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"POLAR" AND "HIGH LATITUDE" SUBSTORMS AND SOLAR WIND CONDITIONS

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Abstract. All substorms observed at high latitudes can be divided into 2 types - "polar" (observed only at >70º latitudes; at <70º latitudes disturbances are absent) and "high latitude" substorms (propagating from auroral (<70º) to polar (>70º) geomagnetic latitudes). The aim of this study was to compare solar wind conditions during these two types of substorms. For this purpose, we used the data of IMAGE magnetometers and the solar wind data base (OMNI) for 1995, 2000, 2006-2011 periods. There were selected 105 "polar" and 55 "high latitude" substorms. It is shown that "polar" substorms observed at low solar wind velocity, after passing high speed stream, during late recovery phase of a geomagnetic storm. "High latitude" substorms, on the contrary, are observed at high values of the solar wind velocity, increased temperature and pressure of the solar wind, while passing by the Earth recurrent high speed stream. In addition, the variability of the solar wind parameters for the "high latitude" substorms is stronger than for the "polar" substorms.

Introduction

It is well known that auroras and the westward electrojet move poleward during the expansion phase of a substorm ([1], [2], [3]). Substorm disturbances propagate sometimes to extremely high geomagnetic latitudes. Substorms observed at high geomagnetic latitudes can be divided into two different types: "polar" and "high latitude" substorms. In the first type, a disturbance starts at geomagnetic latitudes higher 71° and then propagates poleward; geomagnetic disturbances are absent at latitudes below 70°. These substorm disturbances were called "polar" substorms [6]. Substorms of the second type starts at auroral latitudes, then propagate poleward, and the westward electrojet (or the westward electrojet center) moves to extremely high geomagnetic latitudes (>75°) in the substorm development maximum. These substorm disturbances were called "high latitude" substorms ([7], [8], [9]).

Substorms of the first type, i.e., "polar" substorms, where all disturbances are concentrated in a narrow latitude region near the polar cap, usually occur under a low geomagnetic activity, when the auroral oval is contracted and poleward shifted [10]. Such substorm disturbances are often called "substorms on the contracted oval." Studies have shown that "substorms on the contracted oval" do not differ from usually substorms in the parameters, both in the ionosphere and the magnetospheric tail, and usually occur when the B_Z IMF component is northward directed (B_Z>0) [11],[12],[13],[14].

Substorms of the second type, i.e., "high latitude" substorms, start in the auroral zone and then propagate to high latitudes [15], [16], [17], [18], [19], [20], [21], [22]. No differences in parameters were revealed between "high latitude'and ordinary substorms; however, it was shown that the solar wind velocity is a determining factor for occurrence of "high latitude" substorms. "High latitude" substorms are mainly observed during the period of a solar activity minimum, where recurrent high speed streams from coronal holes prevail [7], [23]. During a solar activity maximum, where streams related to coronal mass ejections (CMEs) prevail, "high latitude" substorms are observed seldom [9], [24]. "High latitude" substorms are also identified during compressed plasma propagation at fronts of solar wind streams, the so called Sheath and CIR regions [25]. However, these substorms contribute a little in the observation statistics of substorms at high latitudes, since the duration of Sheath and CIR regions is small as compared to the duration of recurrent high speed solar wind streams.

The aim of this work is the comparison of the interplanetary conditions under which "polar" and "high latitude" substorms are observed.

Data

Data from the IMAGE magnetometer stations for the 1995 and 2006_2001 periods, close to the solar activity maximum, and for the period of the solar activity maximum (2000) were used. The solar wind and IMF parameters were determined from the OMNI data base. We have chosen and analyzed 160 events of substorm observation at high geomagnetic latitudes for the 1995, 2000, 2006–2011 periods: 105 of them were "polar: substorms and 55 were "high latitude" substorms. To study the latitudinal shift of the substorm westward electrojet, data from IMAGE ground based magnetometers were used, namely, the NUR–NAL (Nurnijarvi–Ny Alesund) meridional chain from 56.89° to 75.25° geomagnetic latitudes. To construct a latitudinal profile of the westward electrojet, the MIRACLE network was used (*http://www.space.fmi.fi/MIRACLE/).*

The concept of the westward electrojet "center" (the region of the highest currents) is often used for latitudinal positioning of the westward electrojet, since it occupies a large spatial area during the substorm expansion phase and can be inhomogeneous [26]. The method for electrojet "center"positioning is described in detail in [9]. Let us note that we consider a "high-latitude" substorm if it starts at the auroral zone and the westward electrojet "center" is observed at LYR or NAL stations during the maximal substorm phase, i.e., at 75.12° (78.9°) or 75.25° (78.2°) geomagnetic (geographic) latitude.

Results

Both types of substorms -"polar" and "high-latitude"—were compared with the interplanetary conditions, i.e., the presence/absence of high speed solar wind streams, the presence of a geomagnetic storm, etc. The examples of considered events are presented in Fig. 1.

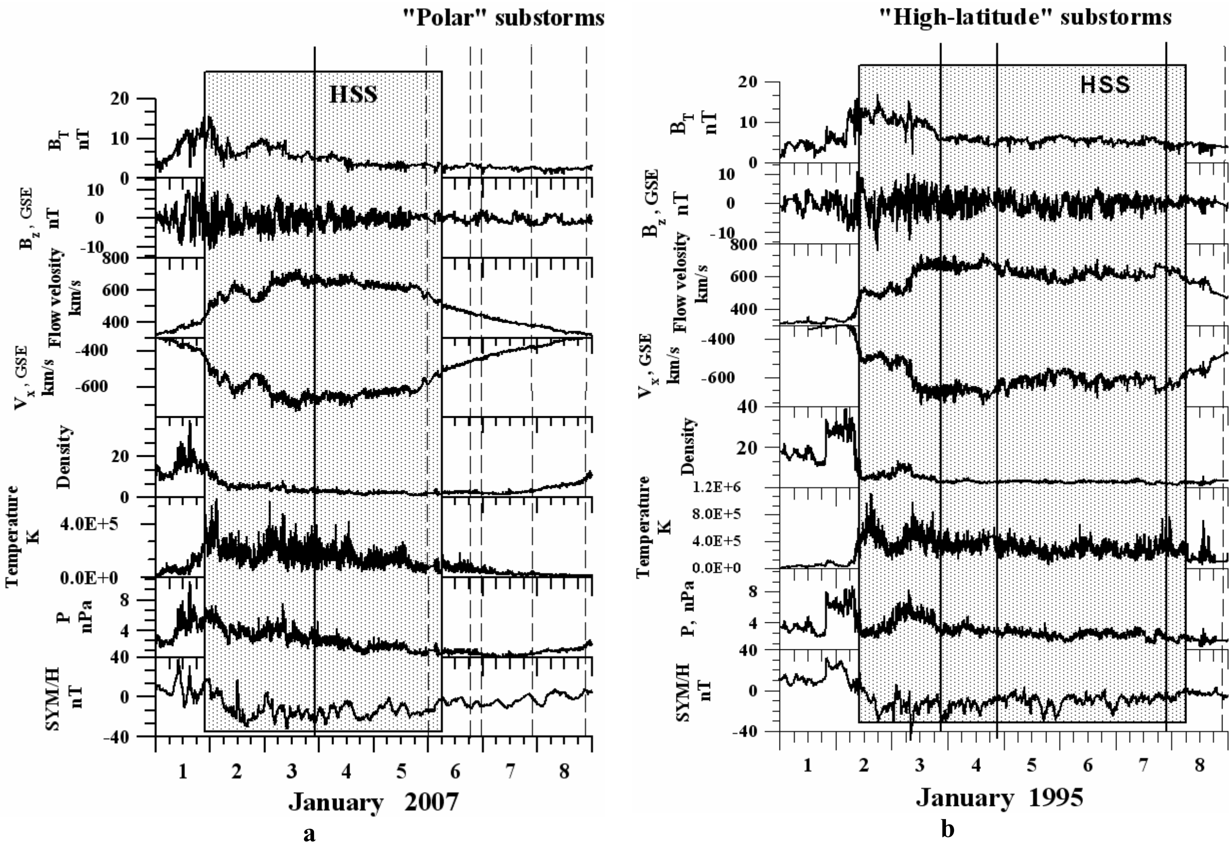

Figure 1. Solar wind and IMF parameters (B_T, B_Z, V, V_X, N, T, P) and the SYMN/H index for two high speed streams on January 1–6, 2007 and January 2–8, 1995. Top-down: magnetic field magnitude and the IMF B_Z component, the stream velocity V, the X component of the solar wind velocity, the density N, the temperature T, solar wind dynamic pressure P, and the geomagnetic index SYMN\H. Boundaries of the high speed stream (HSS) are shown by gray rectangles. The onset times of "polar" and "high-latitude" substorms according to the IMAGE data are marked by the vertical solid and dashed lines, respectively.

Fig. 1 shows the solar wind and IMF parameters for two high speed streams, on January 1–6, 2007 and January 2–8, 1995. High speed streams are shown in the both cases by gray rectangles. The onset times of "high latitude" and "polar" substorms are superimposed on these data according to the IMAGE data; they are shown by the solid and dashed lines, respectively.

Fig. 1a presents the solar wind conditions during the observation of a "polar" substorm, and Fig. 2b shows them during the observation of "high-latitude" substorms. In the first case (January 1–6, 2007), "polar" substorms occurred on January 5, 6, 7, and 8, i.e., at the end of a high speed stream and after it, when the solar wind velocity decreased from the high values to low ones. The solid curve shows a "high-latitude" substorm that was observed on January 3, 2007.

Fig. 1b presents solar wind conditions during "high-latitude" substorms; they occurred on January 2, 3, and 7, i.e., during the high speed stream on January 2–8, 1995; after the stream passed, during the solar wind velocity drop, a "polar" substorm was observed. According to the SYMN\H index, no geomagnetic storm was observed during

January 1–6, 2007. There was a geomagnetic storm January 2–8, 1995, and the"polar" substorm was observed during its recovery phase.

Fig. 2 shows the solar wind parameters for the 1.5 hour interval preceding the moment of the substorm maximal development. The averaged IMF B_Z component, the E_Y component of the electric field, the temperature T, and the dynamic pressure P of the solar wind are shown. "Polar" substorms are marked by the diamonds, and "high-latitude" ones are noted by the crosses. It is evident that the solar wind velocity is the main differentiating factor for these two substorm types. "Polar" substorms are observed at low solar wind velocities (mainly ~300–400 km/s), and "high-latitude" substorms are observed at high velocities (> 500 km/s). In addition, "high-latitude" substorms are observed at higher values of the temperature and the pressure than polar substorms.

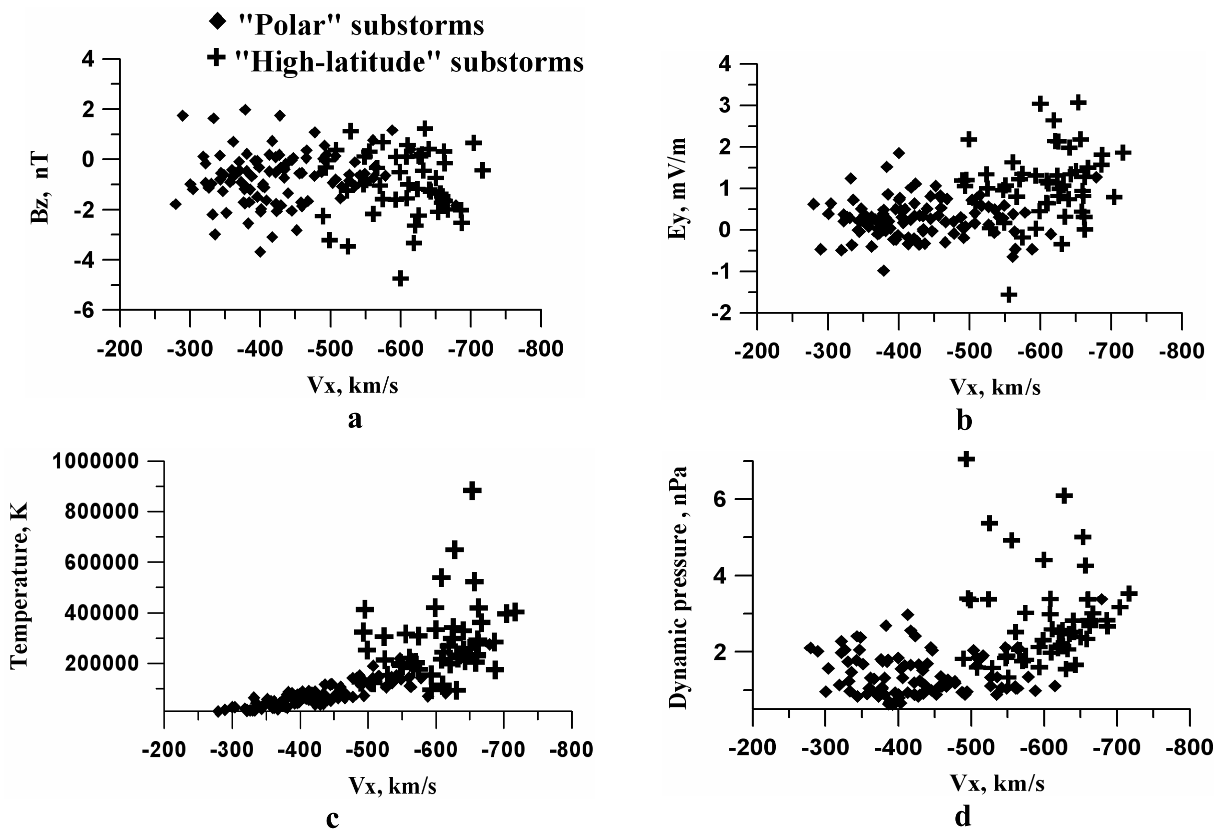

Figure 2. IMF and solar wind parameters: (a) IMF B_Z, (b) IMF E_Y, (c) temperature T, and (d) solar wind dynamic pressure P averaged over 1.5 hours before the onsets of polar (diamonds) and high latitude (crosses) substorms.

The standard deviation was calculated for all considered parameters (V_X, B_Z, E_Y, T, P) before the onsets of these two substorm types. It is shown that disturbances (the standard deviations) of the parameters are higher before the occurrence of "high latitude" substorms than "polar" substorms. (The picture is not presented here).

Conclusions

We have carried out a comparative analysis of the conditions for the occurrence of substorms at high geomagnetic latitudes on the basis of the data of the IMAGE geomagnetic stations.

It has been shown that substorms for which disturbances are identified only at geomagnetic latitudes higher ~70° are observed at a low solar wind velocity, after the passage of a recurrent high speed stream, during the late recovery phase of a geomagnetic storm.

Substorms during which disturbances move from the auroral (<70°) to the polar (>70°) latitudes are, in contrast, observed at a high solar wind velocity and increased values of solar wind temperature and pressure, while a recurrent high speed stream passes by the Earth.

In addition, the variability of solar wind parameters for the "high latitude" substorms is stronger than for "polar" substorms.

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