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STUDY OF MID-LATITUDE POSITIVE BAYS DURING SUBSTORMS OVER SCANDINAVIA – A CASE STUDY

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Abstract. The purpose of this work is to study the midlatitude effects during substorms observed in different interplanetary conditions over Scandinavia. To identify the substorm disturbances, data from the magnetometer networks IMAGE, SuperMAG and INTERMAGNET in the range 31.8° - 75.25° CGMLat and 92° - 104° CGMLon were used. To verify the interplanetary and geomagnetic conditions, data from the CDAWeb OMNI (http://cdaweb.gsfc.nasa.gov/), the catalog of large-scale solar wind phenomena (ftp://ftp.iki.rssi.ru/omni/) and from the WDC for geomagnetism at Kyoto (http://wdc.kugi.kyoto-u.ac.jp/index.html) were taken.

Two isolated substorms were chosen, with different intensity: ALmin values ~ -270 nT and ~ -1300 nT, respectively. The first substorm occured on 6 February 2018, at 21:25 UT, under quiet conditions: during slow solar wind streams. The second substorm, at 19:10 UT on 27 September 2020, originated under moderately disturbed conditions: during a high-speed stream (HSS) in the solar wind, just after the passage of EJECTA by the Earth.

It was found out, that the latitude of the bay sign conversion from negative to positive values in the case of quiet solar wind conditions, appeared at latitude, 7° higher than the one in the case of disturbed conditions. In both cases, the amplitude of the positive bays, after a maximum near the sign conversion latitude decreased gradually towards the lower latitudes, with a difference between the minimal and maximal amplitude of about 50%. The magnetic bays kept their duration throughout the whole latitudinal range, ~115 min. for the first case and ~ 60 min. for the second one. It was ascertained, that the mean positive bays amplitude in the case of disturbed conditions was 4 times higher than the amplitude during quiet conditions.

Introduction

The main magnetic disturbances in the Earth's magnetosphere are associated with the development of substorms, which occur more often than magnetic storms. It is known that substorms are a typical phenomenon in the auroral latitudes (~ 60°- ~ 71° MLAT) [1] but depending on the conditions in the solar wind and the magnetic activity, the substorms can reach both very high latitudes (>70° MLAT) (e.g. [2,3,4]) and can propagate to middle (~ 50° MLAT) latitudes [5]. Note, that magnetic substorms at auroral latitudes are observed as negative X bays, and vice versa, at middle latitudes they are expressed by positive bays in the X-component of the ground-based magnetic field (midlatitude positive bays, MPB) [6]. The first studies of positive bays considered this effect to be low latitude reverse currents of the western electrojet [7]. Subsequently, the emergence of positive bays was explained by ascending field-aligned currents [8]. But then it was discovered that the positive mid-latitude bays, which are usually observed during the expansion phase of a substorm. Currently the generally accepted view is, that the positive bays are associated with a substorm current wedge (SCW) [6].

It is worth noting that substorms, which occurred during different conditions in the solar wind can differ significantly from each other (e.g., [9,10,11]). So, depending on the large-scale structures in the solar wind we can see various categories of substorms: "limited" and "extended" [12], "localized" and "normal" [13], "substorms on the contracted oval" and "normal" [14], "polar" and "usually" [15], "high latitude" and "normal" [4], "expanded" and "polar" [16]. Hence, the development of positive bays at midlatitudes during substorms should also have some diverse characteristics, according to the different conditions.

In this context the basic aim of this study is to evaluate the mid-latitude effects of substorms occurred over Europe during different solar wind conditions. Two isolated substorms were chosen, which developed during quiet and disturbed conditions: on 6 February 2018 and on 27 September 2020.

Data

To identify the substorm disturbances, and to study the further development, data from the magnetometer networks IMAGE, SuperMAG and INTERMAGNET in the longitudinal band 90° - 104° GMLon, which is round the longitude of the Bulgarian station Panagjurishte (~97° GMLon), and the largest possible interval of GM latitudes: 31.8° - 75.25° GMLat were used. To ascertain the interplanetary and geomagnetic conditions, the OMNI data base (http://cdaweb.gsfc.nasa.gov/), the catalog of large-scale solar wind phenomena (http://www.iki.rssi.ru/omni/) and the WDC for geomagnetism at Kyoto (http://wdc.kugi.kyoto-u.ac.jp/index.html) have been used.

Interplanetary and geomagnetic conditions

Two isolated substorms were winnowed out for the study.

The first substorm, at 21:25 UT on 6.02.2018, occurred under quiet solar wind conditions. A slow stream was observed for this day, Vx increased gradually from ~ -320 km/s to ~ -420 km/s before the substorm, the IMF Bz was ~ -4 nT. According Kyoto WDS, the values of the main geomagnetic indexes were moderate: the AL index was about -270 nT, SYM/H~-5 nT, Kp=1-.

The second event, at 19:12 UT on 27.09.2020 occurred under comparatively disturbed conditions, against an interplanetary background of a high-speed stream (HSS), just after a small Coronal Mass Ejection (CME), consisting of Sheath and Ejecta. An interplanetary shock was registered after Ejecta. Before the substorm onset Vx was about -580 km/s and was on the decrease, the IMF Bz, after fluctuations around 0, jumped down by 8 nT, and then keeped to -8 nT for more than one hour. The AL index value was ~ -1300 nT, but a magnetic storm did not yet develop in this time (SYM/H~-25 nT), the general disturbance of the ground-based magnetic field was moderate (Kp=5-).

Substorms development

The IMAGE magnetometers chain (PPN-NAL) data have shown that more than 3 hours before the substorms there weren't perceptible disturbances. The substorm on 6.02.2018 began at 21:25 UT at ~67° GMLat (stations MAS-SOR), and the center of the westward electrojet was at ~69.7° GMLat (between SOR and BJN) (determined by Z – component variations).

The substorm on 27.09.2020 started at 19:12 UT at ~67° GMLat (SOR), and the center of the electrojet propagated to ~75° GMLat (HOR-LYR).

The substorm appearance at midlatitudes

To study the appearance of the selected substorms at midlatitudes, the magnetic field disturbances from auroral to midlatitudes were examined in more detail by data from 20 stations situated in the following longitudinal and latitudinal ranges: from 92° to104° GMLon and from 65° to 31° GMLat. This longitudinal range is located close to the IMAGE meridian (NAL-NUR) and the Panaguriste station (PAG, Bulgaria).

In Fig.1 the variations of X-component of the magnetic field at chosen stations for both substorm events are shown. The approximate time of the midlatitude positive bays (MPB) onset is marked by red vertical lines. The MPB are observed in both cases below the negative bays at auroral latitudes. As it is seen from Fig. 1, the bay sign conversion latitude for the substorm on 06 February 2018 was at about 63° GMLat, between the stations SOD (Sodankyla) and LYC (Lycksele). The conversion latitude for the substorm on 27 September 2020 was at about 56°, between the stations UPS (Upsala) and TAR (Tartu). Thus, the latitude of the bay sign conversion in the case of quiet solar wind conditions appeared at latitude of about 7° higher than the one in the case of disturbed conditions.

From Fig.1 it is seen that the MPB amplitudes in both cases are different. Furthermore, they changed with the decreasing of the latitude. A difference of about 50% between the minimal and maximal positive amplitude at different latitudes for each of the cases was obtained.

In Fig.2, the dependence of the MPB amplitude on the geomagnetic latitude for the event on 6.02.2018 (left panel) and the one on 27.09.2020 (right panel), is presented. In order to reveal better the dependence, in view of the strong dependence on the geomagnetic longitude, as well, the longitudinal band was divided into three narrower strips (90°-95°, 95°-99°, 99°-104° GMLon). The data grouped in this way, are indicated by different symbols. The amplitude of the MPB initially increased towards the lower latitudes and after a maximum at about 50° GM latitude decreased gradually. It is seen also, that the MPB amplitude during the substorm in disturbed conditions is larger than the one during quiet conditions. The mean MPB amplitude for the event on 6.02.2018 was ~13.7 nT, and for the second event on 27.09.2020 - ~55 nT. So, the mean positive bays amplitude in the case of disturbed conditions was about 4 times higher than the MPB amplitude during quiet conditions.

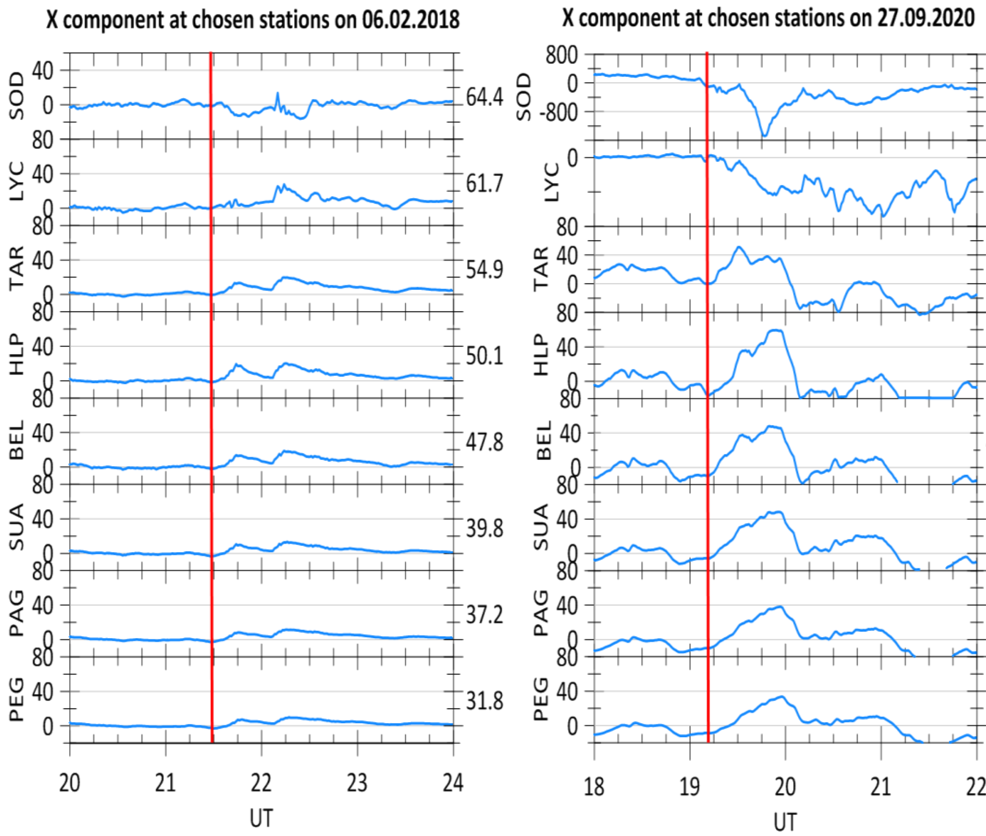

Figure 1. Variations of the X magnetic component by chosen stations of the INTERMAGNET magnetometer network observed during both substorms: on 06 February 2018 (left panel) and on 27 September 2020 (right panel). The station name abbreviations are shown at the left side of the graphs, and their geomagnetic latitudes – at the right side. The approximate time of the MPB onset is indicated by red vertical lines.

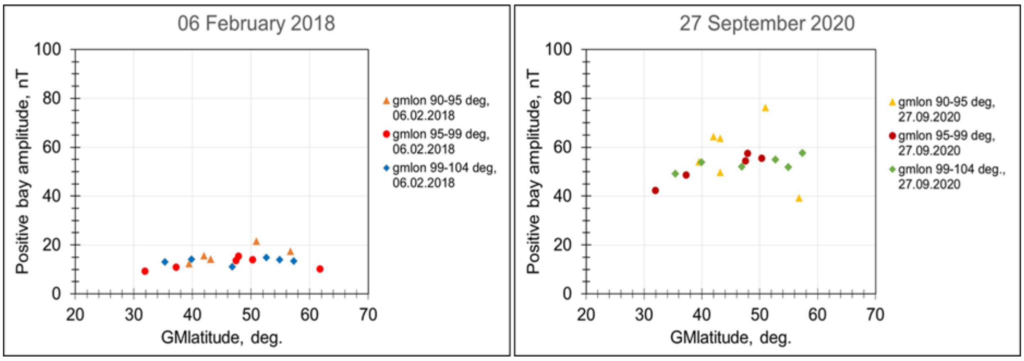

Figure 2. The dependence of magnetic positive bays (MPB) amplitude on the geomagnetic latitude for the substorms on 06 February 2018 (left panel) and on 27 September 2020 (right panel). The results for the examined longitudinal intervals are marked as follows: 90°-95° GMLon – by triangles, 95°-99° GMLon – by circles, and 99°-104° GMLon – by diamonds (shown in the right part of the panels).

Summary

This study has investigated the effect of two substorms, occurred during different interplanetary and geomagnetic conditions, namely the substorms at 21:25 UT on 6.02.2018 and at 19:12 UT on 27.09.2020, at midlatitudes. The following results have been obtained:

1) The latitude of the bay sign conversion from negative to positive values in the case of quiet solar wind conditions appeared at latitude of 7° higher than the one in the case of disturbed conditions;
2) The amplitude of the positive bays initially increased towards the lower latitudes and after a maximum at about 50° GM latitude decreased gradually;

3) A difference of about 50% between the minimal and maximal positive amplitude at different latitudes for each of the cases was obtained;
4) The mean positive bays amplitude in the case of disturbed conditions was about 4 times higher than the amplitude during quiet conditions.

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