"Physics of Auroral Phenomena", Proc. XLIII Annual Seminar, Apatity, pp. 7-10, 2020

Polar
Geophysical
Institute

DOI: 10.37614/2588-0039.2020.43.001

SEVERAL SPECIAL CONDITIONS IN THE SOLAR WIND FOR A SUPERSUBSTORM APPEARANCE

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

[1]*Polar Geophysical Institute, Apatity, Russia;* e-mail: *despirak@gmail.com*
[2]*Schmidt Institute of the Physics of the Earth RAS, Moscow, Russia*

Abstract. Analysis of the space weather conditions associated with supersubstorms (SSS) was carried out. Two magnetic storms, on 11 April and on 18 April 2001 have been studied and compared. During the first storm, there were registered two events of the supersubstorms with intensity of the SML index ~2000-3000 nT, whereas during the second storm there were observed two intense substorms with SML ~ 1500 nT. Solar wind conditions before appearance of the SSSs and intense substorms were compared. For this purpose, the OMNI data base, the catalog of large-scale solar wind phenomena and the data from the magnetic ground-based stations of the SuperMAG network (*http://supermag.jhuapl.edu/*) were combined. It was shown that the onsets of the SSS event were preceded by strong jumps in the dynamic pressure and density of the solar wind, which were observed against the background of the high solar wind speed and high values of the southern B_Z component of the IMF. Comparison with the usual substorms showed that some solar wind parameters were higher before SSSs, then before usual substorms: the dynamic pressure, the speed and the magnitude of IMF. On the other hand, the PC index values was the same for these all substorms, that leads to the conclusion about the possible independence of SSS appearance on the level of solar energy penetrated to the magnetosphere.

Introduction

In the last few years, different cases of extremely intense substorms (so-called "supersubstorms" - SSS) [1-6] have been intensively investigated. At first, the supersubstorms have been determined as very intense magnetic substorms with the very large negative values of the SML index (≤ -2500 nT). This index is similar to the widely used AL-index, but derived from the 88 auroral SuperMAG stations [7]. 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 [6].

Perhaps, the main question that researchers must answer is whether the supersubstorms are different from the usual substorms or not. So far it has been shown that in some SSS cases, the spatio-temporal development of the westward electrojet has a specific feature showing an almost global distribution in the longitude from the evening to noon sector surrounding the Earth [4]. 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 [5]. Besides, the first studies of the behavior of the auroras during the SSSs showed that the development of the visible auroras is also nonstandard; the intense auroras were registered in the pre-midnight and morning sectors of the magnetic local time (MLT) [2].

At the same time, the first studies of the space weather conditions for the appearance of the SSSs showed that the SSS events are typically observed during the main phase of a strong magnetic storm and by the definite conditions in the solar wind and interplanetary magnetic field (IMF) [1], [3]. It was shown, that the 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 carrying 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 the coronal holes [3]. The considered solar wind types have the fairy long duration, so the question is where local drivers for supersubstorms are.

The aim of our work is the search of the local space weather drivers of SSSs. For this purpose, the solar wind and IMF conditions before the onsets of the SSS events were compared with the conditions before the onset of the usual substorms; the data of the SuperMAG network and CDAWeb database were combined. We considered two magnetic storms - on 11 April and on 18 April 2001. During the first storm, there were registered two SSS events with intensity of the SML index ~2000-3000 nT, whereas during the second storm there were observed two intense substorms with SML ~ 1500 nT.

Four substorm events, chosen for the study, are shown in Figure 1. The time variations of the SML index are presented for the period of 11-12 April 2001 (the top panel) and for the time period of 17-18 April 2001 (the bottom panel), the moments of all substorms 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); whereas usual substorms were observed at 01:16 UT (SML ~ -1640 nT) and at 04:08 UT on 18 April 2001 (SML ~ -1400 nT).

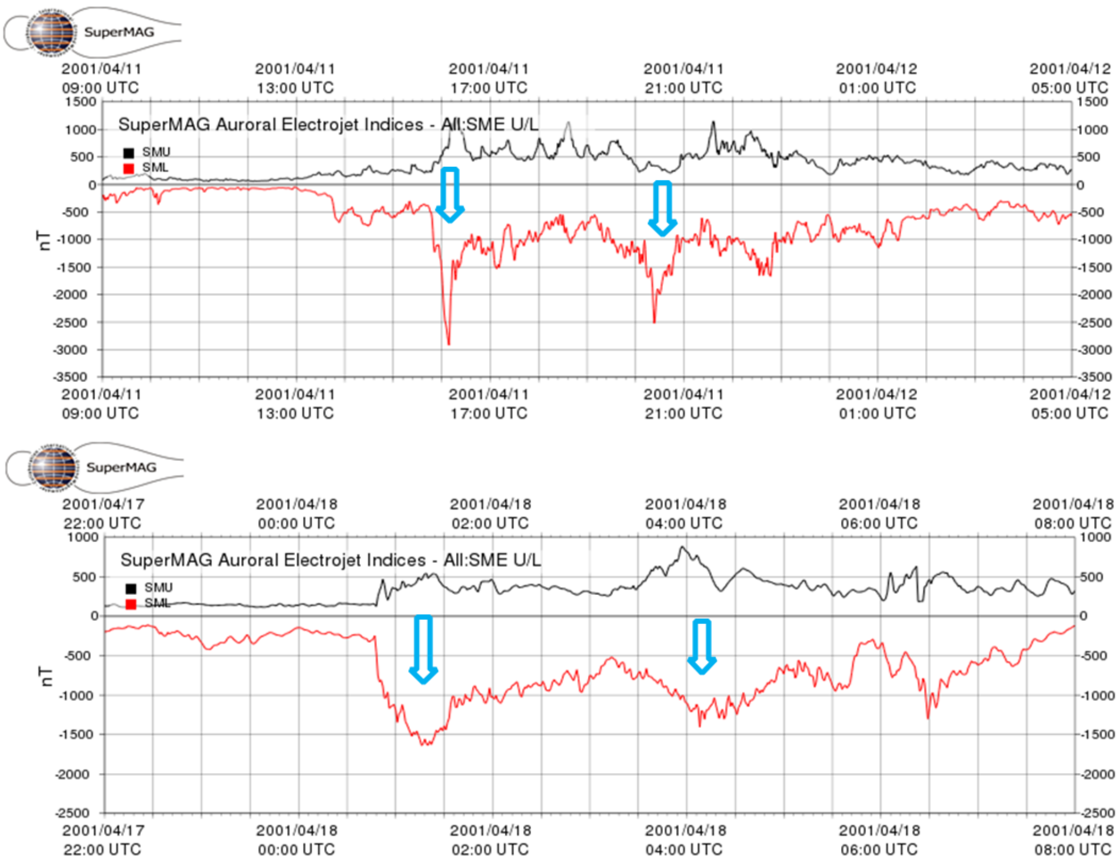

Figure 1. Variations of the SMU and SML indexes of geomagnetic activity by SuperMAG data are presented for two time periods: from 09 UT on 11 April to 05 UT on 12 April 2001 (top panel) and from 22 UT on 17 April to 08 UT on 118 April 2001 (bottom panel). SML index is shown by the red line. Four moments of SSS and usual substorms are shown by the blue arrows.

Data

We used the OMNI data base and the catalog of the large-scale solar wind phenomena for determination of the solar wind types [8]. These parameters were taken from the 1-min sampled OMNI data base of the CDAWeb (*http://cdaweb.gsfc.nasa.gov/cgi-bin/eval2.cgi*).

The 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/*). The supersubstorms are defined as those events with the SML (AL) peak < -2000 nT, whereas usual intense substorms are detected as events with SML (AL) peak < - 1000 nT.

Results

Here we present some results of our study of the space weather conditions for the chosen 4 events during two magnetic storms on 11 and 18 April 2001. Figure 2 shows the several solar wind and IMF parameters observed before SSSs events on 11 April 2001, from top to bottom: 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, PC-, SYM/H- and SML- indexes of geomagnetic activity. From the left panel of Figure 2, it is seen that 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, both supersubstorms, which were marked in the picture by the vertical dotted blue lines, were registered at the main phase of the storm, during the SHEATH region. The behavior of the solar wind parameters shows in more detail in the right panel of Figure 2. It is seen that before both SSS occurrence, the local jump of the solar wind dynamic pressure was observed (~ 20 nPa). Additional, the high values of the southern B_Z component of the IMF (~-15-30 nT), the total magnetic field (~ 25-35 nT), velocity of the solar wind (~ 700 km/s) were also registered before the SSSs onsets. Besides, before two SSSs, the values of the B_y component of the IMF was negative.

Figure 3 shows the solar wind parameters observed before the usual substorms on 18 April 2001. The format of Figure 3 is the same as of Figure 2. It is seen that both substorms were registered at the main phase of the storm (SYM/H ~140 nT), caused by high values of the southern B_Z component of the IMF during the SHEATH region. From the right panel of Figure 3, it is seen that before both usual substorms occurrence, the relatively small values of the solar wind dynamic pressure (~ 5 nPa) and velocity (~ 450-500 km/s), the magnitude of the IMF (~ 10-15 nT) were observed. But PC- index values were similar for the substorms and SSSs (~12-14 mV/m).

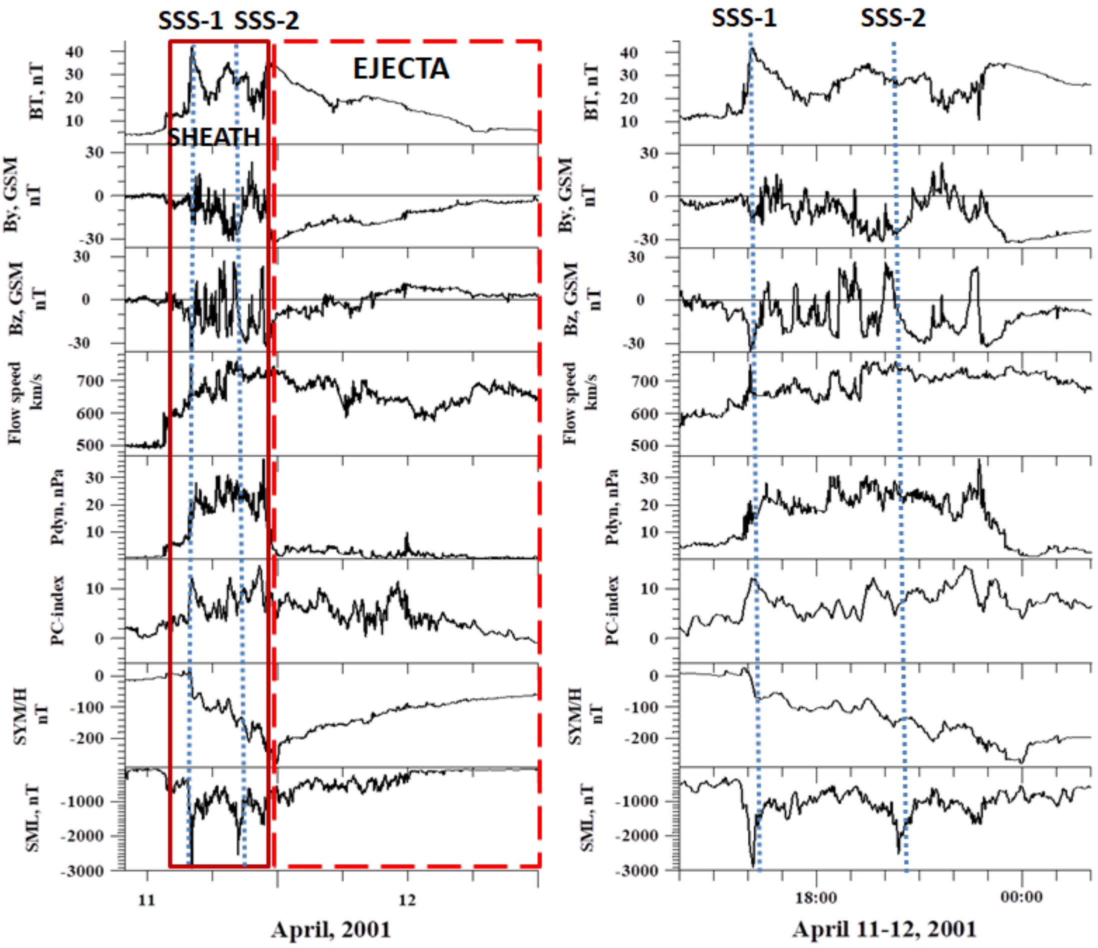

Figure 2. Variations of the solar wind and IMF parameters for two time periods: from 10 UT on 11 April to 24 UT on 12 April 2001 (left) and from 14 UT on 11 April to 02 UT on 12 April 2001 (right). The boundaries of the solar wind types are marked by the red rectangles: SHEATH – by the solid lines, EJECTA – by the dotted lines. The moments of the SSS are shown by the vertical dotted blue lines.

Summary

We found the following differences in the behavior of the solar wind parameters before the onsets of the usual intense substorms and SSSs:

1) The solar wind dynamic pressure was relatively low for usual substorms ~ 5 nPa, while for SSSs - ~ 20 nPa;
2) The solar wind velocity for usual substorms was between high – and low values (~ 450-500 km/s), while for SSSs, it shows very high values (~ 700 km/s);
3) The magnitude of the IMF for SSSs is higher (~ 25-35 nT) than for usual substorms (~ 10-15 nT);
4) The PC index was about the same (~12-14 mV/m) for both types of intense substorms.

Thus, we found some differences in the behavior of the solar wind parameters: the dynamic pressure, the velocity and the magnitude of IMF was lower for usual substorms than for SSSs. However, the PC index values were similar for both types of intense substorms. So we may suppose the possible independence of the SSSs appearance on the level of the solar energy penetrated to the magnetosphere.

Acknowledgements. The WIND data used in this study were taken from OMNI web site *http://cdaweb.gsfc.nasa.gov/cdaweb/istp_public/*. We are grateful to J.N. King and N. Papatashvili, the heads of the experiments conducted with these instruments. The authors are grateful also to the creators of SuperMAG (*http://supermag.jhuapl.edu/) and IMAGE (http://space.fmi.fi/image/*) for allowing us to use these databases in our study. The reported study was funded by RFBR and National Science Foundation of Bulgaria (NSFB), project number 20-55-180003.

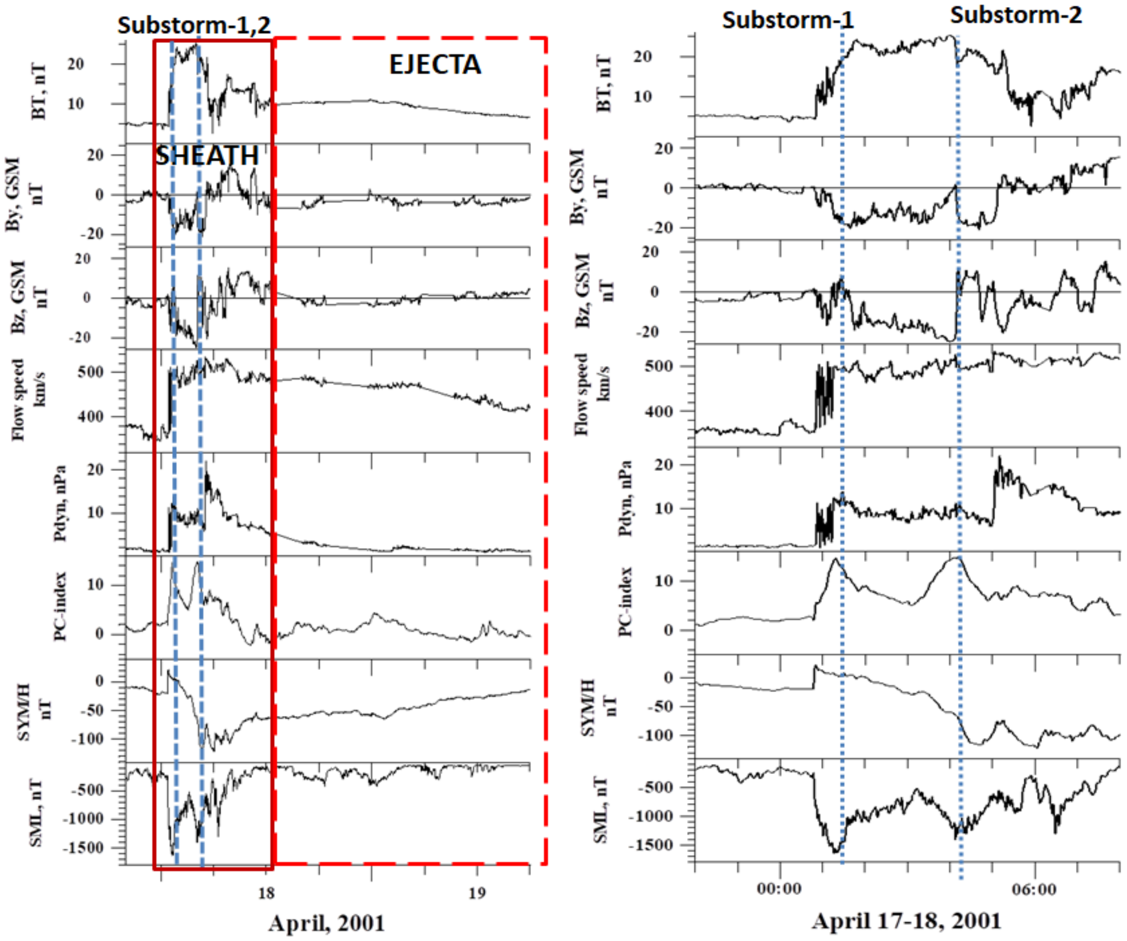

Figure 3. Variations of the solar wind and IMF parameters for two time periods: from 18 UT on 17 April to 24 UT on 19 April 2001 (left) and from 22 UT on 17 April to 08 UT on 18 April 2001 (right). The boundaries of the solar wind types are marked by the red rectangles: SHEATH – by the solid lines, EJECTA – by the dotted lines. The moments of the SSS are shown by the vertical dotted blue lines.

References

1. 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, 519–524.
2. 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
3. Despirak I.V., Lyubchich A.A., Kleimenova N.G. (2019). Supersubstorms and conditions in the solar wind. *Geomag. Aeron*., 59, no 2, 170-176.
4. 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.
5. 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.
6. 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
7. Gjerloev J.W. (2012). The SuperMAG data processing technique. *J. Geophys. Res.*, 117(A9), A09213, https://doi.org/10.1029/2012JA017683
8. Yermolaev Yu.I., Nikolaeva N.S., Lodkina I.G., Yermolaev M.Yu. (2009). Catalog of large-scale solar wind phenomena during 1976-2000. *Cosmic Research (Engl. Transl.*), 47, 81-94.