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WESTWARD PROPAGATION OF SUBSTORM BY THEMIS AND GROUND-BASED OBSERVATIONS

I.V. Despirak, T.V. Kozelova, B.V. Kozelov, A.A. Lubchich

Polar Geophysical Institute, Apatity, Russia, e-mail: despirak@gmail.com

Abstract. The analysis of the substorm activity on December 24, 2014 in the interval from ~ 16 to ~ 17:30 UT was carried. During this period, the substorm disturbances of the fields and fluxes of energetic particles were recorded on THE and THD satellites, which were in the midnight sector of the magnetosphere at r ~ 8.5-10.3 R_E. The disturbances in the geomagnetic field are registered at Tiksi, Dixon, Amderma, Lovozero stations and IMAGE magnetometer network. In addition, aurora activity was observed by all-sky camera in Apatity (APT). Magnetic activity began at the DIX at T_0 ~ 16:10 UT, then the increasing of the westward electrojet occurred at more western stations, from AMD at T_1 ~ 16:35 UT to LOZ at T_2 ~ 16:45 UT. An analysis of ground-based data showed that certain variations of the D-component of the magnetic field were registered and these variations appear at different longitudes according to the moving of the westward traveling surge (WTS). We suggested that the active arc associated with the "onset" of this substorm was located between THD and THE (in the radius direction), because near moment T_0 the different signs of the E_X components on two satellites were observed and more early beginning of the disturbances was registered on THE satellite. The propagation of disturbances from onset region to the West is supported the appearance of several precursors of substorm, which arise over the Apatity, i.e. ~ the 2 MLT to the West from the region of "onset": small, discrete, localized on latitude, auroral arc, the western edge of this arc propagated westward; so-called "beads" in the auroras; "auroral horn", i.e. the bright arc, which moving ahead the WTS faster than WTS. Several precursors confirm the azimuthal propagation of the disturbance from the onset region to the West.

Introduction

Among all substorm observations were investigated also such cases of auroral activity, when the onset and the expansion of the substorm occurs at one longitude sector, but main observations were located at another longitude sector. For example, cases, when the substorm onset was registered at the one longitude, but all-sky camera data were available only on ~ 2-3 MLT to the West. Therefore, arises the opportunity to register some precursors of substorm, which occurs before, simultaneously or small after the substorm onset at more western longitude sector.

Researchers often described the substorm precursors that are registered in the auroras before breakup. Among them distinguished North-South aligned (N-S) auroral features, which occur at the polar auroral boundary and propagated equatorward. Presumably these N-S aligned auroral features are associated with the PBIs (Polar Boundary Intensifications) (e.g. [1]). However, according to the precursors classification of [2], may be also East -West aligned forms of auroras preceding breakup. These E-W features of auroras may be related to the ballooning waves propagating in the plasma sheet [3]. One of the precursors of substorm is the "auroral horn" which sometimes observed before the front of the West Traveling Surge (WTS) ([4]; [5]; [6]). Fig. 1 shown the schematic picture of the westward propagation of "auroral horn" [7]. Onset of the substorm was near Novaya Zemlya archipelago (the geographic longitude ~50^{0}E), after two minutes from onset the auroral "horn" reached the longitude of 12^{o}E, i.e. their velocity was ~ 16 km/s. While the WTS velocity was estimated as ~ 2-3 km/s.

In our work we analyzed the substorm on 24 December 2014 with the onset near Amderma (longitude ~61^{0}40′E), which was registered by ground-based and satellites data, the propagation of substorm to the West according magnetometers data and the occurrence of some precursors of substorm above Apatity (longitude ~33^{0}24′E).

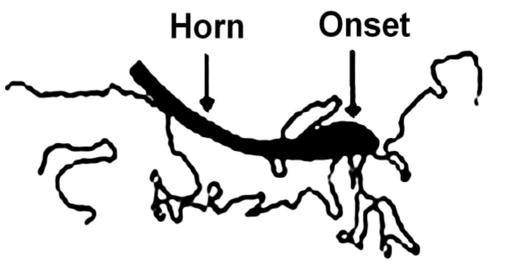


Figure 1. Schematic picture of the auroral horn. Figure takes from work [7]

Data

Ground-based auroras observations on MAIN cameras in Apatity (APT) (67°34′N; 33°24′E), magnetic disturbances at Dixon (DIX), Tiksi (TIK), Amderma (AMD), Loparskaya (LOP) and Lovozero (LOZ) stations and IMAGE magnetometers and also the variations of the fields and particle fluxes from two THEMIS satellites (THE and THD) were used. Schematic development of substorm, coordinates of magnetic stations, projections of THD and THE orbits are presented in Fig. 2. Both satellites were over Amderma region at ~ 16: 30- 17:00 UT, then THD moved to the West and ~ 18: 30 UT reached the Kola Peninsula, and THE turned to the South. Schematic locations of magnetic stations DIX, AMD, LOP, APT and IMAGE network indicated by blue stars. Vertical lines marked the onset of the disturbances by ground-based data and moments of the onset of disturbances on satellites: T_0 - the onset of the substorm near the DIX (red line); T_{FD} и T_{FE} – the moments of the onset of fast plasma flows on the corresponding satellite (green lines); T_2 - the onset of the substorm expansion phase on the satellite (green lines).

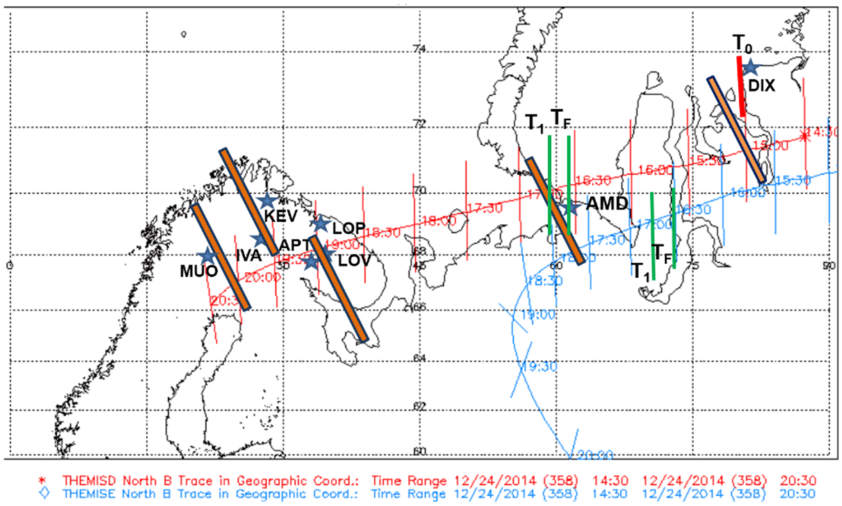


Figure 2. Projections of the THD (*red line*) and THE (*blue line*) from 14:30 to 20:50 UT on 24 December 2014. The locations of magnetic stations are marked by stars. Orange strips shown the schematic substorm expansion to the West.

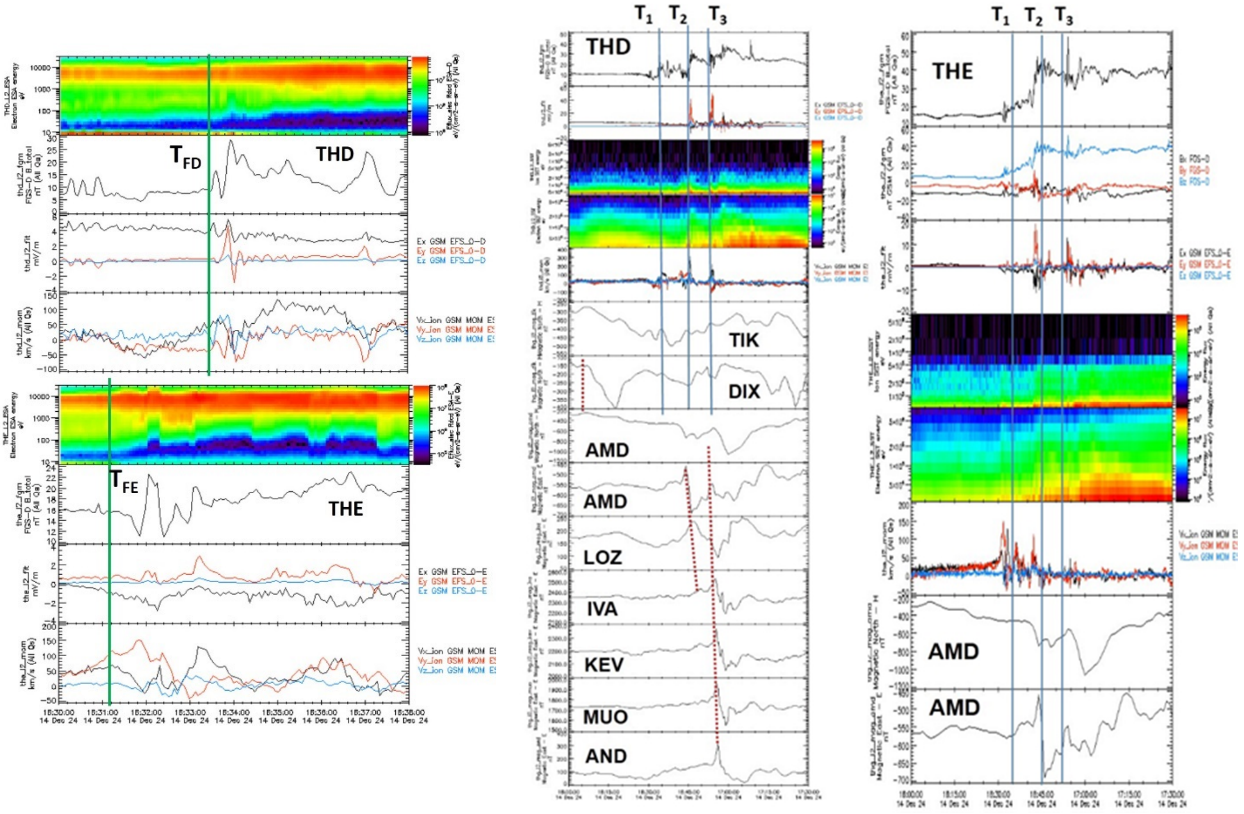
Results

a) Substorm development by satellite and magnetometers data

In Fig. 3a shown the variations of magnetic and electric fields, fluxes of energetic electrons in the initial period, from 16:30 to 16:38 UT. Following moments were distinguished: T_{FD}=16:33:24 UT, moment of beginning of the plasma flow and E- and B- field variations for THD; T_{FE}= 16:31:12 UT, the moment of the beginning of the local dipolarization of the magnetic field and localized increases in the electron fluxes on THE. It is seen the almost simultaneous onset of growth of the magnetic field and plasma flows were registered both for THE and THD satellite. However, it was observed the advance of the beginning of these growth on the THE. The first to observe an increase in the azimuthal velocity component in a western direction (V_Y ~ 150 km/s) on the THE. Moreover, the different signs of the X- components of electric field on the two satellites near moments T_{FD} and T_{FE} were registered: for THD E_X>0 before T_{FD} moment and E_X<0 for THE before T_{FE} moment. It indicates that the active arc associated with the substorm onset was located in radial direction between THD and THE.

The development of magnetic disturbances according to ground-based data is shown in the Figs. 3b and 3c (bottom). Fig. 3b shown the data from FGM, EFI, SST, MOM instruments of THD satellite and magnetometers (TIK, AMD, DIX, LOV, IVA, KEV, MUO, AND) data. In Fig. 3c the same instruments from THE satellite and AMD magnetometer data are presented. First short localized magnetic bay ΔH <0 was observed at DIX at ~16:10 UT (dotted line). This bay was accompanied by riometric absorption (picture not presented), which usually appearing in the grow phase of the substorm. Accordingly, onset of the substorm was registered at the DIX (~16:10), then westward electrojet decreases at eastern stations and occurs at AMD (~16:35) and LOZ (~16:45). The smooth start of the increasing of electrojet at AMD was determined by a small increase in the D-component (ΔD> 0) around the time T_1~ (16: 35-16: 37) UT. Noted that a weak burst of Pi1B pulsations was recorded in Lovozero at this time (picture not presented here). It is seen the azimuthally westward moving of E-component maximums, from AMD to AND station, i.e. from the onset region to the West. Two red dotted lines marked the propagations of magnetic field variations during two substorm intensifications.

Substorm variations from THD and THE satellite data are recorded on the top panels in Figs. 3b and 3c. It is shown the behavior of magnetic field, electric field and particle fluxes in the magnetosphere on r ~ 8.5–10.3 R_E during substorm expansion phase, in the period 16:00 - 17:30 UT. Moments T_1, T_2, T_3 were distinguish by all-sky camera data (see Fig. 4) and shown here for comparison. It is seen that these moments do not coincide with the onset of disturbances on satellites, first variations in the magnetosphere were registered before T_1 (onset of pseudo-breakup). Near T_1, T_2, T_3 were registered the dipolarization fronts (DF), which usually characterized by sudden jump of magnetic field, B_Z component of magnetic field, increasing of ion and electron fluxes.



a b c

Figure 3. ***a***) THD (*top*) and THE (*bottom*) in the initial period of disturbances, 16:30- 16:38 UT; ***b***) FGM, EFI, SST, MOM instruments of THD and magnetometers (Tiksi, Amderma, Dixon, Lovozero, Ivalo, Kevo, Muonoi, Andoya); ***c***) the same instruments from THE + Amderma magnetometer. Vertical lines marked time moments distinguished by all-sky camera (*blue lines*) and by satellite data (*green lines*).

b) auroras observations

Fig. 4 and Fig. 5 demonstrated the auroral activity by data of all-sky camera at the Apatity: keograms for 16:30-17:00 and images of all-sky camera for period 16:33-16:53UT.

According to auroras development, the following time points can be determined: 1) T_1 ~ (16:35-16:37), the appearance of a weak narrow auroral arc along the latitude φ ~ 67.5 ° (precursor of the pseudo-breakup, that occurs near AMD); 2) T_2 ~ (16:43-16:45), the appearance of a new very bright arc to the North of LOZ along the latitude φ ~ 68.5 ° (onset of the breakup); 3) T_3 ~ (16:52-16:53) - the moment when the west edge of westward traveling surge (WTS) of auroras passes by the LOZ meridian. Moments T_1, T_2 and T_3 are marked in Fig. 3 for comparison with THE and THD data. Noted, that moments T_2 and T_3 correspond the time moments of the onset and the maximum of Pi1B pulsations with period τ = 0.2-15 s, which were observed in Lovozero (the picture not presented here).

First precursor was observed near the moment T_1. It was the discrete, localized on latitude, auroral arc occurs over Apatity, then this arc propagated westward. Noted that this arc arises ~ the 2 MLT to the West from the region of substorm "onset" which was determined from Siberian magnetometers. We purpose that this arc is the precursor of "onset" of pseudobreakup, which was registered near Amderma in this time. We estimated the velocities of westward propagation for the arc moving and for moving of onset disturbances registered by THE and THD satellite. According our calculations, the velocity of arc was ~2.5 km/s, while the velocity of propagation of magnetospheric disturbances in the ionosphereic projections (onto the map) was ~3 km/s. Second precursor was registered near ~16:40 -16:42 UT, it was so-called "beads" structure in the auroras, which were usually observed before the breakup arc [8] (the picture not shown here). Additionally, near the moment T_3, it is seen also the bright arc, which moving ahead the WTS front and was aligned from East to West, so-called "auroral horn" [4]. In our event there were three "horns" observed, we estimated the velocity of the third "horn", it was ~ 14.3 km/s. Whereas, according to magnetometers data, the WTS velocity was ~ 3.1 km/s.

Conclusions

1) "Onset" of the substorm was located near AMD, between THD and THE.

2) DFs and injection of energetic electrons in the magnetosphere were observed near the moments of a sudden auroras increase (brightening of auroral arcs, breakup and the appearance of WTS).
3) The azimuthal propagation of the distributions from "onset" region to the West, which confirmed early beginning of disturbances on the eastward satellite (THE) and westward propagation of certain variations of the D components of the ground-based magnetic field.
4) Several precursors (small, localized auroral arc, which propagated westward; so-called "beads" structure in the auroras and "auroral horn"), which were observed before breakup, confirm the propagation of the disturbance from the onset region to the West.

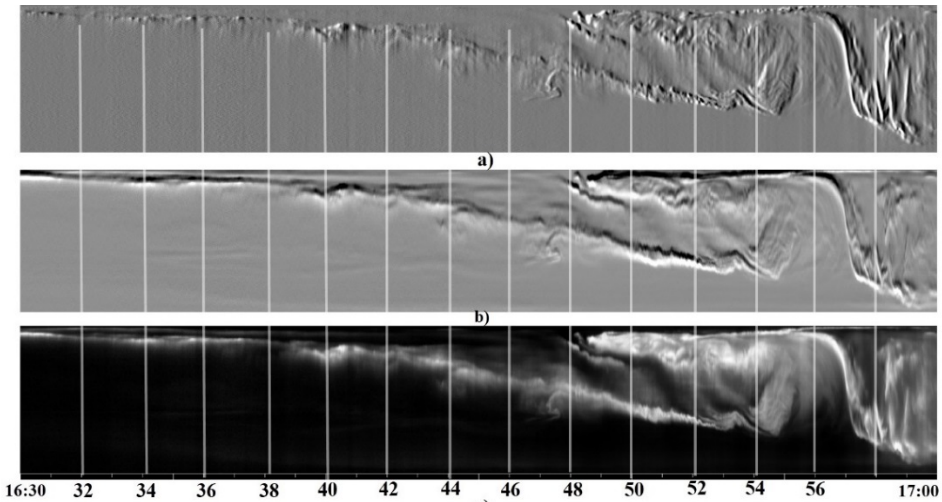


Figure 4. Keograms for time period from 16:30 to 17:00 UT: (***a***) – filtered by the horizontal-time gradient; (***b***)- by the vertical-spatial gradient, (***c***)- non-filtered.

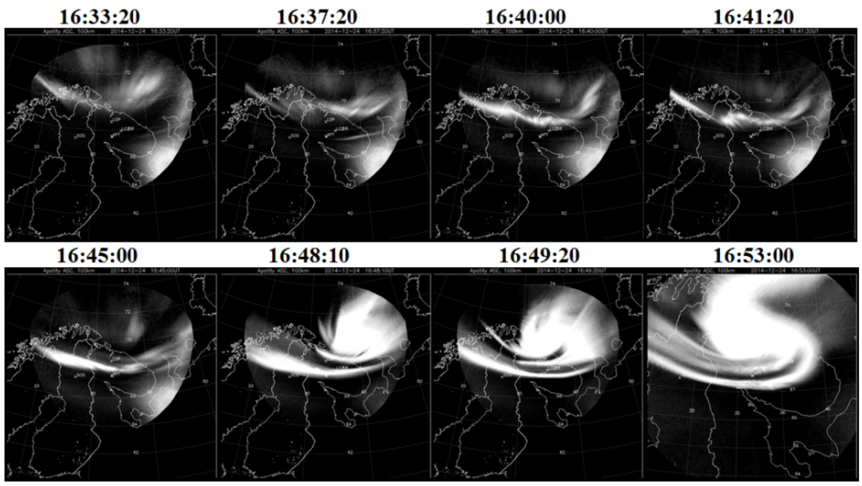


Figure 5. Some images of auroras projections on the altitude 100 km for period 16:33-16:53 UT.

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