"Physics of Auroral Phenomena", Proc. XXIX Annual Seminar, Apatity, pp.44-47, 2006

Polar Geophysical Institute

PROTON PRECIPITATION DURING A SMALL SUBSTORM ON DECEMBER 16, 2004

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Abstract. The hydrogen Balmer alpha emission was observed during a small substorm event on December 16, 2004 with onset ~ 20:14UT by Apatity spectrograph (67.58 N, 33.31 E). This event was also well documented by coordinated ground-based optical and riometer observations at Lovozero observatory(67.97 N, 35.02 E). The dynamics of electron and proton flux precipitation during this event is discussed taking into account the observed spatial-temporal manifestations in aurora: breakup arc, hydrogen band, WTS, N-S forms, ets.

Introduction

The main patterns of substorm development in proton auroras were described already in the 70-ies in a few papers [Montbriand,1971; Fukunishi, 1975; Yevlashin and Yevlashina, 1980]. At the growth phase of substorm in the evening, the proton aurora is found to be at lower latitudes than the discrete arcs of the electron aurora; whereas the situation is opposite at the recovery stage in the morning hours. These conclusions have been supported by the statistics [Hardy et al., 1991]. However, the dynamics of precipitated proton fluxes and the resulting hydrogen emissions during the late growth and early expansion phases of the substorm are not completely understood. As far as the expansion phase is concerned, some important quantitative differences can be found.

Extensive studies of substorm events during the last two decades have revealed an important role of ions fluxes in the development of instabilities associated with the expansion phase [Delcourt et al., 1994, 1996]. Significant variations of proton fluxes found by satellites in the zone of substorm expansion, both near magnetic equator [Sauvaud and Winckler, 1980; Kozelova et al., 2004], and at low altitudes [Sergeev and Kubyshkina, 1996], also attract one's attention. Despite the great achievements of satellite techniques, the direct observation of proton fluxes in various magnetospheric domains is usually lost in the space-time ambiguity associated with satellite data. Therefore, the optical observations, both ground and satellite, are important.

Recently, the results of coordinated, optical ground-based observations of the auroral substorm on March 26, 2004 in the Kola Peninsula were discussed in [Borovkov et al., 2005]. Two different populations of precipitated proton flux were observed during the event. The first of them was a diffuse proton precipitation that is usually observed in the evening sector of the auroral oval and located equatorward of the discrete electron precipitation. The second population of precipitated protons was separated from the first one by the breakup, or onset arc (boundary of WTS). The proton precipitation was observed 1-2 minutes after the breakup and 4-5 minutes into the expansion phase of the substorm into the zone of bright discrete auroral structures. Here we present next case of substrom event with the same morphology.

Equipment

This study is based on observations provided by the Polar Geophysical Institute at two points: Lovozero observatory (67.97 N, 35.02 E) and Apatity station (67.58 N, 33.31 E). During the evening of 16 December 2004, two optical devices were operating at Lovozero observatory: TV All-Sky Camera (TVASC) and Scanning Photometer (SP). The TVASC observed the aurora in "white" light with a broad maximum at blue-green wavelengths. The TV data were recorded by a VHS recorder in a PAL video system, at 25 images per second. The TV data were also digitized using an Acorp TV-Capture plate with an output resolution of 5 images per second, 320 × 288 pixels, 8 bits per pixel.

The Scanning Photometer (SP) was scanning approximately in the magnetic north-south direction and monitoring auroral emissions at the wavelengths 427.8 nm (N_2^+ 1NG), 557.7 nm (OI) and 630.0 nm (OI). The trajectory of SP scans in the field of view of the TVASC is shown in Fig. 1. The magnetometer and riometer at Lovozero observatory was also available to monitor the geophysical environment.

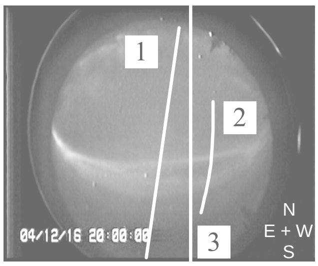

Fig.1. Fields of view for optical devices: 1 -scanning photometer; 2 - Apatity spectrograph; 3 - cross section for keogram.

At the Apatity station, spectrograph observations of auroras were provided by a special device consisting of an imaging spectrograph SpectraPro 306, made by Acton Research Corp. and an intensified CCD camera IpentaMax, made by Princeton Instruments. The CCD sensor was cooled up to -45 °C to reduce the noise level. The resulting mean dark charge for the 10-s exposition was about 4 units of the device ADC (Analog to Digit Converter). The device is mounted by gimbal to the ceiling and obtains emissions through a plexiglass dome. With a Nikkor fisheye lens, the full aperture of the device is ~ 80 × 1 deg. We control the spectrograph and camera with our own original software, using the low level programming possibilities of the software obtained with both instruments. The field of view of the spectrograph is shown in Fig. 1. Some additional details of the equipment were presented in [Borovkov et al., 2005].

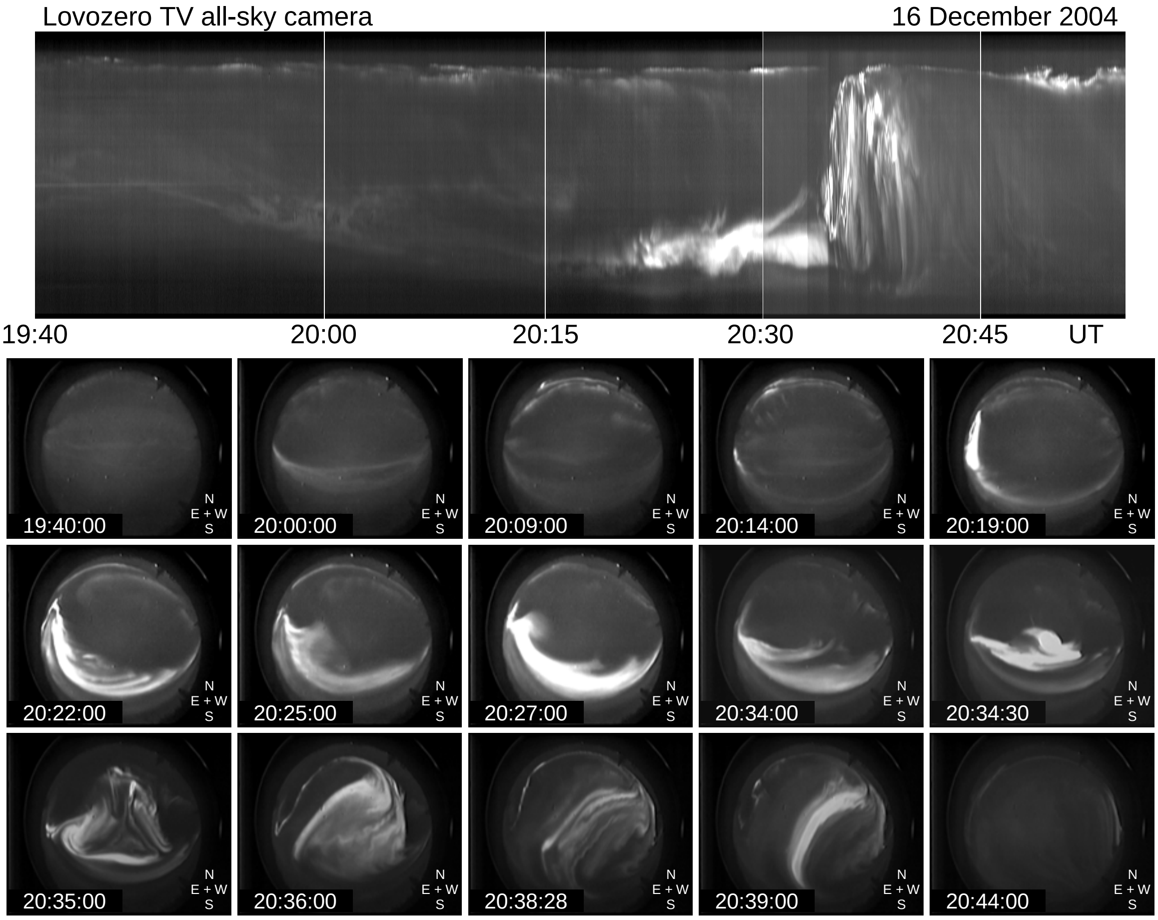

Fig.2. Top: TV keogram in the north-south direction (see Fig. 1); Bottom: TV all-sky images at several moments.

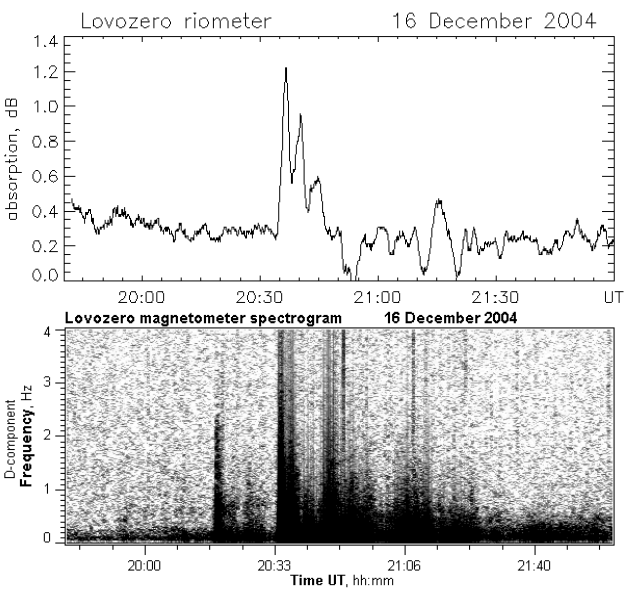

Fig.3. Observations during substorm event 16 December 2004. Top: riometric absorption observed by Lovozero riometer. Bottom: Lovozero magnetometer spectrogram.

Observations

For detailed study we consider the interval 19:40-21:00 UT, on 16 December 2004. During this day the Dst index was near zero. The considered time interval started from AE index value ~300 (due to the recovering phase of previous substorm). The maximum AE value during the considered interval was ~600. The observations are presented in figures 2-4. Figure 2 illustrates the TVASC observation at Lovozero observatory during the considered interval. Figure 3 shows riometric absorption and magnetic pulsations at the same place. Figure 4 contains the spectrograph data from Apatity station.

The interval under consideration started with weak auroral activity in the field of view of Lovozero optical devices. According to TVASC data, in the beginning of the interval, an active arc was located in the north horizon of the all-sky image (>300 km from Lovozero), and a slow diffuse pulsing arc was observed near the zenith. During the next 35 min there was a large-scale motion of the arc system in the southward direction for ~300 km; this is a normal feature for the growth phase of the substorm. No any remarkable variations in the magnetic pulsations and riometer absorption were observed.

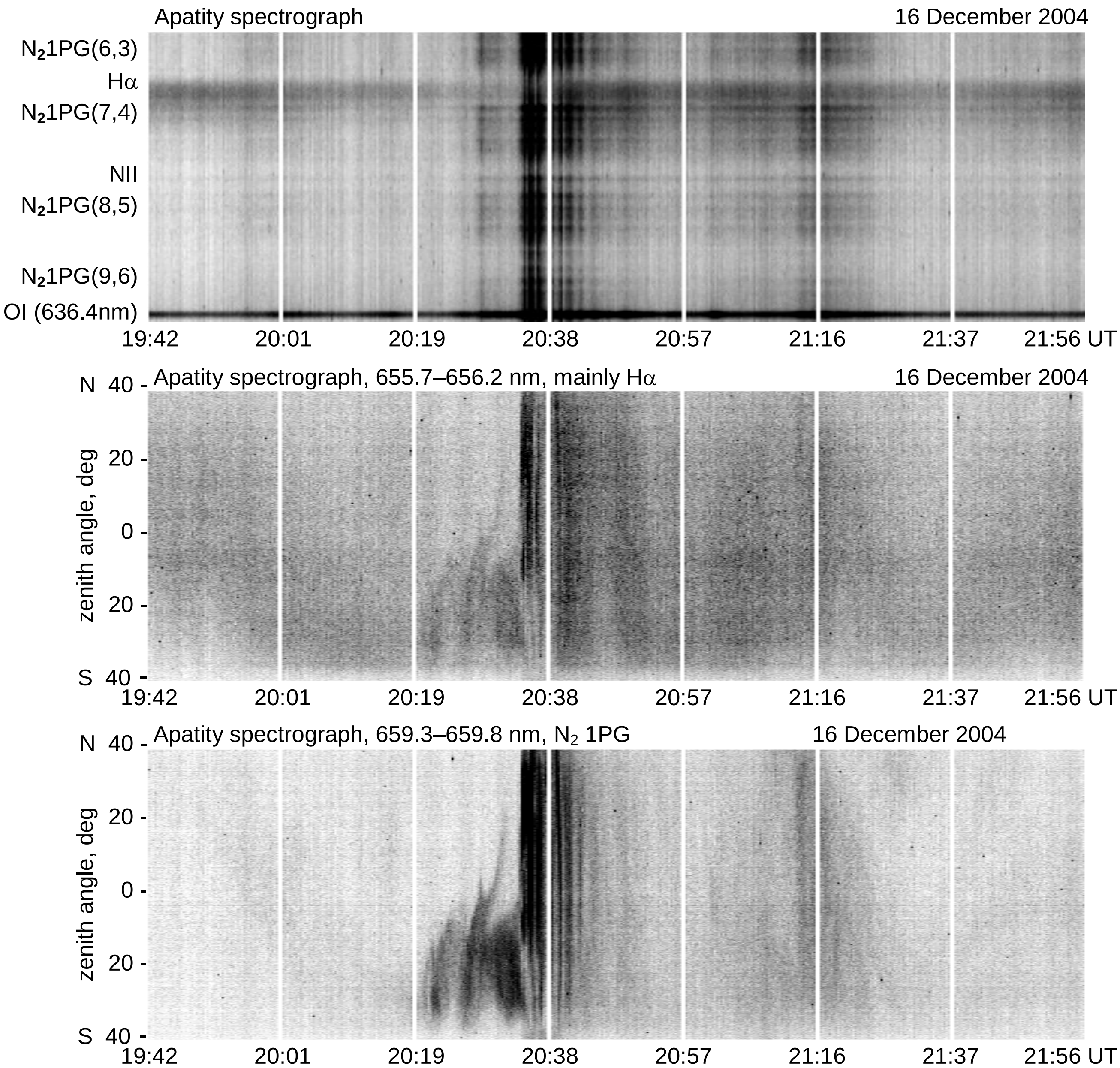

Fig.4. Spectrograph data in Apatity: (top panel) evolution of spectrum averaged in 0 -18^{o} North zenith angles; (middle panel) north-south keogram in the emission band 655.7–656.2 nm, mainly Doppler-shifted Hα; (bottom panel) north-south keogram in the emission band 659.3–659.8 nm, N_2 1PG.

During this interval, the Hα hydrogen line with Doppler shift to the blue side was observed at all view angles of the spectrograph (see Fig. 4), that indicates a wide zone of proton precipitation. In the northern part of the view angles the intensity of the hydrogen line was gradually decreasing, but in the southern part, it was increasing. Therefore, we can deduce that the proton precipitation zone was moving towards the south, too. The estimated width of the diffuse zone of the hydrogen emission was ~ 200 km. The slow electron arc mentioned above was also in the spectrograph's field of view. The arc tends to be poleward of the median of the hydrogen emission band.

An intensification of the equatorial arc started from ~20:14 UT at the east boundary of the TVASC field of view. An increase of magnetic pulsations (Fig. 3) was observed at 20:16 UT. The expansion phase of the substorm was developed as several streams-like bright auroral arcs which flew from the east side of the sky. Next intensification was observed on ~20:34 UT near the Lovozero zenith, leading to the forming of a large-scale spiral structure which dissipated in pulsing north-south (N-S) arcs. This intensification was also observed in the magnetic pulsations and riometer absorption. The riometer was observed several pulses of absorption with period ~5 min. The intensity of pulses was decreasing gradually.

From spectra presented in the top panel of Fig.4 one can see that there practically was no hydrogen emission observed near the moment of the local intensification of the electron arc (~20:34 UT). However, a few minutes later there was an increase of the Hα emission. The region of this emission occupied all the field of view of the Apatity spectrograph. Comparing with TVASC data, we can conclude that the proton precipitation was located inside the region of N-S auroral structures.

The observed dynamics of the hydrogen emission during the considered event agrees well with the conclusions obtained previously for substorm event on 26 March 2004 [Borovkov et al., 2005]. However, in contradiction with this case, an intensive hydrogen emission was seen during 2 hours after the substorm intensification (not shown here).

Conclusions

The small substorm and auroral activity on Dec 16 2004 is well documented by ground-based observations at Lovozero and Apatity.

In the Scandinavian region the equatorial drift of the auroral oval is observed during the growth phase of the substorm. Hydrogen emissions was located southward from the electron arcs.

Several pulses of high-energy electron precipitation with period ~5 min were observed after the substorm activization. The intensity of pulses was decreasing gradually.

A strong hydrogen emission was observed simultaneously with N-S forms after onset. An intense hydrogen emission was seen during 2 hours after the substorm intensification.

The observed dynamics of the hydrogen emission during the considered event agrees well with the conclusions obtained previously for the substorm event on 26 March 2004 [Borovkov et al., 2005].

Acknowledgments. This study was supported by RFBR (grant 06-05-65044) and by the Program for Basic Research of RAS №16 (part 3).

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