Morning Polar Substorms and Their Possible Mid-Latitude Effects

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Abstract

The specific type of high-latitude magnetospheric substorms (i.e., negative magnetic bays) have been found above ~70° MLAT in the local morning under the absence of the magnetic activity at the lower latitudes. Thus, they are observed on the contracted auroral oval as the nighttime polar substorms. But, unlike polar substorms, the morning polar bays were recorded under both positive and negative IMF *Bz* with different spatial distribution and nature. The high-latitude morning polar bays, observed under the negative IMF *Bz*, could be the result of an azimuthal expansion of the “classical” night substorms to the morning side of the Earth. The morning polar negative bays just like polar substorms were accompanied by mid-latitude positive bays. However, the morning polar bays, observed after a period of long lasting non-variable negative IMF *Bz* in the absence of “classical” night substorms, could be attributed to develop of, so called, “convection” substorms. In this case, there were no positive mid-latitude magnetic bays, i.e., the absence of a substorm current wedge, as well as in the case of the morning polar bays, recorded under the positive IMF *Bz* and being the result of an azimuthal expansion of the daytime polar magnetic bays.

Keywords: magnetic substorm, interplanetary magnetic field, mid-latitude positive bay

1. Introduction

It is well known that during the low magnetic activity, the night-side magnetosphere substorms and visible auroras are observed at the geomagnetic latitudes higher than the normal auroral oval location so that the auroral oval becomes contracted and poleward shifted. In earlier publications, these high-latitude substorms have been termed as “substorms on contracted oval” [e.g., Akasofu et al., 1973; Lui et al., 1976], later on they were known as “polar substorms” [Kleimenova et al., 2012; Despirak et al., 2014; Safargaleev et al., 2020].

Our study of the ground-based observations showed that the polar substorms are observed not only in the night, but also in the local morning as negative magnetic bays, recorded at the high-latitudes above ~70° MLAT in the absence of magnetic disturbances at the lower latitudes. We called such bays, “morning polar substorm” because they often demonstrate some typical substorm behavior. While there is a number of papers dedicated to the research of the different aspects of the evening polar substorms, the morning ones remain practically unknown.

The aim of this paper is to study the behavior and sources of the ***morning polar substorms*** basing on the IMAGE magnetometer data (http://space.fmi.fi/image/).

2. Main behavior of morning polar substorms and their occurrence

Figure 1a presents the geographic map of the IMAGE station on which our study was based, and Figure 1b shows the example of a morning polar substorm. It is seen that the negative magnetic bays are observed only at BJN-NAL stations. Their absence at lower latitudes indicates that these bays are not the result of the polar expansion of a 'classical' substorm. We found that morning polar bays are usually observed at low solar wind speeds (V < 450 km/s) like nighttime polar substorms.

We selected 112 cases of morning polar bays registered in 2006-2012. Their daily variations are shown in Figure 1c demonstrating the maximum of occurrence at 08-09 MLT, i.e., before the local magnetic noon. Unlike "classical" substorms, the morning polar substorms were characterized by small amplitude~~s~~ (less than 200-300 nT) and the gentle onset and end.

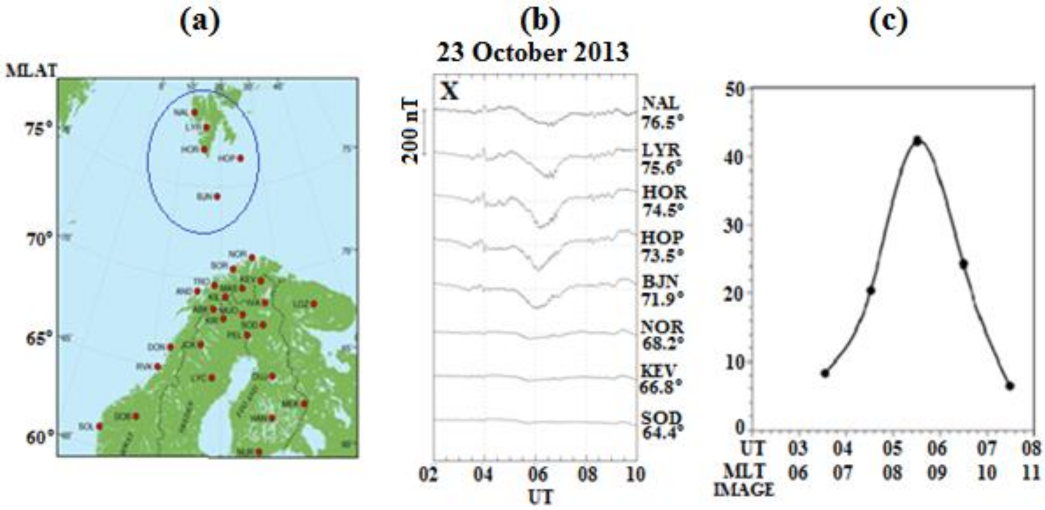


Figure 1. *(a) The map of the IMAGE magnetometer station location; (b) the example of a morning polar substorm at the IMAGE stations (c) the daily distribution of these substorms occurrence.*

To study the global distribution of geomagnetic activity during the morning polar bays, we used magnetic registration data from 66 communication satellites of the AMPERE (*Active Magnetosphere and Planetary Electrodynamics Response Experiment)* project, simultaneously operating at altitudes of 780 km [e.g., Anderson et al., 2014]. In our work, we used the AMPERE project data (http://ampere.jhuapl.edu/products) as the maps of the distribution of geomagnetic disturbances summarized in 10 min with 2 min shift and the results of a spherical harmonic analysis of magnetic measurements. The Field Aligned Currents (FAC) are calculated from these data: currents flowing into the ionosphere (inward currents) are shown in blue on the maps, and currents flowing out (outward currents) in red.

During 2010-2017 AMPERE measurements, we selected 48 events of the appearance of morning polar magnetic bays identified at the high-latitude IMAGE stations (BJN-NAL). The analysis of global geomagnetic activity during the studied morning polar substorms showed that their sources could be various perturbations in the magnetosphere, namely, "classical" nighttime substorms, convective bays and daytime polar negative bays.

3. Morning polar substorms under the southward IMF

Magnetospheric substorms developing in the nighttime sector may be also observed in a large longitudinal interval, from the local evening to the late morning. Thus, the morning polar magnetic bays recorded on the IMAGE profile can be the result of the azimuthal continuation of nighttime disturbances in the morning direction. The analysis of the global distribution of magnetic activity based on the AMPERE data confirmed this assumption. We found 5 events of the morning polar substorms on the IMAGE profile, where the enhanced electrojet and FACs were recorded in the night and morning according to AMPERE data. An example of such event on October 23, 2013 is shown in Figure 2a.

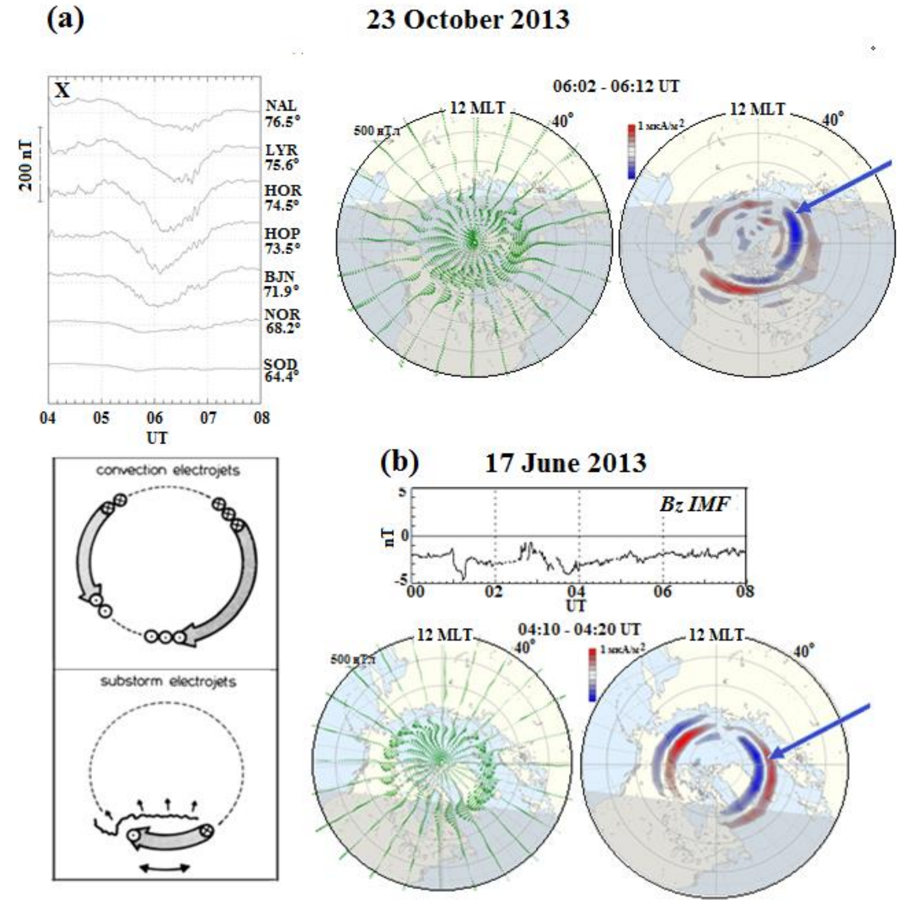
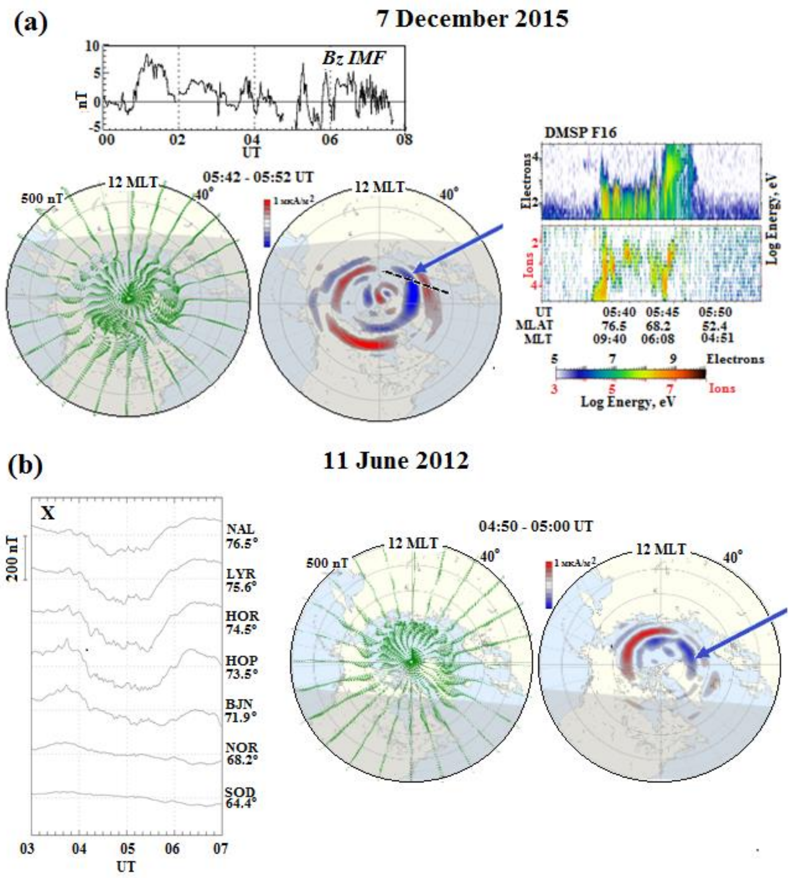


Figure 2. *(a) - The IMAGE magnetogram and AMPERE maps of results of the spherical harmonic analysis of magnetic measurements and distributions of the Field Aligned Currents on 23 October 2013; (b) – the convection and substorm currents diagram adopted from [Baumjohann, 1983] and AMPERE maps for event on 17 June 2013.*

The AMPERE maps (Figure 2a, right) show that at this time, the westward electrojet (a "classical" substorm) and enhanced FACs were observed from the evening sector to the late morning sector (IMAGE meridian). Before midnight (at 20-23 MLT), the high-latitude westward electrojet was accompanied by a lower-latitude eastward electrojet, which is a substorm current wedge (SCW) typical of a “classical” substorm [McPherron et al., 1973; Rostoker et al., 1980].

It is well known that in the high-latitude ionosphere, plasma convection is almost constantly observed, which has the form of a two-vortex structure [e.g., Heppner, 1977] with vortex centers in the morning and evening sectors, and increases with an increase in the southward IMF. Long periods (several hours) of the stable state of the southern IMF contribute to the continuous supply of energy to the magnetotail and the establishment of the regime of the so-called "steady magnetospheric convection" discussed in many papers [e.g., Yahnin et al., 1994; Sergeev et al., 1996]. Some of its intensifications were called "convective bays" [Pytte et al., 1978; Baumjohann, 1983]. The convective bay represents the development of a two-vortex current system with vortex centers in the morning (the westward electrojet) and evening (the eastward electrojet) sectors, as shown in the diagram in Figure 2b adopted from [Baumjohann, 1983].

We found 6 events when magnetic disturbances were observed simultaneously at the morning and afternoon sectors in their absence in the local night, that is typical for the enhanced convection. One of such events on June 17, 2013 is shown in Figure 2b. All morning convective negative bays were not accompanied by positive magnetic bays at the middle latitudes.



F**igure 3**. *(a)- An example of the global distribution of magnetic disturbance and field-aligned currents according to AMPERE data, as well as variations in IMF Bz on 7 December 2015 and the spectrograms of precipitating electrons and ions measured by the low-apogee DMSP F16 satellite (http://sd-www.jhuapl.edu/Aurora/spectrogram); (b) - the same as in Figure 2a but on 11 June 2012.*

An analysis of the observational data showed that most (32 events out of 48) of the morning polar substorms were a superposition of disturbances caused by the interaction of nighttime substorm and convective phenomena, the separation of which is a very complex, not always solvable problem, especially in disturbed conditions. Figure 3a shows an example of such complex case (December 7, 2015), when geomagnetic disturbances were recorded by the AMPERE data simultaneously in the morning, evening, and afternoon sectors.

At that time, the low-apogee (~830 km) DMSP F16 satellite [Redmon et al., 2017] measured the fluxes of precipitating particles over Svalbard at the beginning of the morning polar substorm. In Figure 3a, the descending part of the orbit is shown schematically; the satellite first crossed the region of downward FACs (shown in blue), and then the region of upward ones (shown in red). The AMPERE data shows that at that time, an intense eastward current was observed in the nighttime sector southward from the westward electrojet. That is a typical picture of the development of the substorm current wedge. It stretches across North America, from the west to the east.

4. Morning polar substorms under the northward IMF

Under the northern IMF direction, magnetic bay-like high-intensity disturbances can be observed in the near-noon sector of the polar latitudes [e.g., Friis-Christensen et al., 1985, Levitin et al., 2015; Gromova et al., 2017, 2019], the time variations and sign of which are usually controlled by the IMF *By* component. An analysis of the AMPERE data showed that the ionospheric electrojet and enhanced field-aligned currents can be observed in a fairly wide daytime longitudinal region from the morning sector to afternoon one as it is shown in Figure 3a. It is seen that the morning negative bay could be the result of the azimuthal expansion of the daytime polar electrojet into the morning sector and they did not accompany by positive magnetic bays at the middle latitudes.

4. Possible mid-latitude effect of morning polar substorms

It is well known that the main feature of a substorm current wedge (SCW) is the development of mid-latitude positive magnetic bays. The most considered morning polar negative magnetic bays associated with an azimuthal expansion of "classical' night-side substorms have been found accompanied by positive mid-latitude magnetic bays in the *X*-component, but with a strong negative amplitude of the *Y*-component. That can indicate that the center of SCW is located far eastward. One of such events is presented in Figure 4. The *X*-component was stronger at BEL (47.7° MLAT) than at PAG (42.6° MLAT).

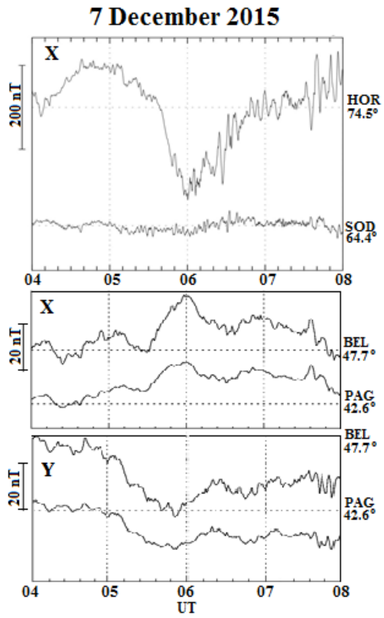


Figure 4. *Magnetograms from polar- and mid-latitude stations on 7 December 2015.*

5. Summary

At latitudes above ~70° MLAT, the polar substorms can be observed not only in the evening, but in the morning as well with the maximum of occurrence at ~08-09 MLT. The morning events are recorded both under the negative and positive IMF *Bz*.

Under the negative IMF *Bz*, the *morning* polar substoms can be a result of an azimuthal expansion of *nightside* "classical" substorms (in that case they are accompanied by mid-latitude positive magnetic bays) as well as a result of an enhancement of the magnetosphere convection without the mid-latitudes effects.

Under the positive IMF *Bz,* the *morning* polar substoms are a result of an azimuthal expansion of *dayside* polar magnetic bays controlled by IMF *By*).

The majority of the morning polar substorms are a superposition of "classical" substorms and convective negative bays.

Acknowledgments

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