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# Harang Discontinuity, "Polar" Substorms and Subauroral Positive Magnetic Bays

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## Abstract

The Harang discontinuity (HD) is a longitudinally extended ionospheric signature before the local magnetic midnight of a latitude flow reversal (from westward to eastward). The "polar" substorms are those substorms that recorded at the geomagnetic latitudes above 70° MLAT under the absence of negative magnetic bays at the lower latitudes. Like the "classical" substorms, the "polar" substorms are accompanied by aurora brightening, poleward expansion, substorm current wedge formation. Onsets of "polar" substorms are typically located near 70° MLAT at ~19-23 MLT. This MLT sector is common area of the HD development. The aim of our work is to study a possible relationship between the "polar" substorm onsets and the HD location. Our study of about 250 "polar" substorms, recorded at IMAGE magnetometer profile in 2010-2020, revealed the tendency of these substorms to occur near the HD location, detected by the AMPERE measurements at the 66 ionospheric satellites. It was found that in the case of the "polar substorm", the Harang reversal was observed at higher latitude then during the "classical" substorm. That explained why the strongest amplitudes of lower-latitude positive magnetic bays, accompanied "polar" substorms, are recorded not at middle, but at subauroral latitudes. Near the eastward edge of the HD, we found a magnetic vortex associated with FACs enhancement separated the evening "polar" substorms and after-midnight westward electrojet. Some individual events of the "polar" substorms are discussed.

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

## Introduction

The "polar" substorms are the high-latitude magnetic substorms observed at geomagnetic latitudes higher 70° MLAT under the absence of negative magnetic bays at the lower latitudes [Kleimenova et al., 2012, 2023; Despirak et al., 2014, 2022; Safargaleev et al., 2018; 2020]. It is well known that during the low magnetic activity, the magnetic 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], because according to (Lui et al., 1973), the equatorward boundary of the contracted auroral oval is located higher 66◦MLAT.

We found [Kleimenova et al., 2023] that the onset of a "polar" substorm is typically located near 70° MLAT at ~19-23 MLT. Another important phenomenon, namely, the Harang discontinuity [Harang. 1946, Heppner,1972; Kamide and Vickrey, 1983] is often observed at this area.

The Harang discontinuity (HD) represents a narrow latitude-zone between the closely spaced simultaneous westward and eastward electrojets [e.g., Kissinger et al., 2013 and the references there]. The schematic picture of the Harang discontinuity is given in Figure 1, adopted from [Koskinen and Pulkkinen, 1995].

The Harang discontinuity (HD) is a region of sharp reversal of the evening sector (around 2200-2400 MLT) ionospheric convection. In the terms of auroral electrojets, the Harang discontinuity corresponds to the shear zone where the eastward electrojet (EEJ), equtorward of the shear, and the westward electrojet (WEJ), poleward of the shear, meet. That is, HD is the area latitude separating the positive and negative bay regions. The HD is dynamic in nature. As magnetic activity decreases, it shifts poleward and spreads out in latitudinal width.

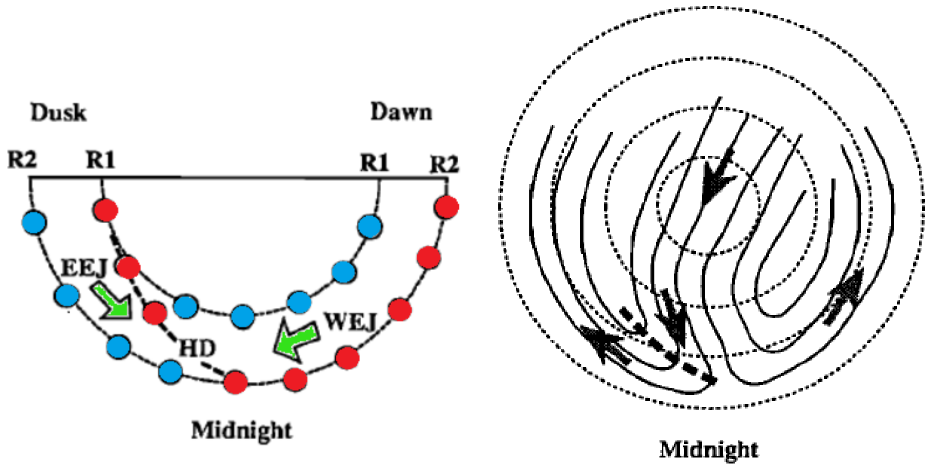


***Figure 1***. *Schematic picture of the Harang discontinuity (HD) in the nightside northern hemisphere. The HD is indicated by the dashed line. In the left panel the directions of the dominating electrojets are given and in the right panel the green arrows indicate the plasma flow in the velocity shear zone. The R1 and R2 indicate the region 1 and 2 of the Field-aligned currents (FACs); EEJ - eastward electrojet; WEJ, westward electrojet. Adopted from, 1995.*

The aim of our work is to study a possible relationship between the "polar" substorm observed at the Scandinavian IMAGE magnetometer chain (http://space.fmi.fi/image/) and the HD location obtained from AMPERE (*Active Magnetosphere and Planetary Electrodynamics Response Experiment)* magnetic measurements by the simultaneous 66 ionospheric Iridium communication satellites planetary distributed at the altitude of ~780 km (https://ampere.jhuapl.edu) as 10-min averages with the 2 min cadence [e.g., Anderson et al., 2014].

**Observations**

We selected the 254 "polar" substorm events, recorded at the IMAGE chain during the winter seasons of 2010-2020 and compared their occurrence with the global distribution of the ionospheric electrojets and field-aligned currents (FACs) obtained from the AMPERE project.

It is well known [e.g., McPherron al., 1973, McPherron and Chu, 2018] that at the meridian of a substorm onset, a mid-latitude positive magnetic bay in the $X$ magnetic component is observed under near a zero variations in the $Y$ component. The positive deviations in the $Y$ component occur if the substorm onset meridian is located far eastward, the negative $Y$ values occur if the substorm onset is located westward.

As the mid-latitude stations, we used Borok station (BOX, 54.5° MLAT) located in near the IMAGE meridian and Irkutsk station (IRT, 47.8° MAT) located 65° eastward (https://intermagnet.org/#services).

Here we show the results of the analysis of the three selected events observations: 28 January 2020 (Figure 2), 5 December 2020 (Figure 3), and 28 December 2020 (Figure 4).

**28 January 2020**

**IMAGE data** **AMPERE data**

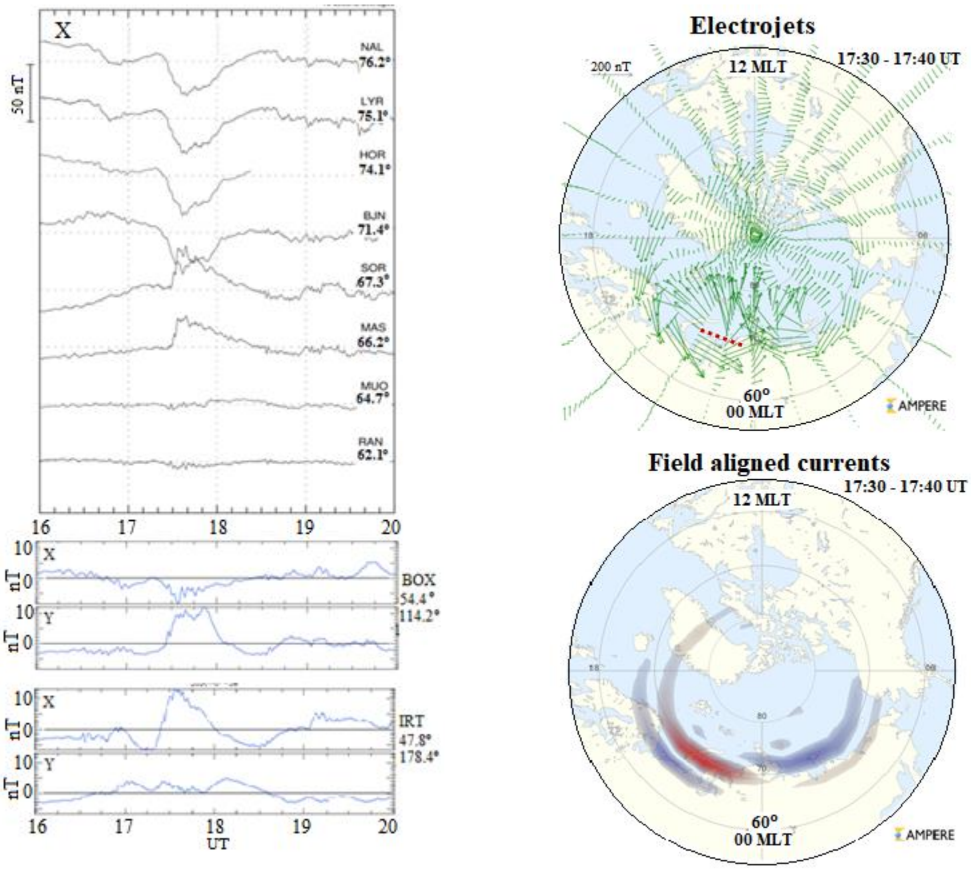


***Figure 2**. Magnetograms from polar- and mid-latitude stations and AMPERE electrojets and FAC data on 28 January 2020*

As one can see in Figure 2, the AMPERE maps of 28 January 2020 demonstrate two vortices in the magnetic field near the ends of the enhanced downward (blue) and upward (red) field aligned currents (FACs).

At the mid-latitude BOX station, the amplitude of the magnetic *X* component was significantly less than the amplitude of the *Y* component. It indicates that this station was located far westward of the meridian of the onset of the "polar" substorm. The AMPERE maps confirm this.

At the mid-latitude IRT station, the amplitude of the magnetic *X* component was much stronger than the amplitude of the *Y* component. It indicates that this station was located near the meridian of the onset of the "polar" substorm. It is seen on the AMPERE maps as well.

The AMPERE maps on 5 December 2020, shown in Figure 3, demonstrate two vortices in the magnetic field near the ends of the enhanced downward (blue) and upward (red) field aligned currents (FACs).

**5 December 2020**

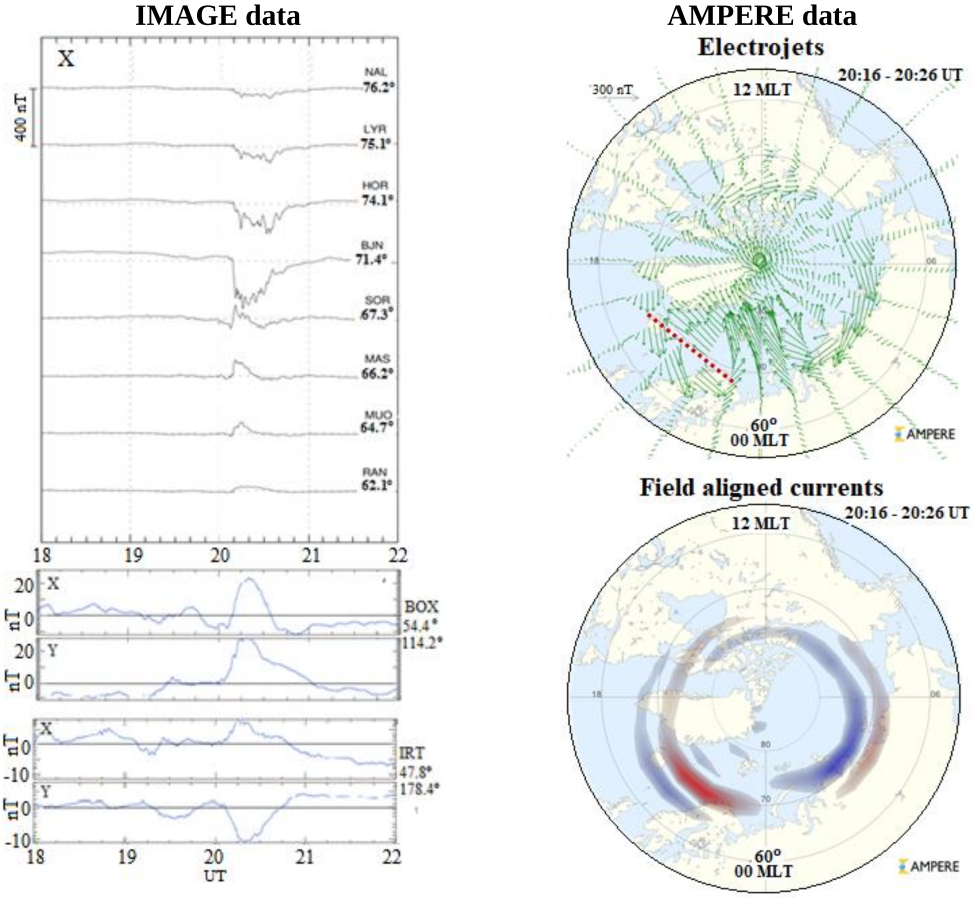


***Figure 3.*** *Magnetograms from polar- and mid-latitude stations and AMPERE electrojets and FAC data on 5 December 2020*

At the mid-latitude BOX station, the amplitude of the magnetic *X* component was similar than the amplitude of the *Y* component, which was positive. It indicates that this station was located away from the meridian of the onset of the "polar" substorm, namely westward. It is seen at the AMPERE maps too.

At the mid-latitude IRT station, the amplitude of the magnetic *X* component was less than the amplitude of the Y component, which was negative. It indicates that this station was located far eastward the meridian of the onset of the "polar" substorm. The AMPERE maps confirm this. The meridian of the polar substorm onset was located between the BOX and IRT stations**.**

Figure 4 shows the AMPERE maps of 28 December 2020. They demonstrate two vortices in the magnetic field near the ends of the enhanced downward (blue) and upward (red) field aligned currents (FACs).

At the mid-latitude BOX station, the amplitude of the magnetic *X* component was much stronger than the amplitude of the *Y* component. It indicates that this station was located near the meridian of the onset of the "polar" substorm. It is seen on the AMPERE maps too. At the mid-latitude IRT station, the amplitude of the magnetic *X* component was significantly less than the amplitude of the *Y* component, which was negative. It indicates that this station was located far eastward of the meridian of the onset of the "polar" substorm. The AMPERE maps confirm this.

**28 December2020**

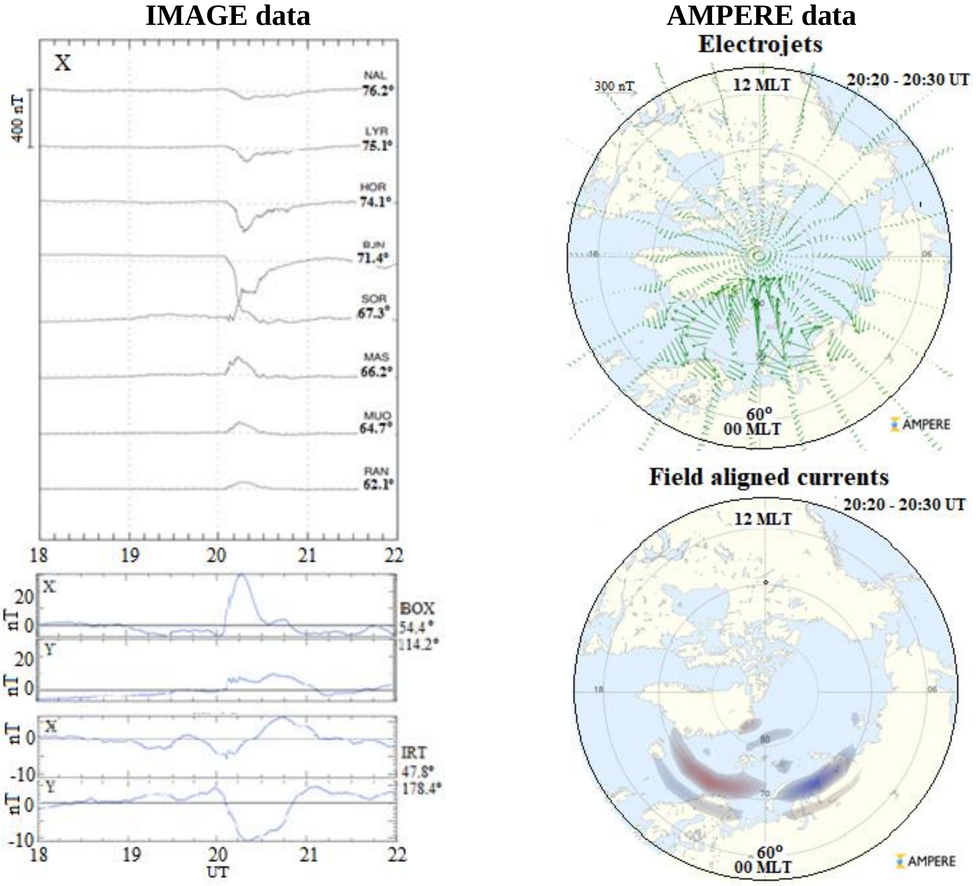


***Figure 4***. *Magnetograms from polar- and mid-latitude stations and AMPERE electrojets and FAC data on 28 December 2020*

## Results

- We found that all studied "polar" substorm events were associated with the Harang discontinuity observed by the ionospheric AMPERE satellites.
- The "polar" substorms were recorded at the ground-based IMAGE magnetometer chain poleward the Harang discontinuity location.
- The onset of the "polar" substorms was located in the vicinity the latitude of the poleward boundary of the Harang discontinuity.
- In most cases, "polar" substorms were accompanied by the development of magnetic vortices indicating the appearance of enhanced field-aligned currents at the edges of the eastward and westward electrojets.
- - The Harang discontinuity started usually between the center location of these vortexes.

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