Polar Substorm, Svalbard Auroras and Mid-Latitude Positive Magnetic Bays: Case Study

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Abstract

The high-latitude magnetic substorms known as "polar substorms" or "substorms on a contracted oval" have been studied basing on the analysis of the data from the Scandinavian IMAGE magnetometer chain and the visible auroras observed by the Svalbard all-sky-cameras in the 2010-2011 winter. In addition, there was a study of the relationship between the polar substorm occurrence and the localized intensification of the Field Aligned Currents (FACs) near the poleward edge of auroral oval, inferred by the AMPERE data (cancellation of the 66 simultaneous commercial satellites with magnetometer measurements). We also compared the polar substorms recorded at Svalbard with the magnetic data from the mid-latitude stations located at the same meridian, e.g., Borok (BOX) and Kiev (KIV). We found that all polar substorms under consideration were accompanied by the well-defined mid-latitude positive magnetic bays with the amplitudes of ~ 15-40 nT in the X-component of the geomagnetic field. These positive magnetic bays are usually interpreted as the evidence of the substorm West Travelling Surge (WTS) development due to the dipolarization process. Thus, it allows us to conclude that the source of polar substorms is located on closed magnetic field lines. The analysis of two events of the selected polar substorms is presented.

Introduction

Bay-like magnetic disturbances observed at high latitudes above 70° MLAT in the absence of disturbances at the lower auroral latitudes, are called the "*substorms on a contracted oval*" [*Lui et al*., 1976] or the "*polar substorms*" [*Kleimenova et al*., 2012]. It was found [*Despirak et al*., 2019] that polar substorm are typically observed under slow solar wind. The statistics [*Kleimenova et al*., 2012] showed that polar substorms are observed mainly in the pre-midnight sector. Similar to the classical substorms, the polar substorms are accompanied by Pi2 geomagnetic pulsations and auroral breakups. Polar substorms are poorly studied because the observation data at such high latitudes are not included in the estimation of the geomagnetic indexes. Moreover, the mid-latitude effects of polar substorms have not yet been investigated.

The aim of our work is to study the relationship of polar substorm with visible auroras observed at Svalbard and with the high-latitude distribution of the Field Aligned Currents (FAC) inferred by AMPERE satellite system. We also compared the polar substorm occurrence with simultaneous magnetic mid-latitude observations at the same meridian area.

Instrumentation

Our study is based on: (i) ground-based magnetic data of the Scandinavian IMAGE magnetometer chain (http://space.fmi.fi/image/) with the time resolution of 10 s [*Tanskanen*, 2009]; in addition to the magnetogram, we used data of the ionospheric equivalent currents [*Amm and Viljanen*, 1999]; the all-sky cameras (ASC) at Ny Alesund station (76.6° MLAT) was used for imaging auroral borealis covering a circular area with a diameter of about 600 km at 110 km altitude; (ii) the global network of the stations INTERMAGNET (http://www.intermagnet.org), (iii) the AMPERE data, based on the ionospheric magnetic measurements on 66 low-altitude globally distributed Iridium communication satellites (http://ampere.jhuapl.edu/products/plots), (iiii) OMNI database of the Interplanetary Magnetic field (IMF) data of the 1-min resolution (http://omniweb.gsfc.nasa.gov).

Observation results and discussion

First at all we selected all events of the visible aurora occurrence obtained by the Svalbard Ny Alesund (76.6° MLAT) all-sky-camera (ASC) in the 2010-2011 winter, because this record is possible only under certain meteorological conditions. It was found that all considered aurora events were accompanied by polar substorms. Two substorm events are presented below: 29 December 2010 (Fig.1) and 12 February 2011 (Fig. 2).

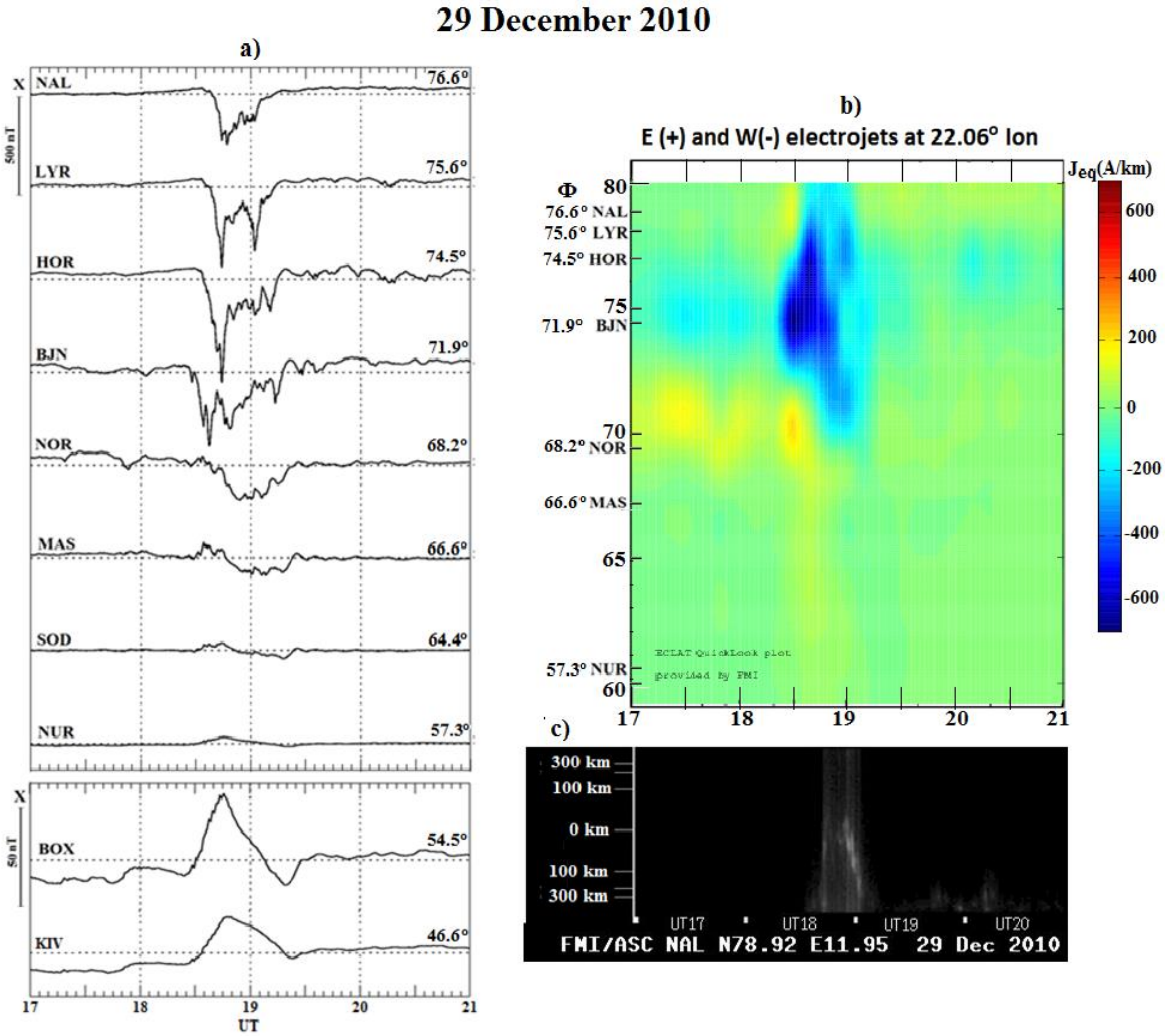
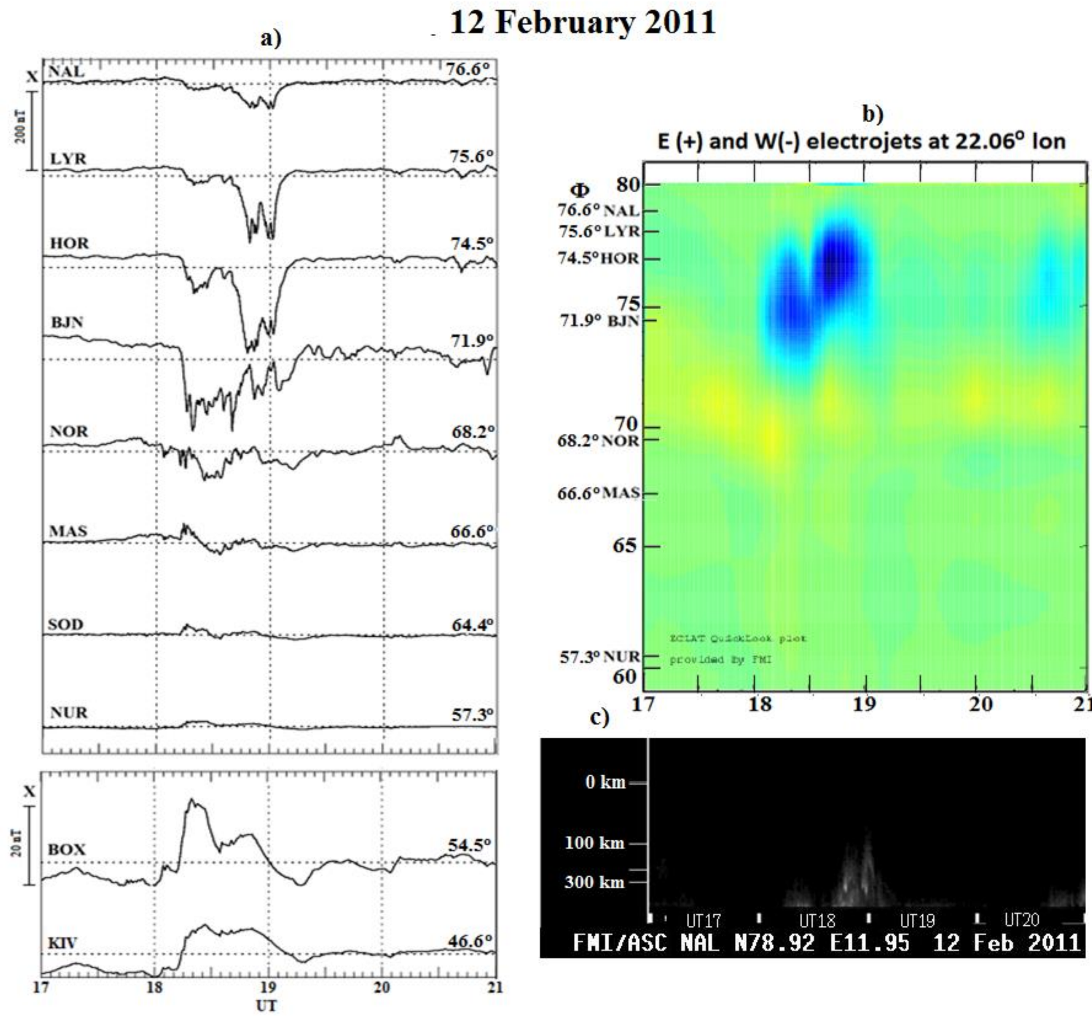


Fig.1. Here are shown: (a)- the magnetograms from selected high-latitude IMAGE stations and from two mid-latitude INTERMAGNET stations; (b)- the correspondent equivalent currents distribution; (c) aurora keogram from the Ny Alesund all-sky-camera.

The magnetograms from the selected stations IMAGE (Fig. 1a) demonstrate the polar substorm at ~18.30-19.15 UT, recorded only at the highest latitudes. The plot of the Ionospheric equivalent currents (Fig. 1b) confirms the presence of the westward electrojet enhancement at the latitudes higher 70° MLAT in the same time interval at the same time. The keogram from Svalbard cameras shows the visible aurora development at the same time and in the same area.

We compared this polar substorm occurrence with the INTERMAGNET magnetic observations at the mid-latitude stations Borok (BOX, 54.5° MLAT) and Kiev (KIV, 46.6° MLAT) located at the IMAGE meridian. It was found that at this time, there were the positive mid-latitude magnetic bay observed with the amplitude of ~40 nT at BOX and of ~25 nT at KIV.

The second polar substorm event is shown in Fig. 2.



• *Fig.2. The same as in Fig. 1 for the second event.*

• As in the previous event, the magnetograms from the selected stations IMAGE (Fig. 2a) demonstrate the polar substorm development at ~18.15-19.15 UT, recorded at the highest latitudes. The plot of the Ionospheric equivalent currents presents the westward electrojet enhancement at the latitudes higher 70° GMAG in the time interval of ~ 18-19 UT. The keogram from Svalbard camera shows the visible aurora development at the same time and in the same area.

• As in previous event, we compared this polar substorm occurrence with the INTERMAGNET magnetic observations at the mid-latitude stations Borok and Kiev and found that at this time, there were the positive mid-latitude magnetic bays observed with amplitude of ~20 nT at BOX and of ~10 nT at KIV.

The next step was to study the relationship between polar substorm and the Field Aligned Current distribution inferred from the AMPERE data, based on the ionospheric magnetic measurements on 66 low-altitude globally distributed Iridium communication satellites. These results for two considered events are shown in Fig. 3*a* and 3*b*.

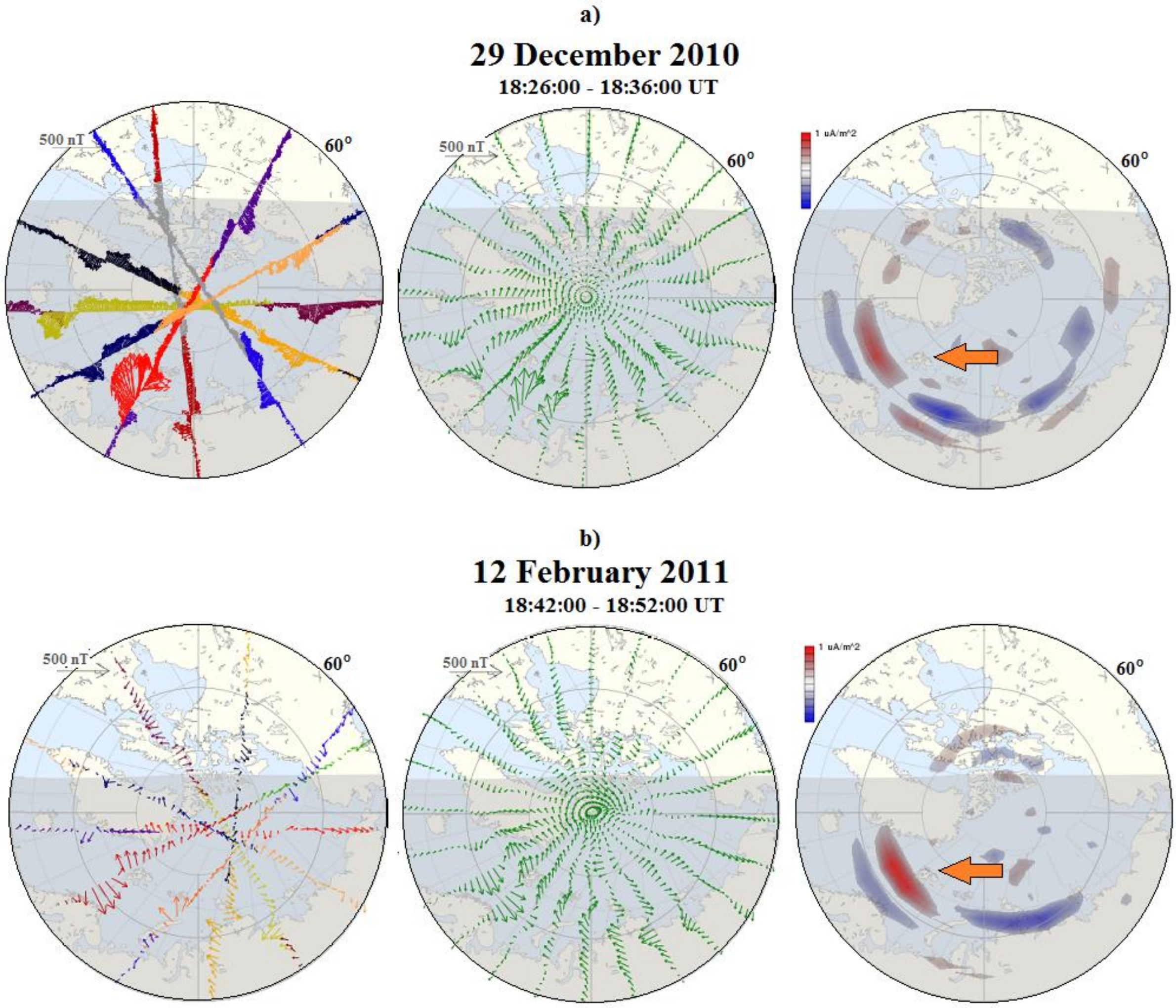


Fig.3. Maps of the distribution of magnetic vectors in the ionosphere (on the left), its spherical harmonic analysis (in the center}, Field Aligned Currents (on the right) inferred from the AMPERE system. Upward FACs are shown in red and downward FAC in blue. The red arrows show the Svalbard location.

It is seen that both considered polar substorms were accompanied by the localized enhancement of the upward Field Aligned Currents in the vicinity of the poleward boundary of the auroral oval. This indicates the increasing of the soft electron precipitation into the lower ionosphere, causing the aurora as well as electrojet progress, i.e., polar substorms occur.

We found (Fig. 4) that the both events were recorded under quiet magnetic conditions: (Kp ~ 0-1), the slow solar wind velocity (Vsw ~ 360 km/s) and low dynamic pressure (Psw ~ 08-1.2 nPa), the IMF Bz values changed from near zero to +1 nT. Under such conditions, the auroral oval should be constructed. The polar substorm were accompanied by a small enhancement of the PC-index indicating a moderate solar wind energy input into the magnetosphere.

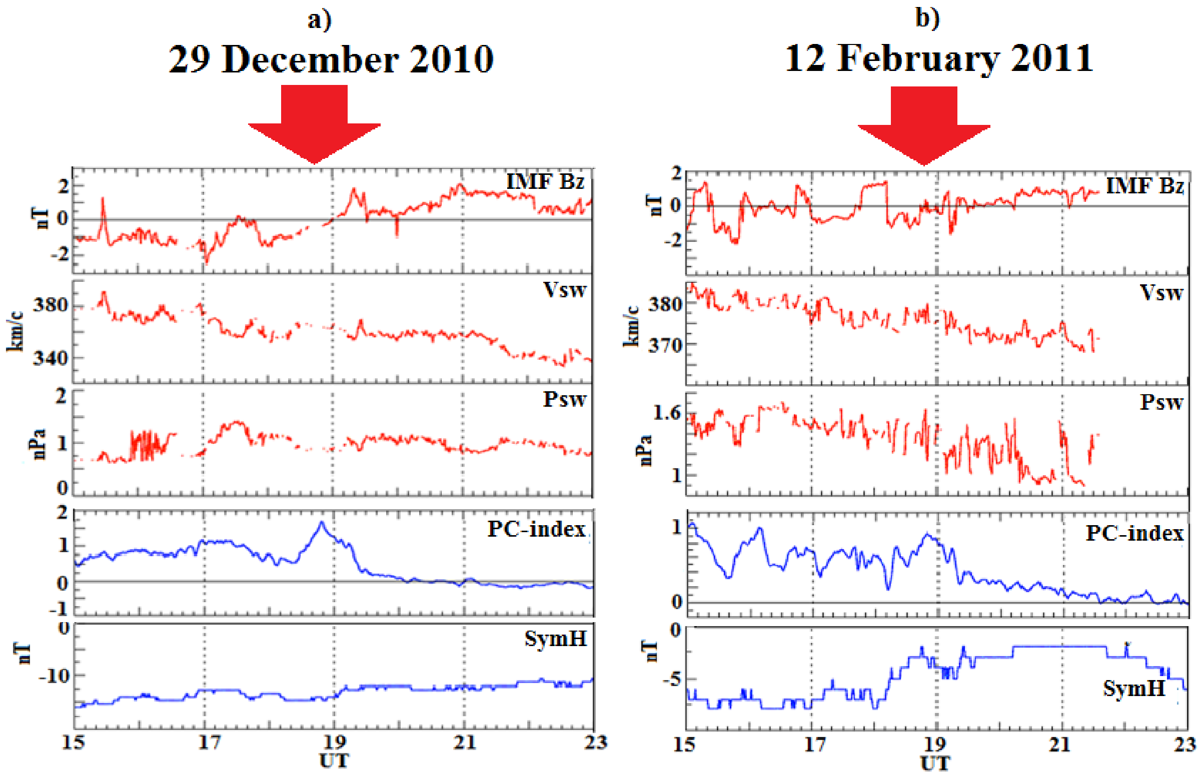


Fig. 4. OMNI data during the studied polar substorms

Later on, we identified 120 events of the polar substorms, based on the analysis of the IMAGE data from 10 winter seasons (November-February, 2010-2020). The most of these events have been recorded during the local late evening (at 21-23 MLT, i.e., 18-20 UT), only 30 events were observed near or immediately after midnight.

These events were compared with the simultaneous magnetic observations at mid-latitude INTERMAGNET stations Borok (BOX) and Kiev (KIV) located along the IMAGE meridian. It was found that 85% of the considered polar substorms were accompanied by positive mid-latitude magnetic bays. The most of the non-effective polar substorms were recorded near or after local magnetic midnight (at ~00-02 MLT, i.e., 21-23 UT).

In many papers, e.g., [*McPherron and Chu*, 2018; *Stepanov et al*., 2021], the mid-latitude positive magnetic bays, associated with "classical" sustorms, are interpreted as the effects of the appearance of the dipolarization process and the substorm West Travelling Surge (WTS) formation. The analysis of the satellites and ground data performed in [*Safargaleev et al.*, 2020] fit to the near-tail current disruption scenario as a possible source of the dipolarization and WTS, associated with polar substorm onset.

Conclusion

1. It was found that all visible aurora enhancement, recorded by the Svalbard Ny Alesund (76.6° MLAT) all-sky-camera (ASC) in the 2010-2011 winter, have been accompanied by polar substorms observed at the IMAGE stations at the latitudes higher ~70° MLAT. At the same spatial area, there were located the amplified Field Aligned Current inferred from the AMPERE data, based on the ionospheric magnetic measurements on 66 low-altitude globally distributed Iridium communication satellites.

2. We have analyzed the 120 events of polar substorm recorded by ground-based IMAGE magnetometer network in 2010-2017 in vicinity of the auroral oval poleward boundary, in the association with the simultaneous mid-latitude INTERMAGNET station data. It was found that the polar substorms as the "classical" ones are typically accompanied by the mid-latitude positive magnetic bays being an indicator of the night-side magnetic field dipolarization causing the energy injection into the inner magnetosphere. Thus, we could conclude that the polar substorm have the similar generation mechanism as the "classical" substorms, and the source of polar substorms is located on closed magnetic field lines of the inner magnetosphere, not in the distant magnetotail.

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