“Physics of Auroral Phenomena”, Proc. XLIV Annual Seminar, Apatity, pp. 16-19, 2021

Polar Geophysical Institute

DOI: 10.51981/2588-0039.2021.44.003

OBSERVATIONS OF SUBSTORM ACTIVITY FROM THE DATA OF MAIN CAMERA SYSTEM AND THD SATELLITE IN THE PLASMA SHEET

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Abstract. We investigated an interesting case of the space-time dynamics of substorm activations (AL ~ 800 nT) on December 24, 2014, when there were simultaneous observations on the THEMIS D satellite in the plasma sheet (|X| ~ 6.2 R_E) and ground-based observations on the Kola Peninsula. The development of the substorm activity in the interval of ~ 19:00 to ~ 20:00 UT was considered. In this interval, at Lovozero station (LOZ), three peaks in the Pi1B pulsations were recorded, associated with the brightening of arcs near LOZ. The first peak was observed in connection with the appearance of beads structures in the auroras along the growth phase arc to the south from LOZ latitude. The second and third peaks in Pi1B pulsations were associated with the expansion phase, when three dipolarization fronts (DFs) were registered according THD data. DFs and injection of energetic electrons into the magnetosphere were observed near the moments of sudden intensification of auroras: brightening of arcs, breakup in aurora. Besides, it was shown that the development of substorm occurs near the Harang discontinuity (HD) according to the IMAGE magnetometers data. In this case, we can follow the development of aurora around the HD according to the data of the all sky camera in Apatity. It was shown that the pre-onset auroral forms were moved accordingly the two-cell ionospheric convection developed during the growth phase of the substorm.

Introduction

Despite a large number of studies, there is significant uncertainty regarding the space-time relations between the magnetosphere and the ionosphere during substorm expansions. Therefore, further research is needed using combined satellite and terrestrial data. For this purpose, one interesting event were chosen, on 24 December 2014, when simultaneous observations of the THEMIS satellites (THE and THD), the ground-based observations of aurora in Apatity and magnetic disturbances on the IMAGE magnetometers network and Russian Siberian stations (Dixon, Tiksi and Amderma) were available. Note, that the initial case of substorm activity in this day, during interval from ~ 16: 00 to ~ 17: 00 UT, was considered in our previous work [1]. During time interval from 14:30 to 20:50 UT on 24 December 2014, THE and THD satellites were located in the midnight sector of the magnetosphere and crossed over Siberia and Kola Peninsula. Figure 1 shown the geographic map with projections of the THD (red line) and THE (blue line) and the locations of magnetic stations. The first case of substorm activity (~ 16 ~ 17 UT) marked by a blue oval and inscription "1)"; the second case (19- 20 UT), marked as "2)".

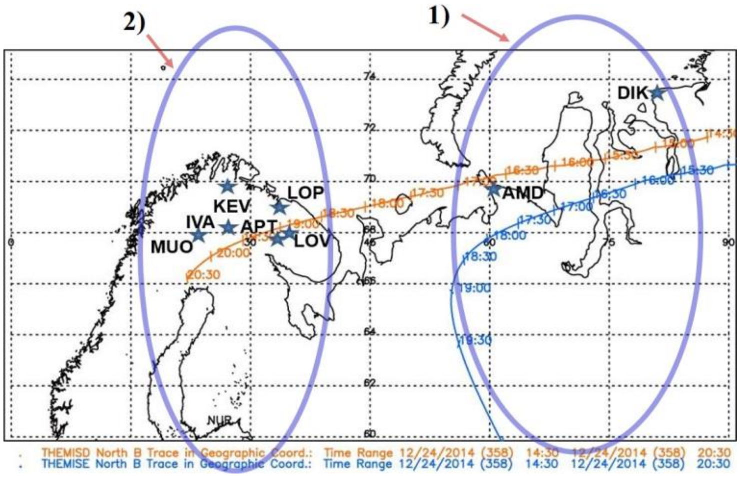


Figure 1. Projections of the THD (red line) and THE (blue line) from 14:30 to 20:50 UT on 24 December 2014. The locations of magnetic stations are marked by stars, the time intervals under study - by blue ovals.

It was shown, that the onset of disturbances was in the ionosphere near Amderma (~ 16:35 UT) and several substorm precursors were observed in aurora development over Apatity - small localized auroral arc, which propagated westward, so-called beads structure in the auroras and the auroral horns [2], [3].

In this work, we considered substorm activity from ~ 19: 00 to 20:00 UT, when THD was at a distance |X| ~ 6.2 R_E in the plasma sheet, and its projection crossed the Kola Peninsula. Aurora activity was observed by the MAIN camera system in Apatity, magnetic disturbances were recorded by magnetometers of the IMAGE network, Pi1B pulsations were registered by Lovozero observatory (LOZ). It is interesting event, when the development of substorm injection occurs near the Harang discontinuity (HD).

Data

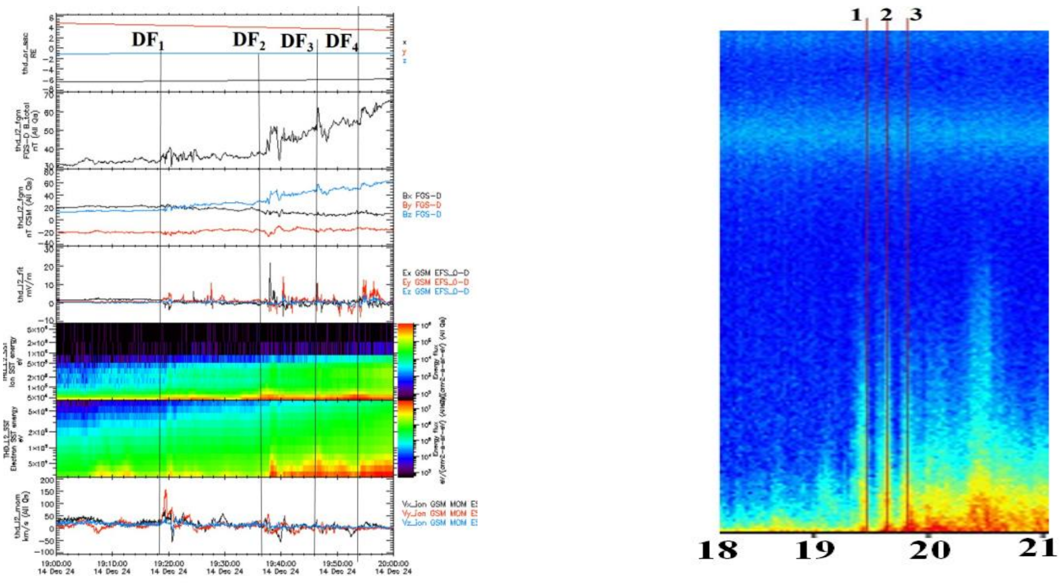
For our analysis we used complex ground-based data: the auroras observations on MAIN cameras in Apatity (APT), the magnetic disturbances at IMAGE magnetometers network and the geomagnetic pulsations in Lovozero and also the variations of the fields and particle fluxes from THEMIS satellites (THD). To study the substorm development, we used the keograms and the selected full-frame images from the Apatity all-sky camera (APT, 67°34N; 33°24E). The camera specifications, their mutual location and the measurement process are described in detail in [4]. Geomagnetic disturbances were observed by analyzing the data of the IMAGE magnetometers network (http://space.fmi.fi/image/). Geomagnetic pulsations were observed by data from the induction magnetometer located in Lovozero. The data used here are the spectrograms in frequency range from 0.01 to 16 Hz, where the whole spectrum of natural pulsations Pi1B is well seen, if their existed. The variations of fields and particles in the magnetosphere were studied by THD data. During the time period from 19:00-20:00 UT the THD was located at r ~ 8.9–6.1 R_E, in the midnight sector: in 19:30 UT GSM coordinates were (-6.2; 4.1; -1.05) R_E.

Results

1. Development of disturbances from satellite data

The data of FGM, EFI, SST, MOM instruments of the THD satellite are shown in the Figure 2a. It is seen that four dipolarization fronts (DF) were registered by THD data (DF_1 =19:18; DF_2 =19:37; DF_3 =19:45, DF_4 =19:54 UT). DFs were determined by sudden jumps of the magnitude and B_Z component of the magnetic field, the strong variations in the electric field, the growth of the plasma velocity and the increasing of ion and electron fluxes (e.g. [5]). Four vertical black lines marked the DFs moments. As will be shown below, DF_1 was observed during the growth phase of the substorm, the last three dipolization fronts were associated with the development of the expansion phase of the substorm and connected with brightening of arcs near the THD projection.

In the Figure 2b shown the Pi1B pulsations (the period τ = 0.2-15 sec) observed in Lovozero. Note, that these pulsations are associated with substorm expansion phase and correlated with precipitations of auroral electrons [6]. Three peaks of Pi1B pulsations were recorded in Lovozero: 19:22 - 19:25, 19:34 - 19:37 and 19:46 - 19:49 UT. The first peak was observed in connection with the appearance of beads at the growth phase arc located south of LOZ latitude. The second and third peaks were associated with the expansion phase of the substorm.

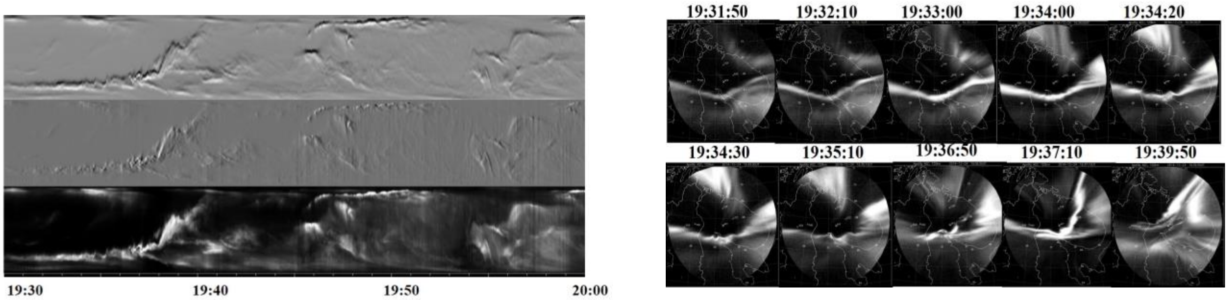


a) b)

Figure 2. Data of FGM, EFI, SST, MOM instruments of THD from 19:00 to 20:00 UT (a) and geomagnetic pulsations at Lovozero from 18 to 21 UT on 24 December 2014 (b). Moments of four dipolarization fronts (DF) marked by vertical black lines (a), moments of three peaks in Pi1B pulsations – by red vertical lines (b).

2. Aurora observations

Auroral activity captured by all-sky camera at the station Apatity (APT) is presented in Figure 3. Left three panels of Figure 3 illustrate the temporal dynamics of the camera field of view as keogram: top panels - the keograms filtered by the horizontal-time difference and by the vertical-spatial difference; bottom panel - non-filtered keogram for interval 19:30 - 20:00 UT. Some selected images of all-sky camera are shown in Figure 3b. During growth phase of substorm were registered "beads" in aurora ~ from 19:18 UT, which are visible both on the arc near the zenith and on the southern arc (picture not presented here). At this time, THD registered the first dipolarization front (DF_1) and there were some weak disturbances in the ground-based magnetograms (Figure 4a). Note, that the first peak in Pi1B pulsations at Lovozero was recorded a little later (~ 19:22 UT), when the auroras approached to LOZ latitude. At the end of the growth phase (~ 19:31:50 UT) a brightening of the most equatorial from all arcs was observed. Then on the arc, azimuthally spaced auroral folds are formed, moving from East to the West. This corresponds to the first phase of the breakup (or pseudo-breakup). At ~ 19:33:50 UT, the equatorial arc again became brighter, ~ 19:34 UT rapidly expand to the pole. This moment concerns to the onset of the second peak in Pi1B pulsations in LOZ. At ~ 19:37 UT (the maximum of second peak of Pi1B pulsations) an N-S arc occurred, then this arc moves equatorward and reaches E-W aligned arcs.

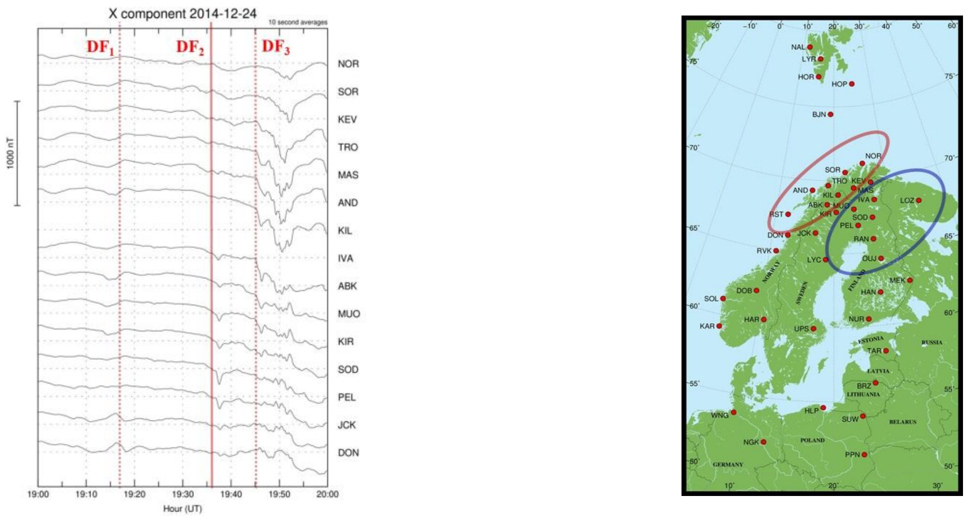


a) **b)**

Figure 3. Data of all-sky camera at the Apatity: a) keograms for time period from 19:30 to 20:00 UT: filtered (top panels) and non-filtered (bottom panel) keograms for 19:30-20:00 UT (a) and some images of all-sky camera for period 19:31:50-19:39:50 UT (b).

3. Ground-based magnetic observations

Figure 4 shown variations of X-component of geomagnetic field by IMAGE network data. Vertical red lines corresponded to 3 moments of dipolarization fronts (DFs) registered by THD satellite, solid line DF_2 marked also the onset of expansion phase. It is seen that near DF_2 moment were observed two different regions containing positive magnetic bays and negative magnetic bays, which marked also as red and blue ovals in the Figure 4b. So, accordingly IMAGE magnetometers observations, the development of substorm occurs near the Harang flow shear.



a) **b)**

Figure 4. X- component of geomagnetic field from IMAGE magnetometers, the DFs moments are marked by red vertical line (a); the map of locations of IMAGE magnetometers, red and blue ovals marked the region of positive and negative bays accordingly (b).

Discussion

Crossing the Harang discontinuity (HD) by the earth's rotation, magnetometer observations detect a change in magnetic perturbations from that dominated by the eastward electrojet to that dominated by the westward electrojet [7]. In terms of convection flows, flow vectors rotate clockwise from higher to lower latitudes. This configuration is referred to the Harang reversal (HR) in reference to the plasma convection pattern from eastward flow reversing to westward flow with decreasing magnetic latitude [8]. Schematic illustration of motion of pre-onset auroral forms and their relation to nightside ionospheric convection presented in Figure 5 (the picture taken from [9]). The pink star, NS-oriented pink line, and azimuthally extended wavy lines indicate a PBI, NS-oriented arc and onset arcs, respectively. Blue arrows illustrate the plasma flow pattern inferred from pre-onset auroral motion. Numbers 1–5 show time evolution of pre-onset aurora.

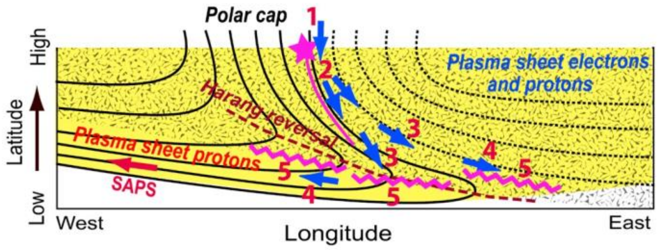


Figure 5. Schematic illustration of motion of pre-onset auroral forms near the Harang discontinuity and their relation to nightside ionospheric convection. The Figure was taken from [9].

Conclusions

Analysis of substorm activity using THD satellite data on |X| ~ 6.2 R_E and ground-based data led to the following results:

1) The fronts of dipolarization and injection of energetic electrons into the magnetosphere were observed near the moments of sudden intensification of auroras: brightening of arcs, breakup in aurora;

2) According to the magnetometers data, the development of substorm occurs near the Harang discontinuity;

3) The development of aurora was organized according to the preceding two-vortex pattern of ionospheric convection observed in the growth phase around the Harang discontinuity.

Asknowlegments

Ground-based magnetometers data were taken from IMAGE network: https://space.fmi.fi/image/. We are grateful to staff of Lovozero observatory of Polar Geophysical Institute for data of ground-based observations. THEMIS satellites data were taken from NASA CDAWeb https://cdaweb.sci.gsfc.nasa.gov/cgi-bin/eval1.cgi. We are grateful the heads of the experiments conducted with these instruments. The work was carried out within the framework of the State assignment for Polar Geophysical Institute (PGI).

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