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COMPARISON OF THE "EXPANDED" AND "POLAR" SUBSTORMS BEHAVIOR DURING THE 23 AND 24 SOLAR CYCLES

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Abstract. We presented the comparative analysis of the two different types of substorm behavior during the 23-th and 24-th solar cycles. The substorms have been studied in: (a) close to the 23-th solar cycle maximum (1999- 2000, Wp> 100); (b) close to the last maximum (2012-2013, Wp~60), (c) during the 23-th and 24-th solar cycle minima (1995-1996, Wp=3-17 and 2008-2009, Wp=3). As in previous study, we divided the considered substorms into 3 types according to auroral oval dynamics. The first type – the substorms which are observed only in auroral latitudes (called "usual" substorms); the second type – the substorms which propagate from auroral latitudes (<70º) to polar geomagnetic latitudes (>70º) (called "expanded" substorms, according to an expanded oval); and the third type – the substorms which are observed only at latitudes above ~70º in the absence of simultaneous geomagnetic disturbances below 70° (called "polar" substorms, according to a contracted oval). The aim of this work is the analysis of the space weather conditions before the onset of two types of substorms which observed at high geomagnetic latitudes - before "expanded" and "polar" substorms. Our analysis was based on the 10-s sampled IMAGE magnetometer data, and the 1-min sampled OMNI solar wind and Interplanetary Magnetic Field (IMF) data. The following substorm characteristics have been compared: (i) the seasonal variations of the occurrence, (ii) the solar wind parameters before the substorm onset, and (iii) the polar cap PC-index values before the substorm onset. The new interesting result of our study is the finding the different values of the PC-index before the different types of substorms. The PC-index was stronger before the "expanded" substorms than before the "polar" substorms. So, the PC-index values before the "expanded" substorm onsets were 1.5±0.7 (1995-1996, Wp~13), 1.1±0.8 (2008-2009, Wp~3) 1.6±0.9 (2012-2013, Wp~60), 2.0±0.8 (1999-2000, Wp ~105), and they were more than twice lower before the "polar" substorm onsets - 0.7±0.4 (1995-1996), 0.4±0.3 (2008-2009), 0.52±0.5 (2012-2013), 0.8±0.6 (1999-2000. It is shown also that for the substorms which observed during the solar minima (1995-1996 and 2008-2009), the PC-index values were 1.3 times less than ones closed to the solar maxima (1999-2000 and 2012-2013).

Introduction

One of the factors of the space weather is the magnetetosheric substorms excitation in the night sector of the auroral latitudes. Typically, the substorm intensity is estimated by the AE, AL, and AU indices of geomagnetic activity. These indices are calculated accordingly to the observation data from 12 ground-based auroral stations located at the different longitudes. However, these indices estimate the substorm activity too roughly because they do not reflect the substorm latitudinal features. The aim of this work is the analysis of the space weather conditions before the onset of different types of substorms. Substorms were divided into different types according their latitudinal features.

It is known that under the normal conditions, the auroral oval is located at the geomagnetic latitudes of about 65-67 degrees. Under the quiet conditions, the auroral oval shrinks and shifts to higher latitudes (above 70 degrees of the geomagnetic latitudes). It is the "contracted oval". In the disturbed conditions, the equatorward boundary of the auroral oval shifts to the lower latitudes, up to 50 degrees of latitudes, and the poleward boundary extends to the higher latitudes, it is the "expanded auroral oval" [1]. A search for the difference between the substorms occurring on the "normal", "contracted" and "extended" oval attracted the attention of the researchers [2] for a long time. In different studies, substorms were divided into "confined" and "widerspead" [3], "localized" and "normal" [4], "substorms on a contracted oval" and "normal" [5], "small" and "normal-size" [6], "high-latitude" and "usual" [7, 8], "polar" and "usual" [9], "polar" and "high-latitude" [10].

So, all substorms may be divided into 3 types according to the auroral dynamics: the first type – "usuall" substorms according to the normal auroral oval, the second type – the "expanded" substorms according to the expanded oval, the third type – the "polar" substorms according to the contracted oval. In our work we will consider only two types of substorms, which are observed at high latitudes. Namely, at the IMAGE profile above BJN station (71 degrees of geomagnetic latitudes). We term the first type of substorms as "expanded" substorms. Such substorm events begin at latitudes of the auroral zone and then move poleward. Namely, the substorm onset is observed at the latitudes from 54 to 66 degrees of the geomagnetic latitudes. And in the substorm maximal phase, the westward electrojet "center" is observed at 75.1 - 75.2 degrees of latitudes (IMAGE stations LYR-NAL). The second type of substorms we term as the "polar" substorms. The disturbances begin at geomagnetic latitudes above 70 degrees of the latitudes. Namely, substorms start and development at high-latitudes from 71 to 75 degrees of the geomagnetic latitudes. Below these latitudes, the disturbances are absent.

It is known that the 23-th and 24-th solar cycles significantly differ in their characteristics and ground effects. And we can assume that they may occur also in the substorm behavior during these periods. In our study, we analyzed the magnetic substorm occurrence during 23-th and 24-th solar cycles.

Data

To study the latitudinal substorm dynamics, i.e. the westward electrojet, we used the magnetic data of the IMAGE magnetometers chain Nurmijarvi – Ny Alesund, so, from 57 to 75 degrees of the geomagnetic latitudes. The solar wind and Interplanetary Magnetic Field (IMF) parameters measured by Wind spacecraft were taken from OMNI database. The 1995-1996, 1999-2000, 2008-2009 and 2012-2013 time intervals, close to two different maximums and minimums of the solar activity are used. There were analyzed above 800 events of "expanded" and "polar" substorms in the listed above years.

Results

We calculated the seasonal variations of substorms, observed in 4 different time periods – in 1995-1996, 1999-2000, 2008-2009 and 2012-2013 years. Fig. 1 presents the results of two different types of substorms study: P- "polar" substorms (green lines); E- "expanded" substorms (red lines).

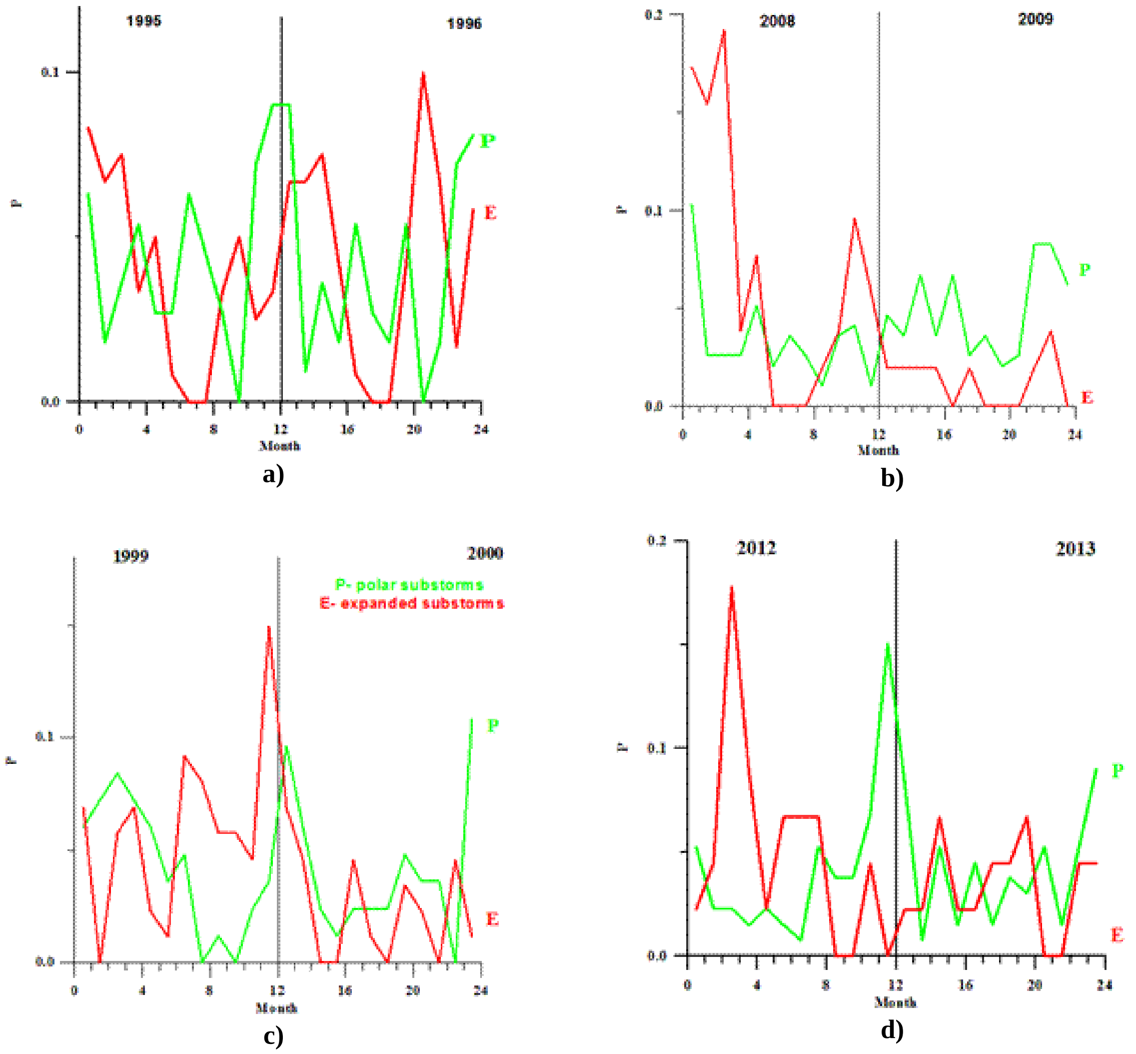

Figure 1. The normalized to the total substorms number distribution of the substorm number by month for "polar" and "expanded" substorms in: **a)** 1995-1996; **b)** 2008-2009; **c)** 1999-2000; **d)** 2012-2013 years.

The distributions of the month substorm number during the 23-th cycle is shown in the left panels, and during the 24-th solar cycles - in the right panels. It is seen that the "polar" substorm behavior was opposite to the "expanded" substorm behavior.

We downloaded the PC-index values before the onset of all the types of substorms, averaged for a 1.5 hours' interval prior to the moment of the substorm onset. PC-index is an empirical index of the magnetic activity in the polar cap, it is aimed to monitor the polar cap magnetic activity generated by the solar wind parameters. It is based on the data from a single near-pole station (Thule or Vostok). It is known, that PC-index values best correlated with the azimuthal component of the interplanetary electric field. In Fig. 2, there are presented the histograms of the PC-index values observed before the onset of the "polar" (P, green lines), "expanded" (E, red lines) and "usual" (U, blue lines) substorms.

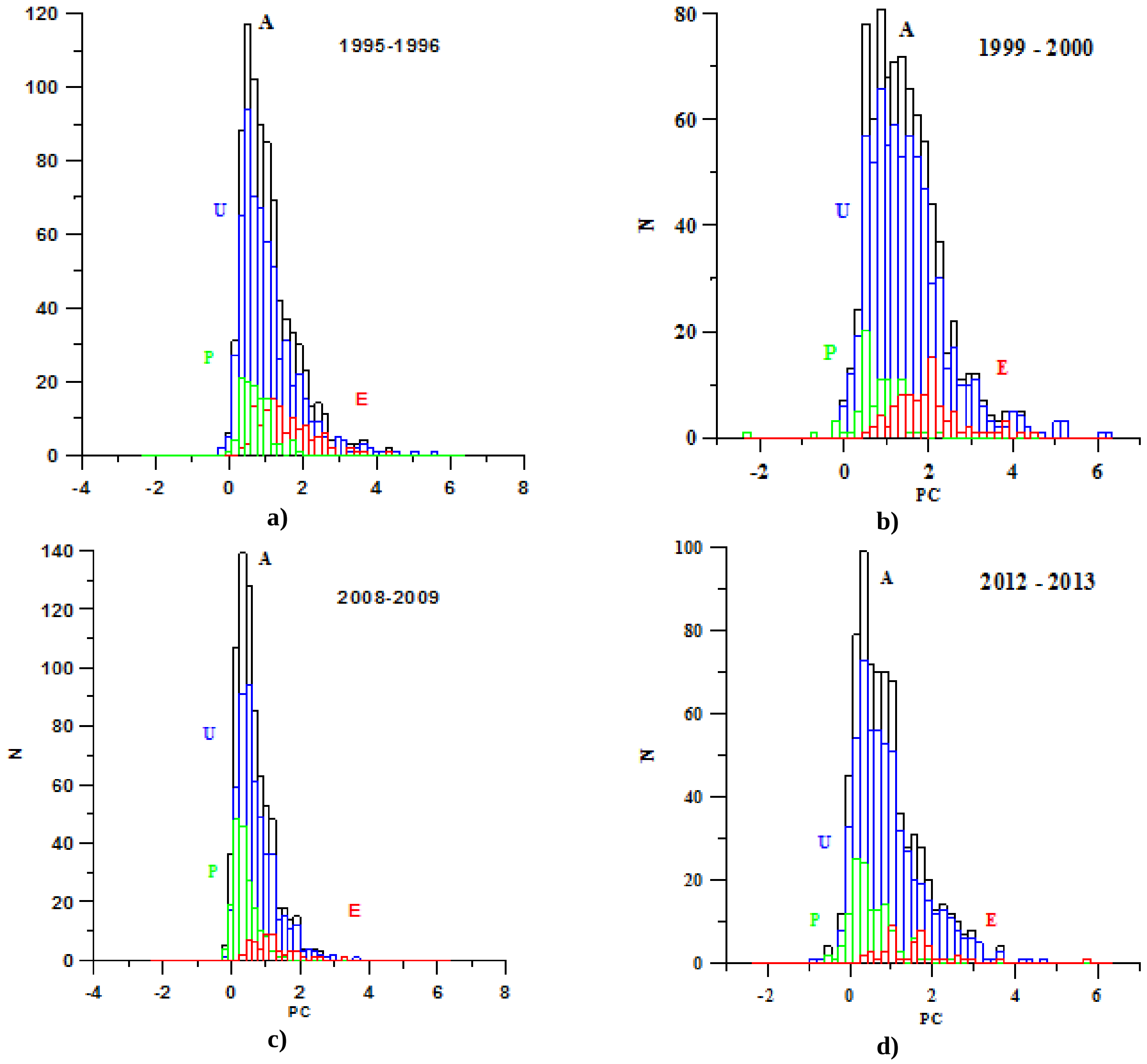

Figure 2. The PC- index values before the substorm onsets in 1995-9996 (**a**), 1999-2000 (**b**), 2008-2009 (**c**), and 2012-2013years (**d**)

Type of substorm	1995-1996	1999-2000	2008-2009	2012-2013
"expanded"	**1.5±0.7**	**2.0±0.8**	**1.1±0.8**	**1.6±0.9**
"polar"	**0.7±0.4**	**0.77±0.6**	**0.4±0.3**	**0.52±0.5**

Table 1. The averaged values of the PC-index before the onsets of the "polar" and "expanded" substorms for two solar cycle maxima (1999-2000 and 2012-2013), and two solar cycle minima (1995-1996 and 2008-2009).

In the Table 1, there are presented also the averaged values of the PC-index before the onsets of the "polar" and "expanded" substorms for these considered year periods.

It is seen that:

1) The PC-index values are about 2.6- 3 times lower for the "polar" substorms than for "expanded" substorms.
2) For all substorms, the PC-index values were 1.3 times lower during the solar cycle minima than solar cycles maxima.
3) For all substorms, the PC-index values were lower during the 24-th solar cycle than the 23th solar cycle.

We considered also some solar wind parameters before the substorm onsets. Namely, we calculated the 1.5 hour averaged components of IMF, Ey component of the interplanetary electric field, temperature, density and dynamic pressure. It is shown that there are no significant differences in the distributions of the solar wind parameters before the substorm onsets observed during the different periods of solar activity (the picture not presented here).

Summary

1. The summer minima and autumns and spring maxima of the substorm occurrence were observed during both cycles. But the substorm number is higher in the 23th solar cycle than in the 24^{th} solar cycle.
2. The seasonal variations of the "polar" substorms behavior was mainly opposite to the "expanded" substorms behavior.
3. The PC-index values are about 2.6- 3 times lower for the "polar" substorms than for "expanded" ones.
4. The PC-index values for substorms observed during the 24-th solar cycle are lower than for substorms during the 23-th solar cycle
5. The PC-index values for substorms during solar cycle minima (1995-1996 and 2008-2009) are ~ 1.3 times lower than for substorms during the solar cycle maxima (1999-2000 and 2012-2013).
6. There were no significant differences of the solar wind parameters before the substorms in the different solar cycle periods.

Conclusions

The comparative analysis of the space weather conditions for "expanded" and "polar" substorm observed at almost identical high geomagnetic latitudes during 23 and 24 solar cycles demonstrated that in both cycles, they appear under different solar wind conditions and IMF parameters.

The "polar" substorms behavior was opposite to the "expanded" substorms behavior, so we can suppose that they reflect different sources. But this question is open yet.

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References

1. Feldstein Y.L. G.V. Starkov (1967), Dynamics of auroral belt and geomagnetic disturbances. Planet. Space Sci., 15, 209-229.
2. Akasofu S-I, P.D. Perreault, F. Yasuhara, C.-I. Meng (1973). Auroral substorms and the interplanetary magnetic field. J Geophys Res, 78, 7490–7508.
3. Lui ATY, C.D. Anger, S.-I. Akasofu (1975) The equatorward boundary of the diffuse aurora and auroral substorms as seen by the Isis 2 auroral scanning photometer. J. Geophys Res, 80, 3603–3614.
4. McPherron R.L, C.T. Russell, M.G. Kivelson, P.J. Jr Coleman (1973) Substorms in space: The correlation between ground and satellite observations of the magnetic field. Radio Science, 8, 1059-1076.
5. Kamide Y, S.-I. Akasofu, S.E. DeForest, J.L. Kisabeth (1975) Weak and intense substorms, Planet Space Sci., 23, 579-587.
6. Petrukovich A.A., W. Baumjohann, R. Nakamura, T. Mukai, O.A. Troshichev (2000) Small substorms: Solar wind input and magnetotail dynamics. J Geophys Res, 105, 21109-21118.
7. Sergeev V.A., A.G. Yakhnin, N.P. Dmitrieva (1979) Substorms in the polar cap – the effect of high-velocity streams of the solar wind. Geomag Aeron (in Russian), 19, 1121–1122.
8. Despirak I.V., A.A. Lyubchich, Kh.K. Birnat, A.G. Yakhnin (2008), Poleward expansion of the westward electrojet depending on the solar wind and IMF parameters. Geomagn. Aeron., 48, no. 3, 284-292.
9. Kleimenova N.G., E.E. Antonova, O.V. Kozyreva, L.M. Malysheva, T.A. Kornilova, I.A. Kornilov, Wave structure of magnetic substorms in polar latitudes (2012), Geomagn. Aeron., 52, no. 6, 785-793.
10. Despirak I.V., A.A. Lyubchich, N.G. Kleimenova (2014), Polar and high latitude substorms and solar wind conditions. Geomagn. Aeron., 54, no. 5, 619-626.