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HIGH-LATITUDE GEOMAGNETIC RESPONSE TO THE ABRUPT IMF CHANGES DURING THE 22 JULY 2009 MAGNETIC STORM

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Abstract. The strongest magnetic storm has happened on 22 July 2009 in the deep minimum of the solar cycle activity. This storm was short, only about one day duration. In the storm main phase, the *SymH* value reached almost -100 nT at ~ 06 UT, after that, the direction of the Interplanetary Magnetic Field (IMF) became northward, and the storm recovery phase started. However, at about 07 UT, the IMF turned southward, that caused the beginning of the second step of this magnetic storm. Near the maximum of this stage, the strong irregularity is appeared when the IMF *By* and *Bz* components simultaneously changed from ~+7 nT to ~-14 nT and from ~-15 nT to ~+5 nT correspondingly. In this paper we analyzed the global effects these abrupt IMF changes on the geomagnetic activity at the high-latitudes. The strong dayside magnetic bay occurred at the Scandinavian IMAGE magnetometer chain. As a rule, such dayside magnetic bays are observed under the absent of the night side substorm activity. However, in the considered event, the dayside polar magnetic bay was accompanied by the intense high-latitude disturbances observed not only in the night side, but in the global scale as well. We suppose that this dayside polar magnetic bay was not typical and was not associated with the local polar field aligned currents enhancement. Probably, it was caused by the development of the global complicated system of the ionospheric currents as a response to the abrupt IMF changes.

Introduction

In the deep minimum of the solar activity (Fig. 1), the magnetic storm was observed on 22 July 2009. It was the strongest storm of 2009 (Ap=24), see *https://www.spaceweatherlive.com.* This storm could be classified as a CIR driven storm [*Perez et al*., 2012]. The magnetic storms driven by corotating interaction regions (CIRs) originating at coronal holes on the Sun is especially interesting because while they are generally weaker storms, they often result in more efficient coupling into the Earth's magnetosphere [e.g., *Tsurutani et al*., 2006]. We analyzed the global effects of the abrupt IMF changes on the geomagnetic activity at the high-latitudes. Typically, high-latitude daytime magnetic bay-like disturbances are observed under the northward IMF and in the absent of the night side substorm activity [*Kleimenova*, 2015, *Gromova*, 2016]. But during this storm, the polar magnetic bay observed at 09-10 UT under the positive IMF *Bz* was accompanied by the intense high-latitude disturbances observed not only in the night side, but in the global scale as well.

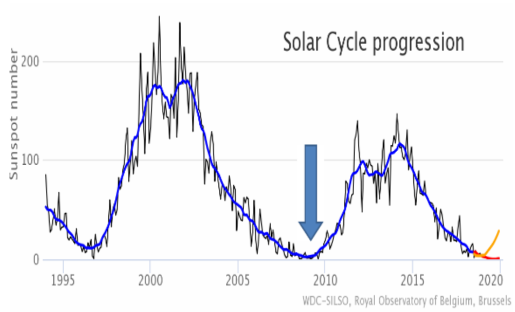

Figure 1. Progression of the Solar Cycles 23 and 24 (*https://www.swpc.noaa.gov/products*).

The aim of our paper is to analyze the global effects these abrupt IMF changes on the geomagnetic activity at the high-latitudes during the storm that was untypical for the most magnetically quiet 2009 year and characterized by unusual development of the recovery phase.

Observations

1. As for every CIR driven storm [e.g., *Tsurutani et al*., 2006], during the magnetic storm on 22 July 2009, the solar wind was characterized by the slow changes in the velocity (300 – 450 km/s). The solar wind density slowly rose (from 12 up to 45 1/cm^3 over the 6 hours interval) and rapidly dropped near the peak of the storm (from 45 to 15 1/cm^3 in one hour). Variations of the *By* and *Bz* components of the IMF, the solar wind parameters *V*, *Np* and *SymH* and *A*l indices of the geomagnetic activity are shown in Fig. 2 (from the IMF data sets of OMNI database, *http://omniweb.gsfc.nasa.gov*).

The storm had two steps in its development caused by the change of the IMF direction. In the storm main phase, the *SymH* value reached almost -100 nT at ~ 06 UT, after that, the IMF direction became northward, and the first recovery phase started. But at about 07 UT, the IMF turned southward, that caused the beginning of the second step of this magnetic storm. Near 09 UT, the IMF *Bz* and *By* suddenly abrupt changed, the IMF *Bz* changed from negative to positive (from ~-15 nT to ~+5 nT) while the IMF *By* became strong negative (from ~+7 nT to ~-14 nT).

2. As a response of the 09 UT abrupt IMF change, the strong (up to 400 nT) negative magnetic bay appeared near local noon at the polar latitude stations of the Scandinavian IMAGE magnetometer chain (Fig. 3a, data from *http://space.fmi.fi/image*). Its sign coincided with the IMF due to the ratio |IMF By|/|IMF Bz| >3. The equivalent ionospheric currents by MIRACLE model (*http://www.space.fmi.fi/MIRACLE/ECLATandMIRACLE/*) demonstrate the time evolution of the westward equivalent currents at the polar latitudes. They shifted from ~70° to ~77° of the geomagnetic latitudes Φ (Fig. 3b).

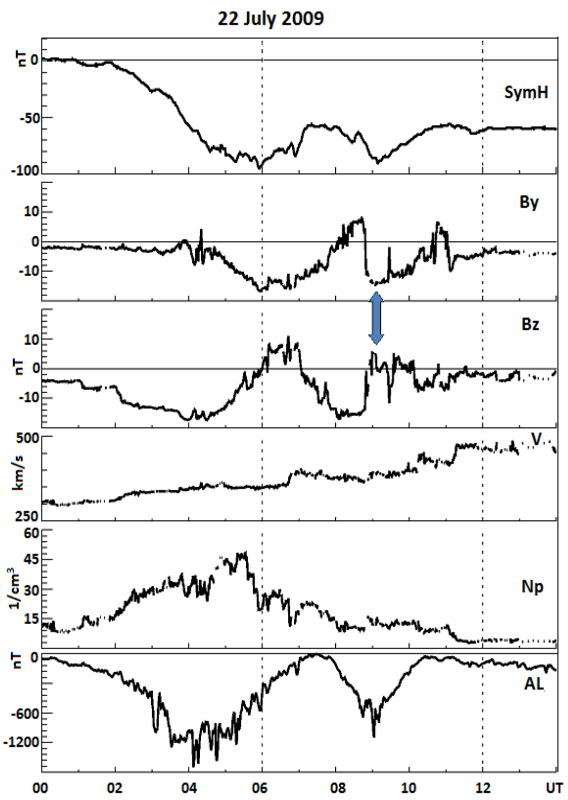

Figure 2. The IMF components, the solar wind parameters and the geomagnetic activity indices *SymH* and *AL* on 22 July 2009. The blue arrow shows the time point of the polar substorm under consideration.

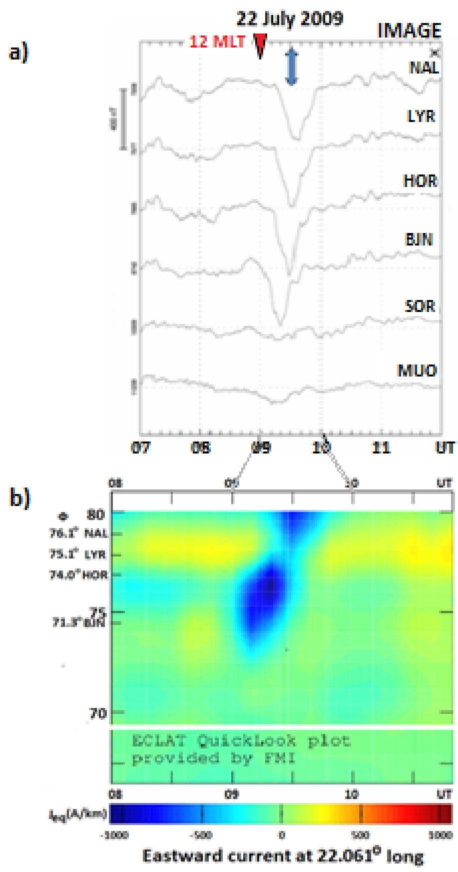

Figure 3. (***a***) High-latitude IMAGE magnetograms. The blue arrow shows the time point of the short polar substorm. (***b***) Equivalent ionospheric currents by MIRACLE model. Blue colors (negative numbers on the scale) mark westward currents.

Discussion

Geomagnetic disturbances in the dayside sector of the high latitudes could be indicated by the horizontal electric currents in the ionosphere which were termed the polar electrojet [*Aakjær*, 2016]. Similar disturbances have been previously reported by many authors [e.g., *Iwasaki*, 1971; *Friis-Christensen and Wilhjem*, 1975; *Feldstein*, 1976, 2006]. It was shown that dayside high-latitude magnetic bays are typically observed under the positive IMF Bz.-The direction of these ionospheric currents (i.e., the sign of the dayside polar bay) is mainly controlled by the IMF By sign [*Sumaruk and Feldstein*, 1973; *Pudovkin et al*., 1977].

Typically, the high-latitude daytime magnetic bay-like disturbances are observed under the IMF Bz > 0 in the absent of the night side substorm activity [*Kleimenova et al*., 2015, *Gromova et al*., 2016]. But during this storm, the dayside polar magnetic bay, observed at 09-10 UT under the positive IMF *Bz* and the negative IMF *By,* was accompanied by the intense high-latitude night side disturbances, so observed in the global scale.

Fig. 4 shows the high-latitude magnetograms and the geographic map with their location. The short negative magnetic bay was observed simultaneously at the high-latitude IMAGE stations (NAL, BJN) in the local daytime, at GDH in the local magnetic morning (blue), and at YKC near the local midnight (dark blue) as well as at other high-latitude stations located in the post-midnight sector of the Earth, e.g., BLC *(http://www.intermagnet.org/).*

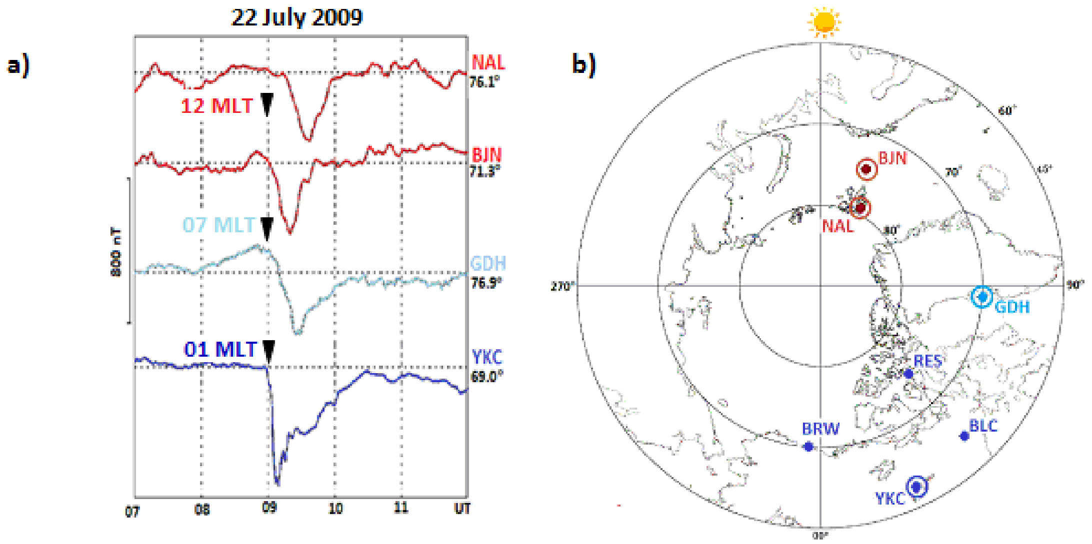

Figure 4. The high-latitude magnetograms at different local time (***a***) and the polar geographic map (***b***). The dayside stations are shown in red, the morning one – in blue and the night side station – in dark blue.

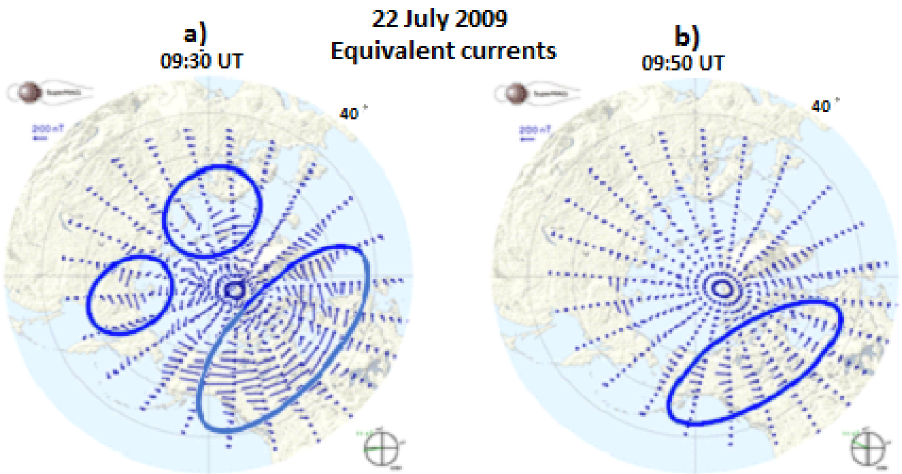

Figure 5. The map of the vectors of electric field calculated according to the measured magnetic disturbances at the SuperMAG station set.

The global distribution of the ionospheric currents provided by SuperMAG system service (*http://supermag.jhuapl.edu/*) demonstrates the occurrence of the high-latitude vortexes occurred simultaneously at the day-, morning- and night-sides at 0930 UT (Fig. 5a) which quickly disappeared by 0950 UT (Fig. 5b).

At the same time, ~09 - 10 UT, the GOES 11 satellite demonstrated the dipolarization [*Perez et al.,* 2012] that could cause the development of the global complicated system of the ionospheric currents as a response to the abrupt IMF changes. It is seen that the westward electrojet was observed at high latitudes from the Harang discontinuity (~21 MLT) through the midnight and morning sectors up to the late afternoon expanding to the polar latitudes.

According to PGI model of different precipitation zone location auroral precipitation model (*http://apm.pgia.ru/docs/api*) we concluded that the considered polar substorm was developed near the poleward border of the auroral oval, i.e., inside of the closed magnetosphere.

During the considered event, the westward electrojet expanded along the longitude from the Harang discontinuity up to the late post-noon including the polar electrojet (PE) and the dayside polar magnetic bay is a result of the westward electrojet flow from the night toward the dayside as it's shown [Feldstein et al., 2006]. We suppose that the strong IMF B*z* (about – 16 nT) before 09 UT promoted the energy loading in the tail which unloaded by the dipolarization leading the westward electrojet development. This westward electrojet expanded azimuthally far from the night-side toward the dayside due to the abrupt IMF changes and the strong value of the ratio |IMF *By*|/|IMF *Bz*|>3.

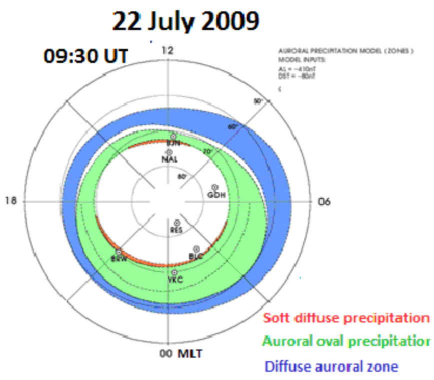

Figure 6. The map of different auroral precipitation zones from PGI model.

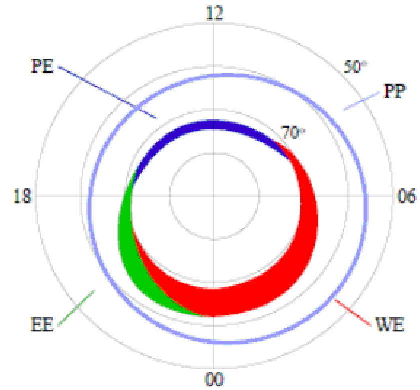

Figure 7. The scheme of electrojet location during the substorm.

Conclusion

The untypical global magnetic bay has been found during the strong magnetic storm in the deep minimum of the solar activity. The bay was caused by impact of the abrupt change in IMF *Bz* and *By*.

In the considered event, the dayside polar magnetic bay was accompanied by the intense high-latitude disturbances observed not only in the night side, but in the global scale as well. We suppose that these global high-latitude magnetic disturbances were the results of the development of the global complicated system of the ionospheric currents as a response to the abrupt IMF changes which caused the dipolarization in the magnetosphere tail.

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