SUBSTORMS DURING TWO SOLAR CYCLES MAXIMUM

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Abstract: *The substorms, observed during the large solar cycle maximum (1999- 2000, with Wp> 100) and during the last maximum (2012-2013 with Wp~60), were studied. All considered substorms were divided into 3 types: "usual", "expanded" and "polar" substorms. First type - substorms which observed only in auroral latitudes; second type - substorms which propagate from auroral latitudes (<70º) to polar geomagnetic latitudes (>70º); third type is substorms which observed only at latitudes above ~70º in the absence of simultaneous geomagnetic disturbances below 70°. Our analysis was based on the 10-s sampled IMAGE magnetometers data, the 1-min sampled OMNI solar wind and interplanetary magnetic field (IMF) data. There were analyzed above 1700 events of "expanded", "polar" and "usual" substorms in 1999- 2000 and in 2012-2013 years. The following substorm characteristics have been studied: (i) the seasonal variations of substorms, (ii) the latitudinal range of all three types of substorms, (iii) dependences of all three types of substorms on solar wind parameters and PC index.*

СУББУРИ ВО ВРЕМЯ ДВУХ МАКСИМУМОВ СОЛНЕЧНОЙ АКТИВНОСТИ

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Ключевые слова: *Суббури, западный электроджет, солнечный ветер, солнечный цикл*

Abstract: *На основе данных наземных наблюдений на скандинавском профиле магнитометров IMAGE и базы данных OMNI по солнечному ветру проведен сравнительный анализ условий появления суббурь вблизи максимумов 23-го (Wp~115) и 24-го (Wp~65) циклов солнечной активности (1999-2000 и 2012-2013 г.г.). Все суббури были разделены на 3 типа в соответствии с динамикой аврорального овала. Первый тип - суббури, которые наблюдаются только в авроральных геомагнитных широтах, ниже 70º («обычные» суббури). Второй тип - суббури, которые перемещаются из авроральных (<70º) в полярные (>70º) геомагнитные широты («высокоширотные» суббури). Третий тип - суббури, которые наблюдаются только на широтах выше ~70º при отсутствии одновременных геомагнитных возмущений на широтах ниже ~70º («полярные» суббури). Было проанализировано более 1700 случаев «высокоширотных», «полярных» и «обычных» суббурь, наблюдавшихся в 1999-2000 и 2012-2013 годах. Проведено сравнение суббурь по следующим характеристикам: (i) сезонный ход, (ii) широтный размах всех трех типов суббрь, (iii) зависимость всех типов суббурь от параметров солнечного ветра и PC-индекса геомагнитной активности.*

Introduction

In this paper we studied substorms during the large solar cycle maximum (1999- 2000, with Wp> 100) and during the last maximum (2012-2013 with Wp~60). Namely, we present a comparative analysis of some substorms characteristics and the solar wind conditions observed before substorm onsets.

It is noted that although the history of the substorm study is very long, there are only a few large statistical substorm investigations (e.g. [1],[2],[3],[4],[5]). In these papers were determined 390 substorms events from POLAR UVI ([4]), were found more than 2400 substorm events from IMAGE FUV instrument ([5]), were identified more 5000 substorm events from IMAGE magnetometers network ([2], [3]). Traditionally, researchers have been considered all substorms. In our work we divided all observed substorms into 3 groups according auroral dynamics. It is known that under normal conditions (moderate disturbance) the auroral oval is located at geomagnetic latitudes about 65-67° ("normal oval"), under quiet conditions (at B_Z>0) the auroral oval shrinks and moves to higher latitudes (>70°GLAT, "contracted oval"), and in disturbed conditions (increased magnitude of the IMF negative B_Z component), the equatorward boundary of the oval is shifted down to 50° geomagnetic latitude, while its poleward boundary extends to higher latitudes ("expanded oval") (e.g. [6]). Thus, in our terminology, we call the first type of substorms as "usual" substorms, i.e. substorms which observed only at auroral latitudes. Similarly as the auroral oval is called an "expanded" oval, meaning its extension in the disturbed conditions, we will call "expanded" substorms those which start at the auroral zone and then propagate to very high latitudes. We point out that in the maximum phase of "expanded" substorms, the westward electrojet can be observed at very high geomagnetic latitudes (> 75º) ([7]). The third type of substorms, we term as "polar" substorms, according to contracted oval. They represent the isolated bay-like magnetic disturbances, observed at geomagnetic latitudes higher than the location of the typical polarward boundary of the auroral oval (> 70° GLAT) and do not accompanied or preceded by substorm activity at auroral latitudes.

The aim of this work is the comparison of some substorm characteristics of all three types of substorms and the solar wind conditions observed before substorm onsets during two solar cycles maximum: (1999-2000 and 2012-2013). It should be noted that details of substorms at the contracted oval ("polar" substorms) and substorms at the enxpanded oval ("expanded" substorms) were considered in the recent paper [8]. There are shown many clear examples of the "polar" and "expanded" substorms observed at the IMAGE meridional chain Nurmijarvi - Ny Alesund located at geomagnetic latitudes of 57-75°. Therefore, in this article we will not give examples of "polar" and "expanded" substorms, and focus on the results of the comparison between the different types of substorms during the two maximums of solar activity.

Data

We used the 10-s sampled IMAGE magnetometer data, namely the data of the meridional chain Nurmijarvi - Ny Alesund. The solar wind and Interplanetary Magnetic Field parameters measured by Wind spacecraft were taken from 1-min sampled OMNI database. Two time intervals, close to the different solar cycle maximums are used. First time interval is the period of 1999-2000, which close to the large solar cycle maximum with Wp> 100. Second time interval is the period of 2012-2013, which close to the last solar maximum with Wp~60. There were selected and analyzed above 1700 events of "expanded", "polar" and "usual" substorms in 1999- 2000 and in 2012-2013 years all together. In Table 1 are presented number of analyzed events of all three types of substorms:

Table 1. Number of selected substorm events for different years

Type of substorm	1999	2000	2012	2013
"usual"	363	320	285	285
"expanded"	62	25	27	18
"polar"	42	39	65	64

Results

a) Seasonal variations of substorm number

We calculated the seasonal variations of substorms, observed in two different solar cycle maximums – in 1999-2000 years and in 2012-2013 years. All substorms observed in these time intervals were divided into 3 types according to auroral oval dynamic: "usual" substorms, "expanded" substorms and "polar" substorms. Figure 1 presents the results for 3 different types of substorms and for all substorms: U - "usual" substorms (blue); P - "polar" substorms (green); E - "expanded" substorms (red line); A - all substorms (black line). The seasonal variations of substorms observed during 1999-2000 time intervals are presented in the left panel (*a*), during 1999-2000 intervals - on the right panel (*b*).

It is seen that number of substorms is higher during 1999-2000 periods than during 2012-2013 periods. It seen also that summer minimums of substorms number and spring and autumn maximums are common to both periods. However, the "polar" substorms behavior was in opposition to the behavior of other types of substorms. Number of "polar" substorms have maximum in the winter months; wherein it is noted that "expanded" substorms maximum was observed in winter 1999-2000, but not observed in winter 2012-2013.

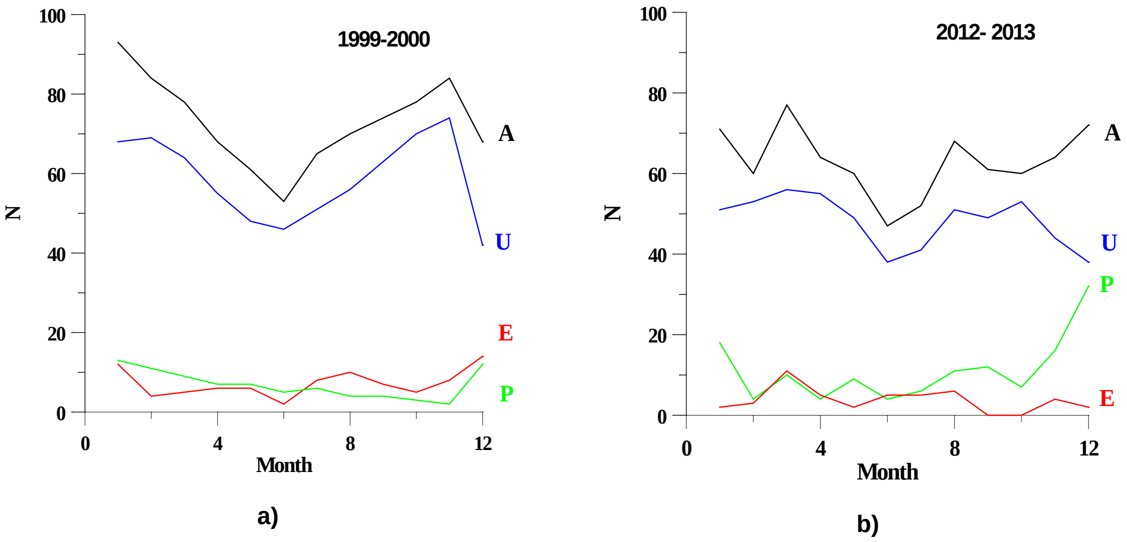

Fig. 1. The seasonal variations of the substorm different types during two solar cycle maxima: (*a*) – in 1999-2000; (b) –in 2012-2013, A - all substorms (black), U - “usual” substorms (blue), E - “expanded” substorms (red), P – “polar” substorms (green).

b) Onset and maximal latitudes of the substorm occurrence

To determine onset and maximal latitudes of substorm, we used the data of the NUR–NAL (Nurmijarvi – Ny Alesund) meridional chain from 56.89° to 75.25° geomagnetic latitudes. It should be noted that the stations are located irregularly along latitude, and, correspondingly, the substorm latitude was measured discretely and was determined with different accuracy (this accuracy varies from 0.5° to 1.5° depending on a distance between adjacent stations). Onset and maximal latitudes of all 3 types of substorms were determined. For example in the Figure 2 are presented the “usual” substorms onsets and its maximal reaching latitudes. Onset latitudes are marked by the black triangles and maximal latitudes by the red ones. For clarity of latitudes presentation, they were presented as dependences of latitudes on X-component of solar wind velocity (V_X) (*b*) and Z-component of Interplanetary Magnetic Field (B_Z) (*a*).

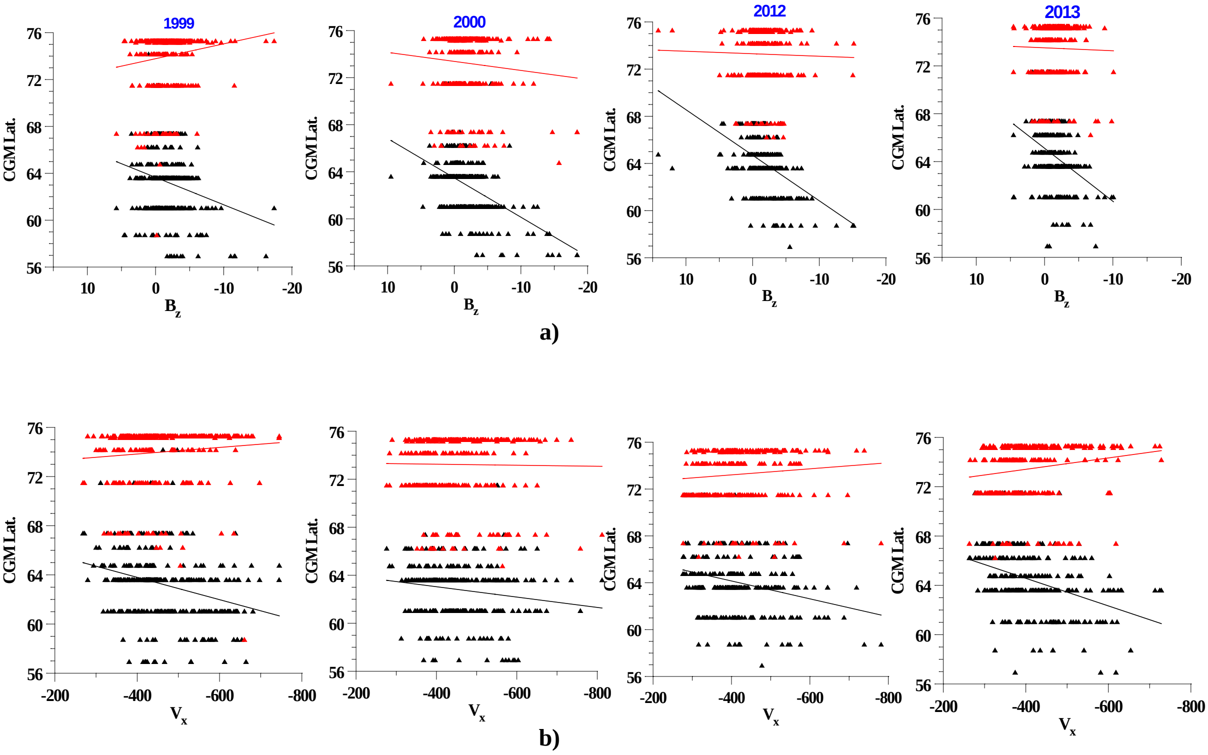

Fig. 2. The maximal reaching latitudes of the “usual” substorm onsets, depending on the solar wind velocity (V_X) (*a*) and IMF B_Z (*b*) in 1999, 2000, 2012, and 2013.

It is seen that substorms onset latitudes for 1999-2000 years were a little lower that onset latitudes for 2012-2013 years. It is shown also that the latitudinal sizes of substorms in 1999-2000 years were a little more than the latitudinal size of substorms during 2012-2013 years.

We considered the solar wind and IMF parameters observed before the onset of 3 types of substorms. We calculated the values of following solar wind parameters averaged for 1.5 hours before the substorm onset: the B_X, B_Y, B_Z components of IMF, V_X component of the solar wind velocity, E_Y component of the interplanetary electric field, temperature (T), density (N) and dynamic pressure (P) of the solar wind. It is shown that significant differences in distributions of the solar wind parameters between substorms during 1999-2000 and substorms during 2012-2013 have been not found (Figure not presented here).

d) PC-index for all three types of substorms

We also calculated the PC-index values (e.g. [9]) before the onset of three types of substorms. PC-index values were averaged for 1.5 hours interval prior to the moment of substorm onset. Figure 4 shows the histograms of the PC-index values observed before the onset of the “polar” (right top panel, (*a*)), ”expanded” (left top panel, (*b*)), “usual” (left bottom panel, (*c*)) and all (right bottom panel, (*d*)) substorms. The histograms of the PC-index values before substorms for periods 1999-2000 (black lines) and 2012-2013 (blue lines) are shown.

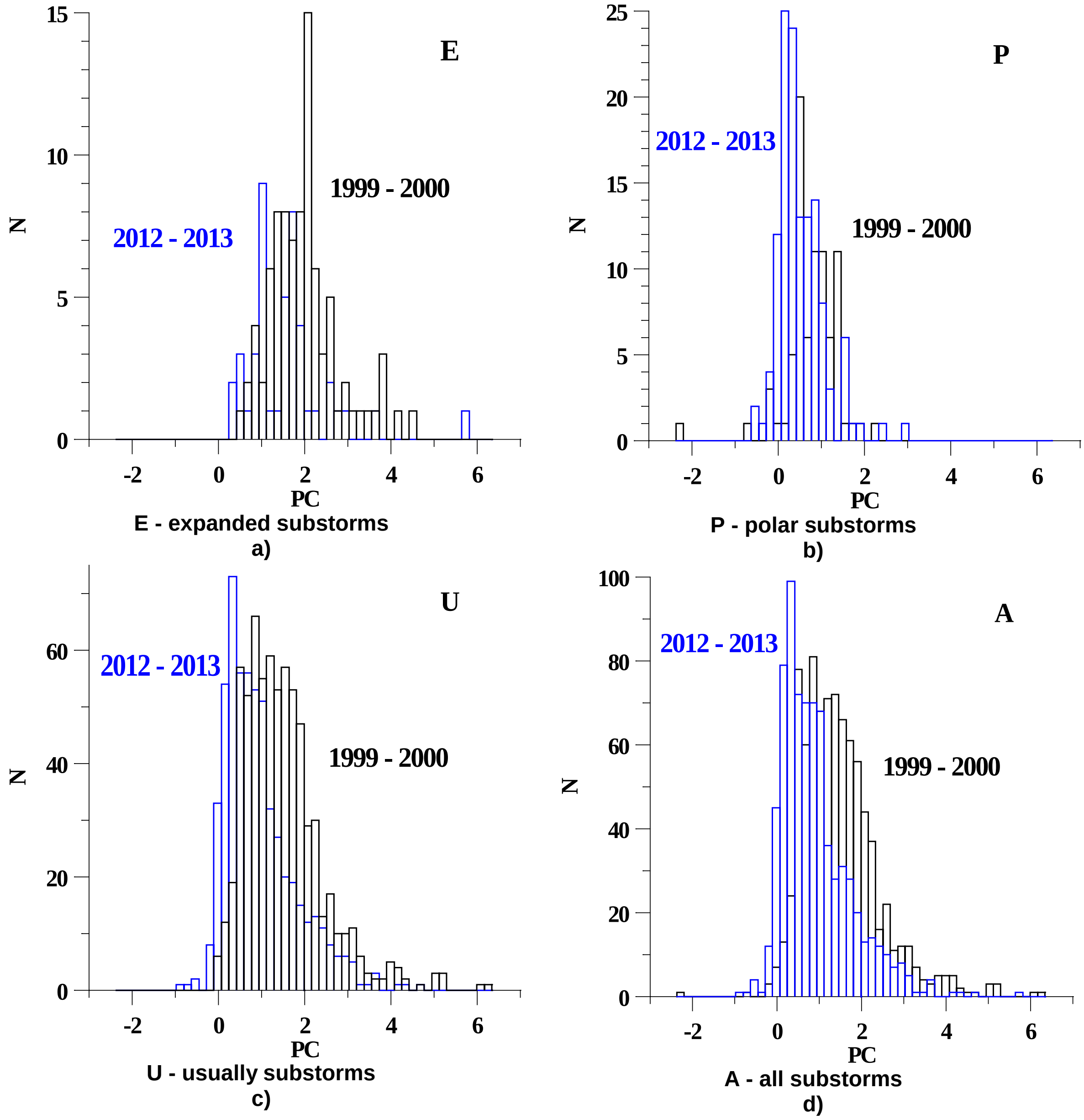

Fig. 3. The PC-index distributions (histograms) before 3 types of substorms during two intervals: 1999-2000 and 2012-2013: E - “expanded” substorms (*a*), P - “polar” substorms (*b*), U - “usual” substorms (*c*), A - all substorms (d).

We also calculated averaged values and the standard deviations of all of the PC-index values before the onset of all of substorms. In the Table 2 are presented averaged values and standard deviations of the PC-index.

Table 2. Averaged values and standard deviations of the PC-index

Type of substorm	1999-2000	2012-2013
“expanded” substorms	1.98±0.80	1.59±0.95
“polar” substorms	0.77±0.59	0.52±0.54
“usual” substorms	1.49±0.92	0.95±0.82
all substorms	1.47±0.93	0.91±0.82

It can be seen that the highest PC-index values are observed before the occurrence of the "expanded" substorms, the lowest value of the PC-index before the occurrence of the "polar" substorms, while the “usual” substorms occur at the intermediate values of the PC-index. At the same time, the PC-index values were 2.57-3.06 times less for the "polar" substorms than for the "expanded" substorms.

It should be noted also that for the substorms which observed during last solar maximum (2012-2013) the PC-index values were 1.3-1.6 times less than for the substorms during the large solar cycle maximum (1999-2000).

4. Discussion

We have carried out a comparative analysis of the occurrence conditions for different types of substorms which observed during the two maxima of solar activity, namely during the large solar cycle maximum (1999- 2000, with Wp> 100) and during the last maximum (2012-2013 with Wp~60). Three types of substorms, i.e., the “polar”, ”expanded” and “usual” substorms, were compared with respect to the interplanetary and geomagnetic conditions, namely, the solar wind and IMF parameters and PC-index values before the onset of three types of substorms, etc.

It is shown that the significant differences in distributions of the solar wind parameters (V_X , B_Z, P, N, T) has been not found between the substorms during 1999-2000 and substorms during 2012-2013. However, if we compare the two types of substorms - the“polar” substorms and the “expanded” subsrorms, one can see that the “polar” substorms are observed at low solar wind velocity and the “expanded” substorms – at higher values of the solar wind velocity. This result was obtained recently by Despirak et al. ([8]). However, in this paper, this result is confirmed by other long-time intervals of observations.

In our opinion, the new interesting result of our study is the finding the different values of the PC-index before the occurrence of all three types of substorms. It is shown that the highest PC-index values are observed before the "expanded" substorms, the lowest value of the PC-index before the "polar" substorms. Thus, the PC-index values are 2.57 - 3.06 times less for the "polar" substorms than for the "expanded" substorms. It should be noted that these two types of substorm observed at almost identical high geomagnetic latitudes. However, they appear in different situations and for different preceding conditions. It argues that the conditions of these substorms generation are different, i.e., they reflect the different processes in the magnetotail or different sources.

Conclusions

- Number of substorms is higher in 1999-2000 than in 2012-2013; the summer minimums of substorms number and spring and autumn maxima are common to both periods; the “polar” substorms behavior was opposite to other types of substorms behavior. The number of the “polar” substorms has maximum in the winter months; wherein it is noted that the “expanded” substorms occurrence maximum was observed in winter 1999-2000, but it was not observed in winter 2012-2013.
- The substorms onset latitudes were a little lower in 1999-2000 than in 2012-2013; the substorms latitudinal exetent was a little greater in 1999-2000 than in 2012-2013.
- There were no significant differences of the solar wind parameters (V_X, B_Z, P, N, T) before substorms in 1999-2000 and in 2012-2013.

- For all three types of substorms which observed during last solar maximum (2012-2013) the PC-index values are 1.3- 1.6 times lower than for substorms during the large solar cycle maximum (1999-2000). It is shown also that the PC-index values are 2.57 - 3.06 times lower for the "polar" substorms than for the "expanded" substorms.

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