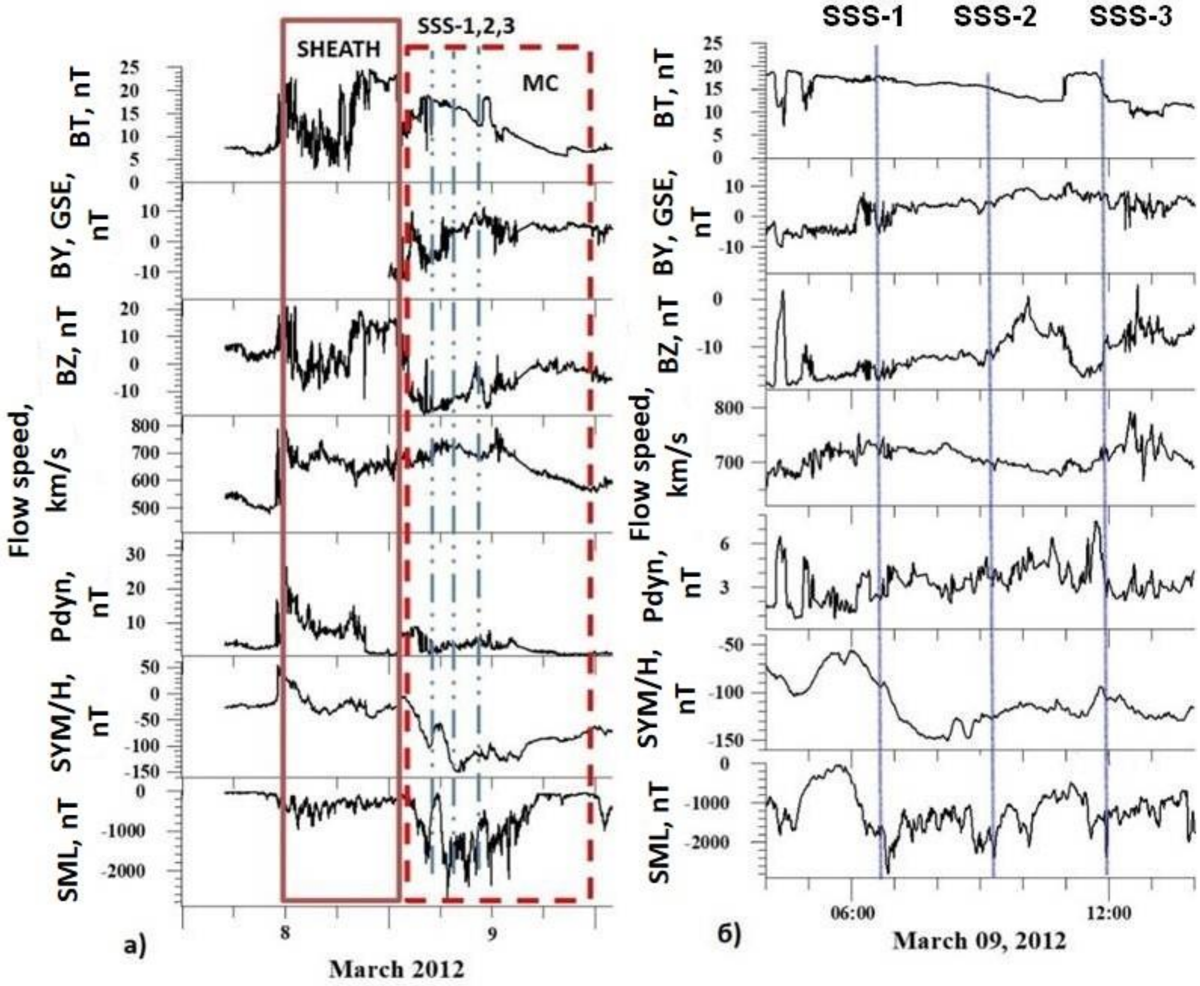

Fig.3. Variations of the solar wind and IMF parameters for two time periods: from 00 UT on 8 March to 24 UT on 9 March 2012 (a) and from 03 to14 UT on 9 March 2012 (b). The boundaries of the solar wind types are marked by the red rectangles: SHEATH – by the solid lines, MC – by the dotted lines. The moments of SSSs are shown by the blue vertical dotted (a) and solid (b) lines.

Conclusions

We considered the space weather conditions for occurrence of the supersubstorms (SSS) during two magnetic storms. The analysis of five SSS events shown that before SSS were registered some local features in the solar wind and IMF behavior:

1) the local jump of the dynamic pressure
2) the high values of the southern Bz component of the IMF (up to -30 nT) and the total magnetic field B_T (~ > 10 nT).
3) the By component of the IMF was small positive or turned from negative to positive values

We may suggested that the most probable source for the appearance of supersubstorms may be an increase in the dynamic pressure by the background of the southward direction of the interplanetary magnetic field and the solar wind speed.

References

Despirak, I.V., Lyubchich, A.A., N.G. Kleimenova, N.G. (2019). Supersubstorms and conditions in the solar wind, Geomag. Aeron., 59, no 2, 170-176.

Despirak, I.V., Kleimenova, N.G. Gromova, L.I., Gromov, S.V., Malysheva, L.M. (2020a). Supersubstorms during storms of September 7–8, 2017, Geomag. Aeron., 60, no 3, 308-317.

Despirak, I., Lubchich, A., Kleimenova, N. Gromova, L., Gromov S., Malysheva L. (2020b). Supersubstorms during two strong magnetic storms, Proceedings of International Conference "Atmosphere, ionosphere, safety", Kaliningrad, 2020, 97-99.

Gjerloev, J.W. The SuperMAG data processing technique (2012). J. Geophys. Res., V. 117(A9), A09213. https://doi.org/10.1029/2012JA017683

Hajra, R., Tsurutani, B.T., Echer E., Gonzalez, W.D., Gjerloev, J.W. (2016). Supersubstorms (SML < –2500 nT): Magnetic storm and solar cycle dependences, J. Geophys. Res., 121, 7805–7816, doi: 10.1002/ 2015JA021835.

Hajra, R., Tsurutani, B.T. (2018). Interplanetary shocks inducing magnetospheric supersubstorms (SML < –2500 nT): Unusual auroral morphologies and energy flow, Astrophys. J., 858, no. 2, id 123. https://doi.org/10.3847/1538-4357/aabaed.

Kan, J. R., Lee, L. C. (1979). Energy coupling function and solar wind-magnetosphere dynamo, Geophys. Res. Lett., 6(7), 577–580, 1979.

1. Nishimura, Y., Lyons, L.R., Gabrielse, C., Sivadas, N., Donovan, E.F., Varney, R.H., Angelopoulos, V., Weygand, J.M., Conde, M.G., Zhang, S.R. (2020). Extreme magnetosphere-ionosphere-thermosphere responses to the 5 April 2010 supersubstorm, J. Geophys. Res. https://doi.org/10.1029/2019JA027654

2. Troshichev, O. A., Podorozhkina, N. A., Sormakov D. A., Janzhura A. S. (2014), PC index as a proxy of the solar wind energy that entered into the magnetosphere: Development of magnetic substorms, J. Geophys. Res. Space Physics, 119, 6521–6540, doi:10.1002/2014JA019940

Tsurutani, B.T., Hajra, R. Echer, E., Gjerloev, J.W. (2015). Extremely intense (SML ≤ –2500 nT) substorms: Isolated events that are externally triggered? Ann. Geophys., 33 (5), 519–524.

Yermolaev, Yu.I., Nikolaeva, N.S., Lodkina, I.G. et al.. (2009). Catalog of large-scale solar wind phenomena for the period 1976-2000, Cosmic Res. (Engl. Transl.), 47, 81-94.

Zhou, X.-Y., Tsurutani, B. T. (2001). Interplanetary shock triggering of nightside geomagnetic activity: Substorms, pseudobreakups, and quiescent events, J. Geophys. Res., 106, 18957-18967.