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# POLAR SUBSTORM PRE-ONSET PHENOMENA AND FEATURES OF AURORAL BREAKUP: A CASE STUDY

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**Abstract.** The results of a comprehensive analysis of a moderate polar substorm (the term was proposed by *Kleimenova et al.,* 2012) are presented. Data of multi-instrument observations in auroral zone and polar cap were used. The onset took place near the poleward boundary of the auroral oval that is not typical for traditional substorms. It was preceded by two negative excursions of IMF Bz component with 15-min interval between them, two enhancements of antisunward convection in polar cap with approximately the same repetition period and 15-minute oscillations in geomagnetic H-component in auroral zone. The distribution of pulsation intensity along meridian has two maxima at equatorial and pole boundaries of auroral oval where pulsations occurred in out-of-phase mode resembling the field-line resonance event. The fast poleward shift of auroras (auroral breakup) had a form of poleward progressing auroral torch that also is not typical for ordinary substorms. The set of satellite and ground data fits better in the near-tail current disruption scenario.

## 1. Introduction

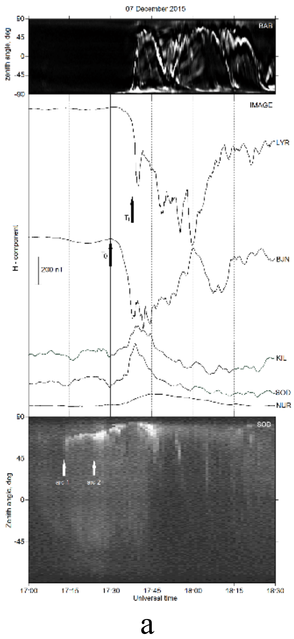
One of the challenges in substorm physics is to understand where and when substorm processes initiate. Two competing scenarios based on in-space observations have been proposed. Many authors have concluded that substorm origin is in the near-Earth portion of the plasma sheet. Dawn-to-dusk current disruption around 10 $R_E$ due to development of some kind of MHD or kinetic instability has been suggested as the initiation of substorm onset. As a result, the current wedge is formed, auroral structure in the form of westward traveling surge develops and the magnetic field is dipolarized. In accordance with other scenario, the substorm starts at 20 –30 $R_E$ as a result of magnetic reconnection. In ionospheric projection, the closer substorms are associated with maximal negative bays in H-component inside the auroral oval whereas distant substorms should be displayed close to its poleward boundary. *Kleimenova et al.* (2012) proposed to distinguish the substorms that are the magnetic bays at high latitudes ("polar" substorms) from those that start inside the auroral zone and then expand poleward. The relatively small statistics show that polar substorms constitute a noticeable part of total amount of substorm disturbances. Similar to classical substorm, polar substorm is accompanied with auroral breakup. However, it occurs in the form of large-scale vortex (*Kleimenova et al*., 2012) or poleward progressing auroral torch-like structure (*Safargaleev et al*., 2018) rather than auroral bulge or WTS which are typical shape of breaking auroras during classical substorms. Multiple onsets are a feature of many substorms on the ground. If they occur before the main breakup, they are called pseudobreakups. Some researchers believe that pseudobreakups are substorm precursor or even trigger.

The substorm trigger in interplanetary medium is one more discussion issue. Substorm may be initiated by variations both in solar wind dynamic pressure and interplanetary magnetic field (IMF). The investigations show that variations in IMF Bz component seem to be more effective factor affecting the state of magnetosphere. *Russel* (2000) suggested that double storm onsets can occur in a time sequence while the northward IMF turns southward and then northward again. *Mishin et al.* (2001) and *Safargaleev et al.* (2018) supposed that the polar substorm might be initiated by the quasi-sinusoidal variation in Bz component with period ~ 15 min. However, IMF is very changeable and one has to be guided by some *a- priori* information to associate substorm onset with a certain IMF variation. Such information may be a time delay between the arrival of IMF irregularity to the magnetopause and the beginning of the substorm which can vary from a few minutes to several hours.

The general aims of the presented study are to expand the statistics on the "polar" substorms and discuss a mechanism that most closely matches the observations.

## 2. Instrumentation

As the basic instrument we use Scandinavian network of magnetometers IMAGE In addition to magnetograms, IMAGE allows also the presentation of local geomagnetic activity via the dynamic of ionospheric equivalent currents. In the equivalent current map a potential footprint of a localized field-aligned currents (FAC) can be identified by a quasi-circular clockwise (counterclockwise) equivalent current vortex around location of upward (downward) FAC. Two all-sky cameras (at Barentsburg, BAB, 78.09° N, 14.21° E and at Sodankylä, SOD, 67.37° N, 26.63° E) were monitoring auroral activity inside the auroral oval and in polar cap close to oval boundary, respectively. Satellites WIND, THB and THC probed IMF and plasma in solar wind whereas GEOTAIL monitored duskside plasma sheet parameters and was magnetically conjugated to the sector where the instruments operated. DMSP F18 data used to estimate the location of BJN station as to be close to the poleward boundary of auroral oval. AMPERE data were used to estimate the location of auroras relatively field aligned currents. The European Incoherent Scatter Radar on Svalbard (ESR) observed density and ion velocity in the F region over Spitsbergen about of 40 km east from all-sky camera in Barentsburg. In addition, data from the SuperDARN were used for monitoring the large-scale ionosperic plasma convection patterns.



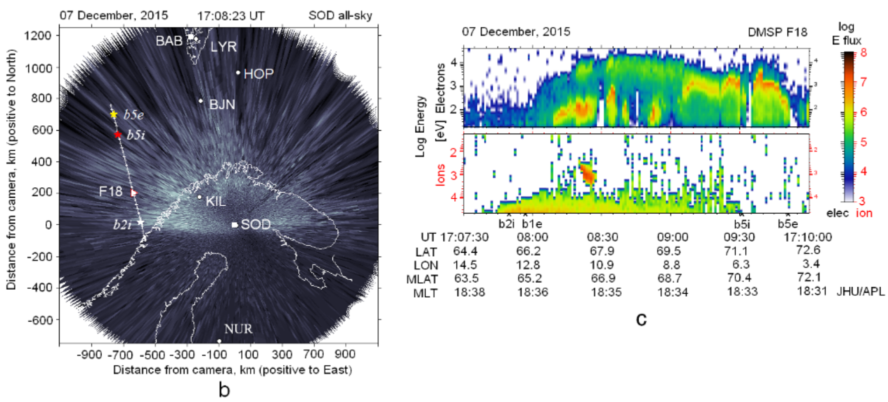




**Figure 1.** (***a***) keograms showing aurora dynamics over Barentsburg, BAB (*top panel*) and Sodankylä, SOD (*bottom panel*) and magnetic data from five IMAGE observatories (*middle panel*); (***b***) SOD all-sky camera image at 557.7 nm. DMSP F18 trajectory is mapped, and the triangle marks the location of the satellite at the time of the image. (***c***) DMSP spectrograms with the magnetospheric boundaries showing the location of BJN near the auroral oval poleward boundary. $T_0$ is the time of polar substorm onset.

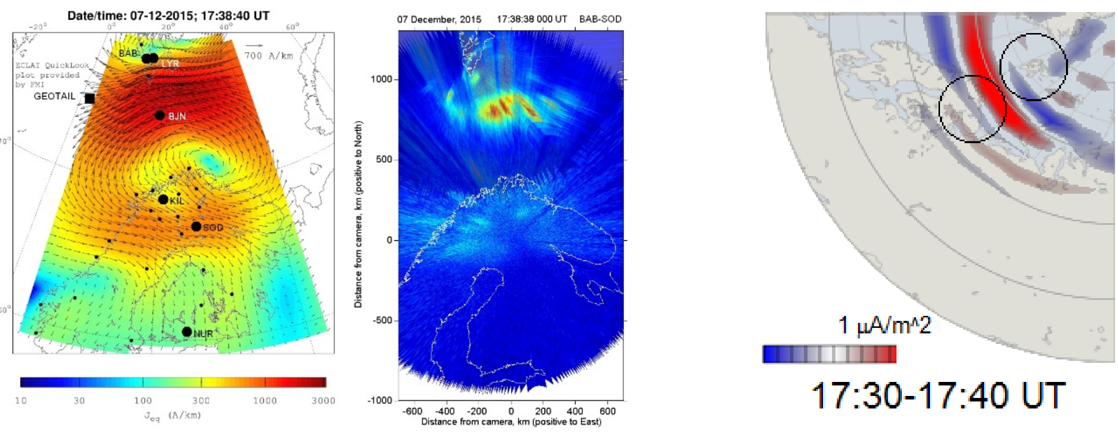



**Figure 2.** *Left panel:* snapshot of 2-D equivalent current and mapped SOD and BAB all-sky images showing the shape and location of auroral torch-like structure between pair of field aligned currents corresponding to two current vortexes. Black square and circles indicate the position of GEOTAIL footprint and IMAGE observatories, respectively. *Right panel:* distribution of the FAC inferred from AMPERE satellite data. Upward currents are shown by red and downward currents in blue. Circles indicate field of view of the all-sky cameras.

## 3. Results

We present the comprehensive description of the moderate "polar" substorm focusing on the multi-instrumental study of pre-onset events in the solar wind, ionosphere and on the ground. The onset took place at pre-midnight near the poleward boundary of the auroral oval that is not typical for classical substorms (Fig. 1). We have shown that the auroral breakup developed between two field-aligned currents with downward current poleward the breaking auroras and upward current south of them (Fig. 2). This morphological feature distinguishes the polar substorm from classical ones.

The onset was preceded by two negative excursions of IMF Bz component with repetition period ~ 15 min (Fig. 3). These variations caused periodic reconnection at the magnetopause. Two enhancements of the antisunward convection in the polar cap and appearance of the ionospheric patch near the polar cap boundary support the reconnection hypothesis (Fig. 4). On the one hand, the reconnection leads to the increase of the magnetic energy in the lobes and corresponding thinning of the plasma sheet that creates favorable conditions for substorm initiation. On the other hand, the periodic erosion of the magnetopause excites the global 15-min oscillation of the magnetospheric cavity. The oscillations are observed in the auroral zone (Fig. 5). Period of the oscillations does not depend on the latitude which means that the pulsations represent forced oscillations of the magnetosphere cavity. Latitudinal distribution of the oscillations' intensity has maxima near the equatorial and poleward boundaries of the auroral oval where the oscillations occur in the out-of-phase regime resembling the field-line resonance.

The onset was accompanied by disruption of the dawn-to-dusk current in the plasma sheet around (X, Y) ~ (-16, 16) $R_E$ and the current wedge formation. We conclude this from data of the GEOTAIL satellite magnetically conjugated with the area of ground observations, enhancement of the westward electrojet and the large positive variation in H-component at low latitudes (Fig. 6). We think that the onset might be initiated by the out-of-phase oscillations in the same way as field-line resonance does (e.g., *Rae et al.,* 2014). One more possible reason for the substorm triggering might be the interchange or ballooning instabilities. External excitation of the out-of-phase oscillations is regarded as the reason for the auroral arc brightening prior and just after onset.

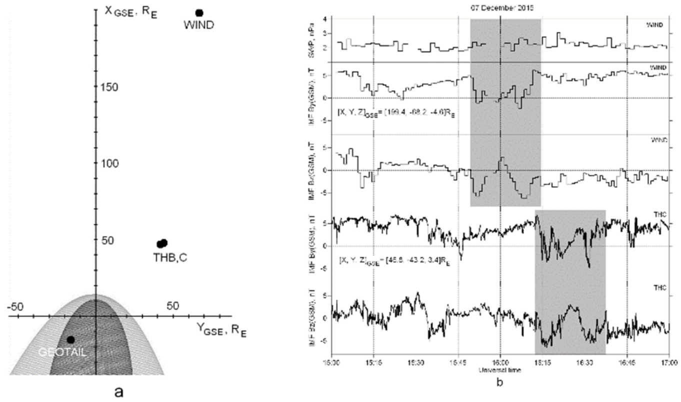



**Figure 3**. (***a***) satellite location at the moment $T_0$; (***b***) variation of interplanetary parameters at WIND and THEMIS satellites. Two negative excursions of Bz on the both satellites resembling the quasi-sinusoidal variation with period ~ 15 min are highlighted by gray.

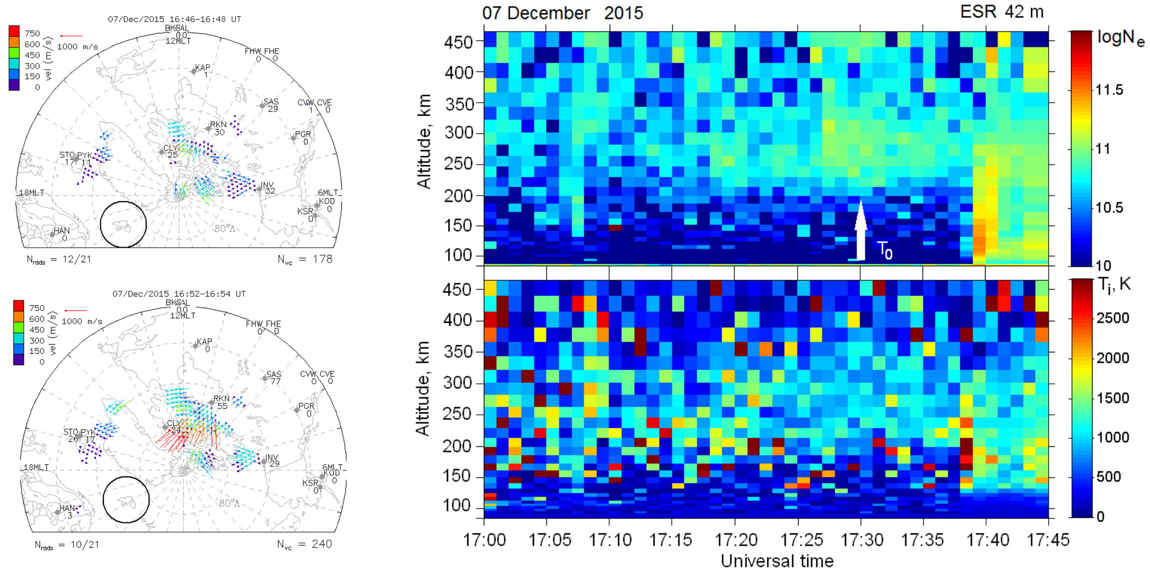



**Figure 4.** Ionosheric signatures of dayside reconnection. *Left panel:* enhanced convection in polar cap in SuperDARN data. *Right panel:* ionospheric patch in ESR data (upper diagram). Ion temperature increase ahead the poleward expanding auroras indicates the presence of field aligned current (lower diagram).

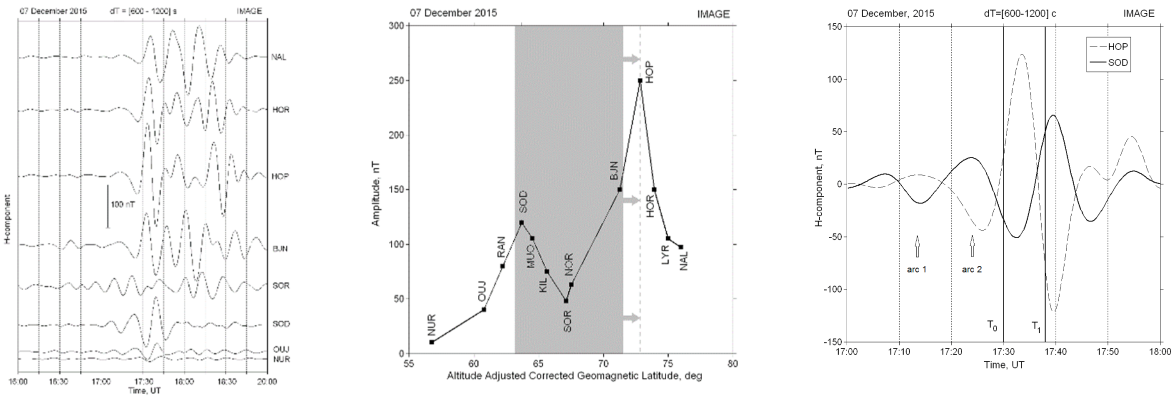



**Figure 5.** Wave "portrait" of polar substorms (*from left to right*): geomagnetic variations in a band 15±5 min; latitudinal distribution of pulsation intensity, the presumable width of auroral oval is indicated with gray; out-of-phase variations at stations SOD and HOP where pulsations have maxima. Open arrows indicate time of enhancement of pre-breakup arcs. $T_0$ and $T_1$ are the times of onset and torch-like structure formation, respectively.

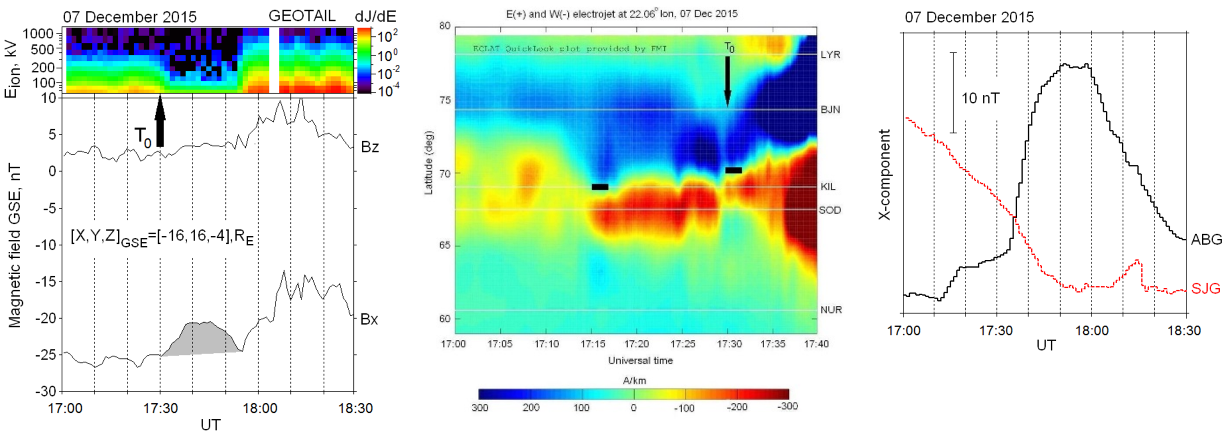



**Figure 6.** Signatures of current sheet disruption (*from left to right*): decrease of differential ion flux and Bx component on GEOTAIL magnetically conjugated with westward electrojet; enhancement of westward electrojet; unexpectedly large magnetic variation at nightside low-latitude station ABG.

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