Response of the High-latitude Daytime Magnetic Bays to the IMF By: Case Study

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Accepted: 22 February 2019

Abstract We studied dayside magnetic disturbances, that were registered at the high-latitudes when the Interplanetary Magnetic Field (IMF) was northward (the IMF Bz > 0) and the IMF By dominated over the IMF Bz (|By|/|Bz| > 1). We investigated the high-latitude daytime magnetic bays observed on 04 August 2010 and 22 January 2012. Our study was based on the ground-based IMAGE magnetometer data; IMF OMNI one-minute data; vector distributions of the geomagnetic field measured by ground-based magnetometers and provided by the AMPERE project; maps of field-aligned currents (FACs) intensity from the AMPERE project, and ionospheric convection patterns from SuperDARN. It was shown that under the positive IMF Bz and |By|/|Bz| > 1, the sign of the dayside polar magnetic bays is controlled by the IMF By sign. We suppose that the studied dayside high latitude bays could be caused by enhancement of the *NBZ* system of FACs.

Keywords: polar magnetic disturbances, interplanetary magnetic field, field-aligned currents, high-latitude ionospheric convection.

Introduction

It is generally agreed that no new energy input into the magnetosphere is evident under the positive IMF Bz component. But in the polar region, dayside bay-like magnetic disturbances could be associated with the high-latitude ionospheric electric currents, i.e., the polar electrojet – PE (e.g., Iwasaki, 1971; Friis-Christensen and Wilhjem, 1975; Feldstein, 1976; Feldstein et al., 2006). We studied this kind of magnetic disturbances observed during several strong magnetic storms in (Kleimenova et al., 2015; Levitin et al., 2015; Gromova et al., 2017). It was shown that these dayside high latitude bay-like magnetic disturbances were typically observed under the northward IMF Bz.

The influence of the IMF By on the dayside high-latitude magnetic bays has been discussed in (Friis-Christensen and Wilhjelm, 1975, Feldstein et al, 2006, Gromova et al, 2018). It was found that polar electorojet (PE) can exist in the daytime sector at the latitudes of the auroral oval location (~73° - 79° of the geomagnetic latitude). The current direction of the PE is determined by the IMF By sign, the eastward PE current is observed under the IMF By > 0 and the westward one is observed under the IMF By < 0. But the role of the ratio of the IMF components in the development of high-latitude dayside magnetic bays was not taken in the consideration.

However, in (Friis-Christensen et al, 1985; Zhou et al., 2000; Vennerstrom et al., 2002; Lukianova and Christiansen, 2006 and some others), it was found that the ratio of the IMF Bz and By components (|By|/|Bz|) plays important role in the dynamics of the high-latitude geomagnetic and ionospheric disturbances, especially during the IMF By-dominated periods.

Previously (Gromova et al., 2017), we examined two cases of daytime magnetic bays in the polar region when the strong *positive IMF Bz dominated over the IMF By*. It was shown that the sign of these dayside magnetic bays coincided with the IMF By sign.

The aim of this paper is to analyse the response of daytime polar magnetic bays to the IMF conditions, when *the IMF By dominates over the positive IMF Bz* unlike the above mentioned events. Here we present the results of case study of the high-latitude daytime magnetic bays observed on 04 August 2010, and on 22 January 2012.

Data

Our study is based on:

– ground-based IMAGE magnetometer data (http://space.fmi.fi/image);
– IMF data sets of the 1-min resolution OMNI database (http://omniweb.gsfc.nasa.gov);
– AMPERE data, based on the magnetic measurements on 66 low-altitude globally distributed Iridium communication satellites (http://ampere.jhuapl.edu/products);
– maps of the ionospheric convection patterns from SuperDARN (http://vt.superdarn.org).

We used ground-based data from 5 high-latitude stations of the Scandinavian magnetometer meridian chain IMAGE: Ny Ålesund (NAL), Longyearbyen (LYR), Hornsund (HOR), Bear Island (BJN) and Sørøya (SOR) spaced from 67^0 up to 75^0 of geomagnetic latitudes. The local geomagnetic noon at these stations corresponds to 09 UT.

Observations and Discussion

In this study, we examined the magnetic disturbances observed in the post-noon sector of the high latitudes. We analyzed the magnetic bays recorded at high-latitude IMAGE stations on 04 August 2010 and 22 January 2012 at 09 – 12 UT (12 – 15 MLT) under various IMF conditions.

1. Let’s consider the IMF variations and daytime high-latitude magnetic bays presented in Fig. 1. The upper panel of Fig.1a demonstrates variations of the IMF Bz and By components. On 04 August 2010 (Fig. 1a), the IMF Bz remained positive during the whole interval, while the IMF By varied in time from positive to negative. On 22 January 2012 (Fig. 1b), the IMF Bz changed from positive to negative, and at the same time, the IMF By changed from negative to positive.

The bottom panel of Fig. 1b shows the difference magnetograms of the IMAGE high-latitude stations during 03÷15 UT (06÷18 MLT) of 04 August 2010, and the same. These vectors during the same interval on 22 January 2012, are shown in Fig. 1b. The difference magnetograms have been computed as the magnetic variations of any given day, comparing to the quietest day magnetograms in the same month of 2009. The ground-based observations of 2009 are used as the reference level of difference magnetograms, because 2009 has been recognized as the most magneto-quiet year due to extremely low level of geomagnetic

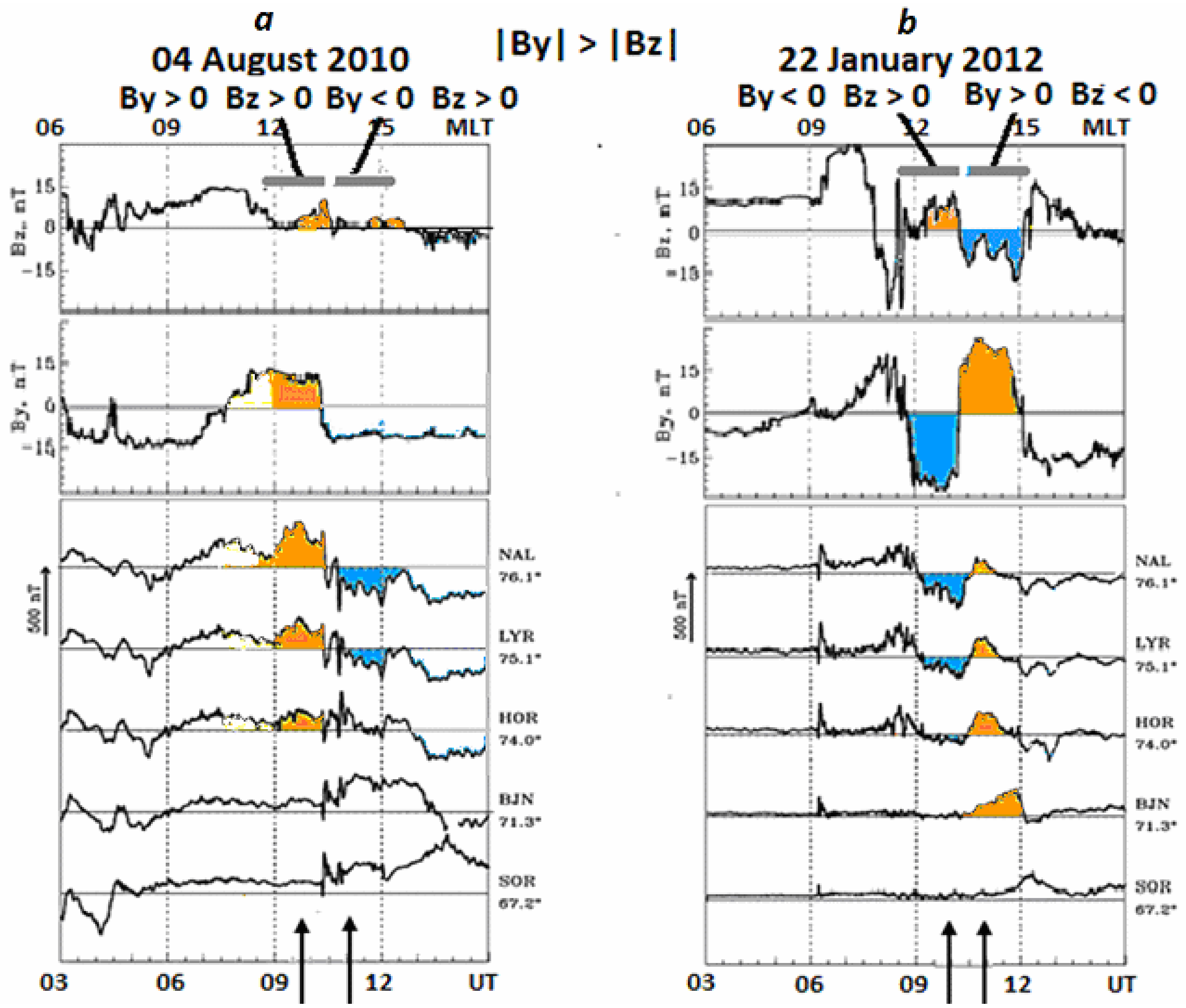

Fig. 1. The IMF Bz and By and the IMAGE difference magnetograms on 04 August 2010 (a), 22 January 2012 (b). The considered dayside magnetic bays are marked by orange/blue depending on IMF By or Bz component signs. The gray horizontal bars show the post-noon daytime intervals under study. The arrows on the UT-time axis point the moments under further consideration.

activity (Levitin et al., 2014). Horizontal bars show the post–noon daytime sector under study.

The positive dayside magnetic bays were observed at the IMAGE high-latitudes NAL – HOR stations at ~ 09:00-10:30 UT on 04 August 2010 and at 10:30 – 12 UT on 22 January 2012. In Fig. 1, they are marked by orange and pointed by arrows on the UT-time axis. Note, that the IMF By was positive in the both intervals while the IMF Bz was positive in the first event and negative during the second one.

At ~10:30 -12:00 UT of 04 August 2010 and at 09:00 – 10:30 UT of 22 January 2012, one can observed the negative dayside magnetic bays at the same high latitude stations. They are marked by blue in Fig.1a and 1b and are also pointed by arrows on the UT-time axis. The IMF By was negative and Bz was positive during both intervals.

The IMF By component dominated over the IMF Bz both on 04 August 2010 and on 22 January 2012. The ratio |By|/|Bz|, averaged for the interval, and was equal 4.5 and 3.2 respectively

We suppose that when |By|/|Bz| >1, the sign of daytime high latitude magnetic bays is controlled by the IMF By sign, both for the northward (positive) IMF Bz and southward (negative).

2. Figures 2 and 3 allow to discuss the spatial distribution of the horizontal vectors of the geomagnetic disturbances on the Earth' surface and on the ionospheric level, observed during the events under consideration.

Figure 2a illustrates the events of 03–15 UT on 04 August 2010 and shows variations of the IMF Bz and By components (upper panel) and the horizontal geomagnetic field vectors (bottom panel) that have been constructed from the ground-based difference magnetograms of IMAGE stations, presented in Fig.1. The vortices created by the horizontal geomagnetic field vectors of *counter-clockwise* direction are pointed by thin red arrows, and *clockwise* vortices are pointed by thin blue ones. These specified time moments are pointed by arrows on the UT-time axis in Fig. 2a. Figure 2b demonstrates the plots of spatial distribution of the horizontal magnetic disturbance vectors on the ionospheric level, provided under the AMPERE project (http://ampere.jhuapl.edu/products/plots) at about 09:45 UT and 11:05 UT. The vortices created by the geomagnetic field vectors over the high-latitude IMAGE stations are marked pointed by red (*counter-clockwise* direction) or blue (*clockwise* direction) arrows. Small circle points the IMAGE station location.

On 04 August 2010, the IMF Bz component remained positive during the whole interval under consideration (Fig. 2a, upper panel). As shown in Fig. 2a and 2b, at about 09:45 UT, when the IMF By was positive, the ground-based magnetic vectors, and also the AMPERE plots, demonstrate the *counter-clockwise* vortex (red arrows) over the high-latitude stations (NAL-HOR) and simultaneously the *clockwise* one (blue arrows) over stations located at the lower latitudes (BJN-SOR).

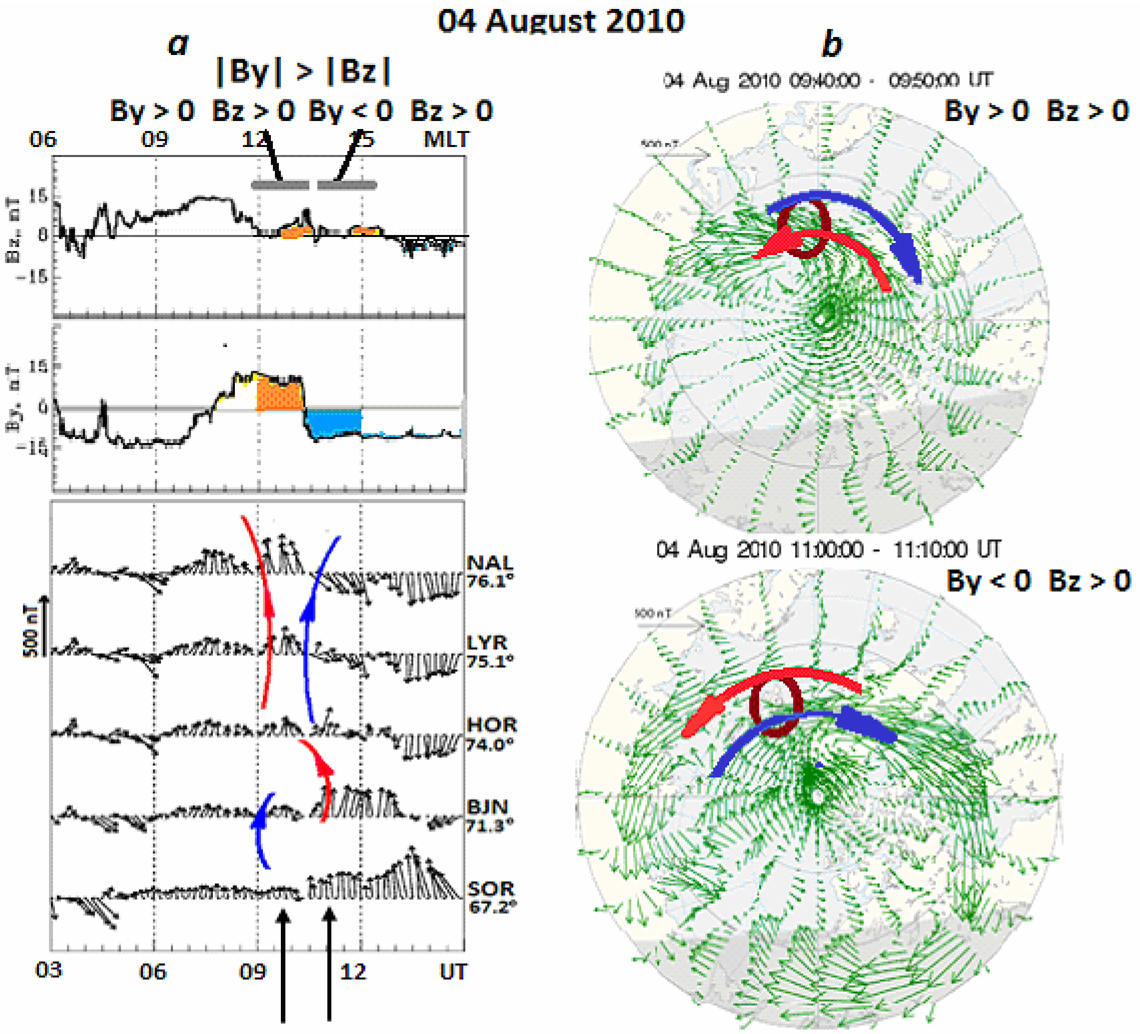

Fig. 2. Event of 04 August 2010: a) Upper: the IMF Bz and By variations. The gray horizontal bars show the post-noon daytime intervals under study. Bottom: horizontal vectors of the geomagnetic field. b) The spatial distribution of the magnetic disturbances horizontal vectors provided under AMPERE. As in Fig2a and in Fig 2b, the arrows indicate direction of the magnetic field vortices. The small ovals show the location of the high-latitude IMAGE stations. Arrows on the UT-time axis point the moments under further consideration.

Later on, at ~11:05 UT, when the IMF By became negative, the vortices changed their direction to the opposite ones, i.e. one can see the *clockwise* vortex (blue arrows) over the high-latitude IMAGE stations and the *counter-clockwise* vortex (red arrows) over the lower latitude ones.

The variations of the IMF Bz and By components, horizontal geomagnetic field vectors, plots of spatial distribution of the horizontal magnetic disturbances vectors on the ionospheric level in the 22 January 2012 event are shown in Fig.3 as in Fig. 2 for the 04 August 2010 event.

On 22 January 2012, the IMF Bz component changed its sign from positive to negative at about 10:20 UT (Fig. 3a, upper panel). As it is seen in Fig. 3a and 3b, at this time, under the negative IMF By, the *clockwise* vortex (blue arrows) is observed over the high-latitude IMAGE stations (NAL-HOR) and the *counter-clockwise* one (red arrows) is observed over BJN-SOR. At about 11:00 UT, the IMF By was positive and one can see the vortex of the opposite direction.

We suppose that in the considered events when |By|/|Bz| > 1, the IMF By sign controlled the direction of magnetic vortex rotation both under the positive (northward) and negative (southward) IMF Bz component.

3. As it is well known, the bay-like magnetic disturbances could be associated with enhancement of the high-latitude Field-Aligned Currents (FACs), and the ionospheric convection, and the *clockwise* vortex is a signature of the downward FAC, and the *counter-clockwise* one is a signature of the upward FAC.

The spatial FAC distribution can be provided by the AMPERE project (http://ampere.jhuapl.edu/products/plots). Alternations in downward-upward directions of the field-aligned currents lead to the development of high-latitude ionospheric currents. The increase of the downward and upward FACs causes an enhancement of polar electrojets (PE). The current direction in the PE determined by the IMF By sign. The eastward PE (positive magnetic bay) develops under the positive IMF By, the westward PE (negative magnetic bay) develops, when the IMF By is negative (Feldstein et al., 2006; Gromova et al., 2018).

Let's consider the cases when the IMF Bz was positive but the IMF By is either positive or negative. The FAC maps at about 09:45 UT and at 11:05 UT of 04 August 2010 are shown on Fig. 4a. The same map, but at 10:05 UT of 22 January 2012, is presented in Fig. 5a. The specified moments are pointed by arrows on the UT-time axis in the Figs. 1a and 2a. The downward and upward FACs are marked on the plots by blue and red respectively.

At 09:45 UT of 04 August 2010, the IMF By was positive, and FAC map showed the upward FACs over the high latitude IMAGE stations (Fig. 4a, left) that caused the development of the eastward polar electrojet and one can see the positive dayside magnetic bay in Fig. 2a. Under the negative IMF By, at ~11 UT of 04 August 2010 and ~10:05 UT of 22 January 2012, the FAC maps demonstrated downward FACs over the same high latitude IMAGE stations (Figs. 4a and 5a) that led to development of the westward current in the PE and the negative dayside magnetic bays (Fig. 2a and 2b).

The field-aligned currents observed under the northward (positive) Bz in the polar region termed *NBZ* FACs (Iijima and Potemra, 1976). They are located in the dayside sector of the high latitudes and are more intensive in summer than in winter (Stauning, 2002 and references therein). We assume that the studied dayside high latitude bays could be caused by increasing of the *NBZ* FACs.

4. The ionospheric convection plots during the studied events are presented in Fig. 4b and Fig. 5b. They are determined using the "optimal interpolation" method of data assimilation to obtain complete maps of electrostatic potential by optimally combining SuperDARN observations and a statistical convection model (http://vt.superdarn.org).

During the both magnetic bays on 04 August 2010 and the bay at ~09 – 10:20 UT on 22 January 2012, the IMF Bz remained positive for a time of the whole interval. It is seen that the IMAGE high latitude stations were mapped into positive cell (marked by red) of the ionospheric convection under the IMF By > 0 (Fig. 4b, left dial), and into negative cell (marked by blue) under the IMF By < 0 (the right dial on Fig. 4b, and the dial in Fig. 5b). So, the positive and negative dayside high latitude magnetic bays occurred correspondingly to positive or negative convection cells.

5. Differently from the high latitude daytime magnetic bay-like disturbances observed under positive IMF Bz component, that we have previously discussed, we found the dayside magnetic bay on 22 January 2012 (after 10:20 UT) that was developed under the negative IMF Bz. However, the small *positive* magnetic bay were observed at the high-latitude IMAGE stations NAL – BJN (Fig. 1b). Its sign coincided with the IMF By sign. We suppose that it happened due to the IMF By domination over the IMF Bz. It was found (see FACs distribution in Fig. 4b) that the magnetic disturbances became much more intensive in the night-side sector of the high latitudes simultaneously with development of this positive dayside magnetic bay when AL index reached ~ -800 nT. We plan to continue our research of this situation

Summary

1. The case study of the three high latitude daytime bays under the positive Bz during the IMF By-dominated periods (|By|/|Bz| > 1), shows that the sign of the dayside polar magnetic bays is controlled by the IMF By sign.
2. We suppose that the studied dayside high latitude bays could be caused by the enhancement of the NBZ FACs.

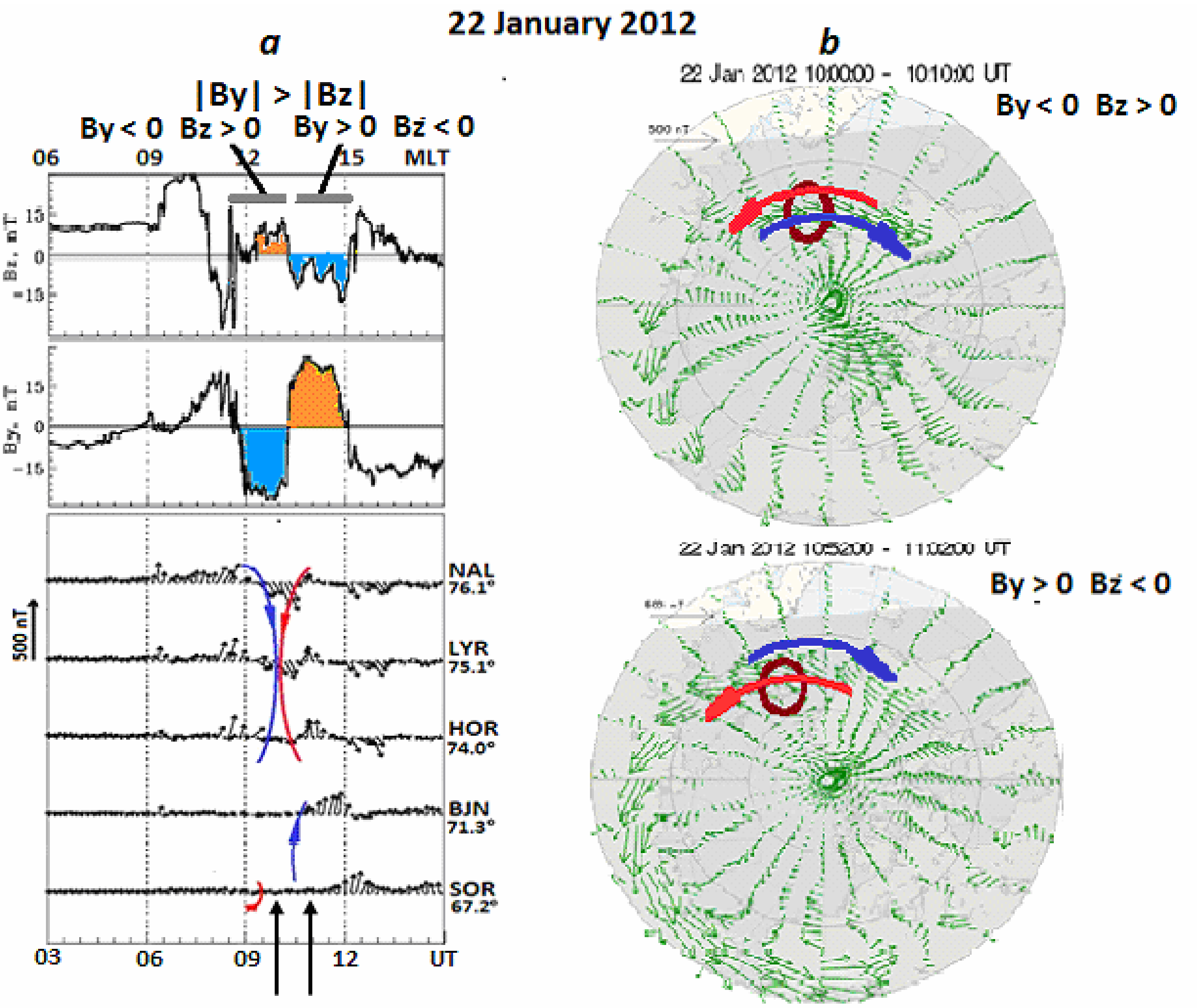

Fig. 3. The same as in Fig. 2 but for the 22 Jan 2012 event.

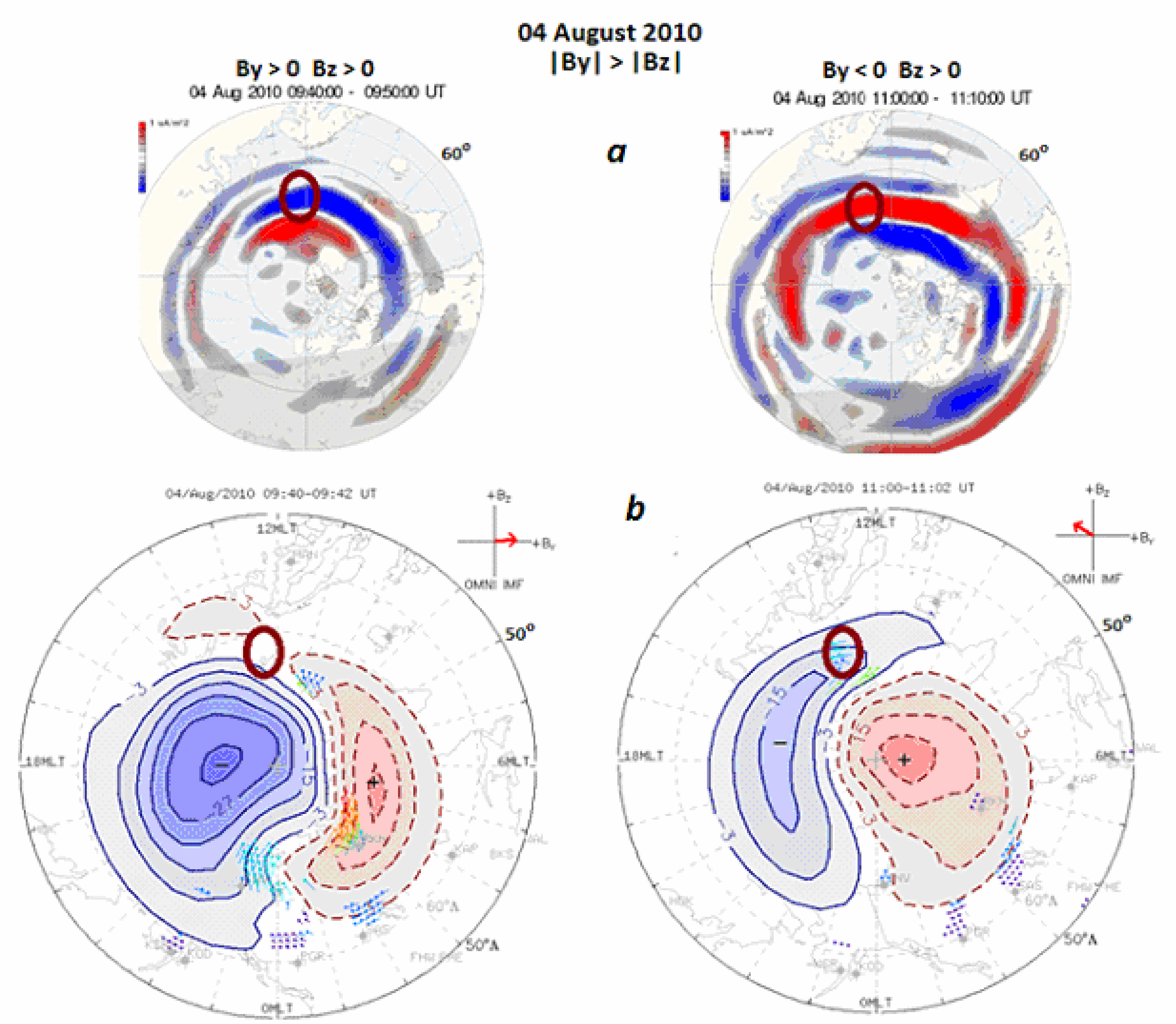

Fig. 4. Event of 04 August 2010: the AMPERE current maps and the convection vortices over the IMAGE stations during the northward IMF Bz under By > 0 (a) and By < 0 (b). Upward currents are shown in red and downward currents in blue. The small ovals show the location of the high-latitude IMAGE stations.

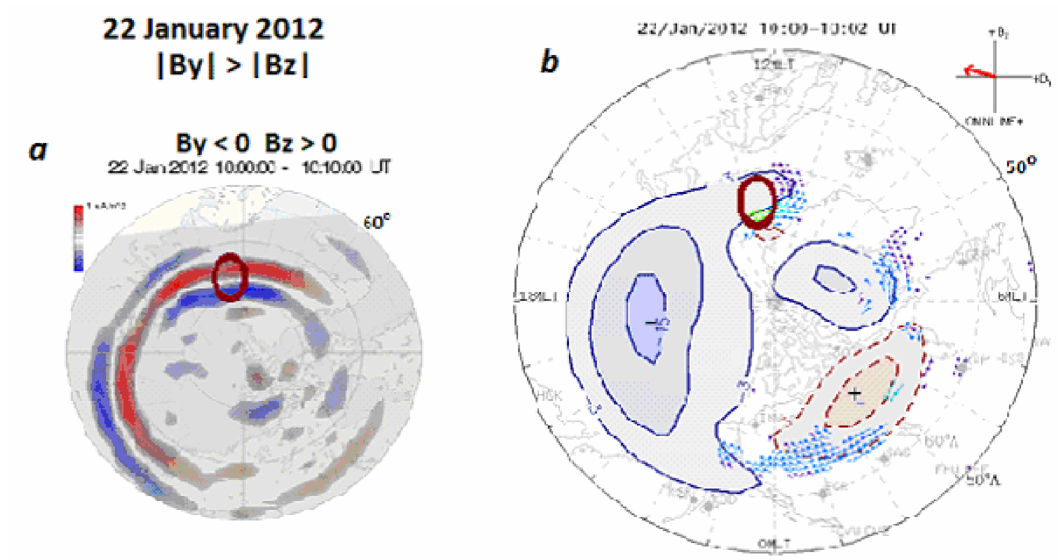

Fig. 5. Event of 22 January 2012 : the AMPERE current maps and the convection vortices over the IMAGE stations during (a) the northward the IMF Bz under the IMF By < 0, Upward currents are shown in red and downward currents in blue. The small ovals show the location of the high-latitude IMAGE stations.

Acknowledgements

The work of N.K. was partly supported by the Program of the Presidium of the Russian Academy of Sciences (RAS) No 28.

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