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AURORAL PRECIPITATION DYNAMICS DURING THE MAGNETIC CLOUD PASSING

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Abstract. Characteristics of auroral precipitation during the magnetic storm driven by the magnetic cloud on December 11-12, 2004 were examined. Meridian scanning photometer observations at Barentsburg (BAB) and Lovozero (LOZ), and an interactive Auroral Precipitating Model (APM) were used to show the possibility of APM using for the description of the auroral luminosity features. Spectral characteristics of aurorae observed from MSP in the pre-noon and after-noon sectors showed that discrete forms were caused by precipitation of relatively soft electrons. In the after-noon auroral arcs were observed near the poleward edge of the red auroral band which was narrower than in the pre-noon and observed at latitudes from 73° to 77° CGL.

1. Data used

To investigate the auroral dynamics during magnetic storm on December 11-12, 2004 with intensity in Dst of about - 40 nT driven by the magnetic cloud the meridian scanning photometer (MSP) observations at Barentsburg (BAB, $\Phi'=75.2^0$; MLT=UT+2.5) and at Lovozero (LOZ, $\Phi'=64.2^0$; MLT=UT+2.5), and the interactive Auroral Precipitating Model (APM) parameterized by magnetic activity (*http://apm.pgia.ru/*) were used. The observations of auroral intensity were made in 557.7 nm and 630.0 nm emissions channels by MSPs. The boundaries of auroral precipitation were examined from APM which yields a global distribution of electron precipitation in different precipitation zones. By using the model we obtained also the locations of BAB and LOZ relative to DAZ, AOP and SDP precipitation zones. This notation of precipitation was proposed by Starkov et al. (2002, 2003).

DAZ (diffuse auroral zone) is the region of diffuse precipitation equatorward of auroral oval.

AOP (auroral oval precipitation) is the region of structured precipitation.

SDP (soft diffuse precipitation) is the region of soft diffuse precipitation poleward the AOP region.

2. Results

Earlier, *Vorobjev and Yagodkina* (2005) compared pre-noon and pre-midnight precipitation features obtained by using APM during a magnetic storm on November 23–29, 1986, with a peak value of Dst being about –100 nT, and verified that the positions of DAZ and AOP boundaries are reasonably consistent with the DMSP F7 spacecraft observations. Recently, *Yagodkina et al.* (2012) examined the dynamics of auroral precipitation boundaries in the dawn and the dusk sectors during three magnetic storms with Dst about -80, -200 and -300 nT by using APM and DMSP F10-14 observations. They concluded that the model describes well enough the global distribution of the auroral precipitation and that model calculations are capable of filling the gaps in spacecraft observations, thereby providing a more complete picture of precipitation dynamics during magnetic storms. The main purpose of this study is to investigate the characteristics of auroral luminosity during the magnetic storm driven by the magnetic cloud and to illustrate possibility of the APM application for characterization of the auroral luminosity boundaries.

Magnetic storm on December 11-12, 2004

In Fig. 1 the solar wind plasma and IMF are shown. The magnetic storm was triggered by the sudden commencement on December 11 at 1400 UT when the cloud Sheath region, which is characterized by the high density, increased velocity and strong IMF variability, reached the magnetosphere. The Sheath is marked by vertical dashed lines in Fig. 1.

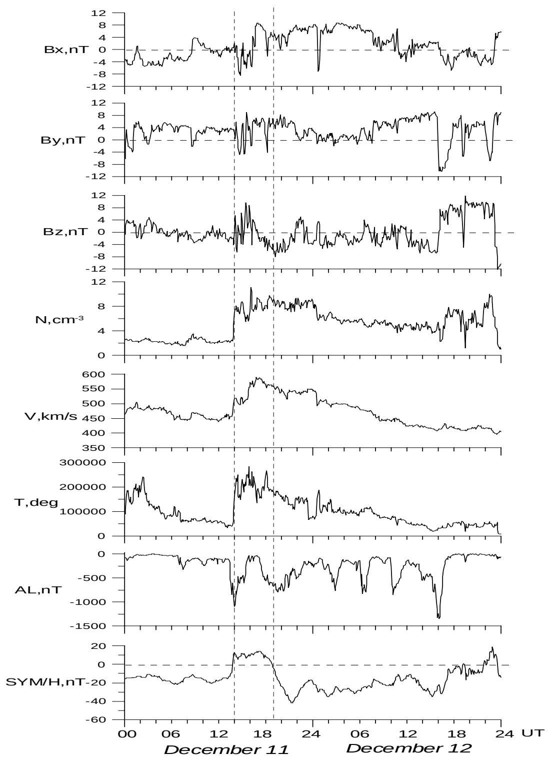

Fig. 1 The solar wind plasma and IMF on Dec. 11-12, 2004

After the shock a velocity grew up from about 450 to 600 km/s, a density increased from 2 to 10 cm^{-3}. The value of the Dst index in the main phase of the storm was -42 nT. During the cloud passage the Dst index stayed at about -30 nT and AL index indicated series of substorms.

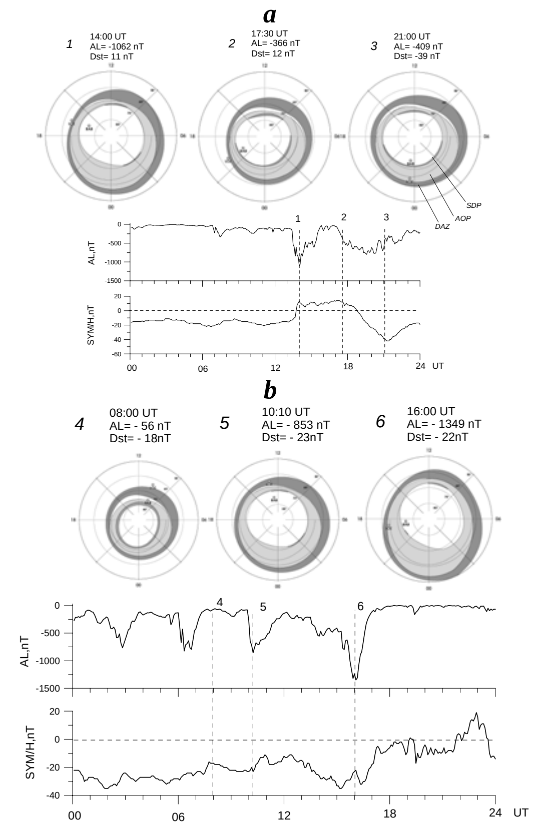

Fig. 2 Global distribution of electron precipitation (geomagnetic latitude - local geomagnetic time coordinates) and magnetic activity on Dec. 11 (***a***) and on Dec. 12 (***b***)

In Fig.s 2 global distribution of electron precipitation in corrected geomagnetic coordinates from APM and magnetic activity (AL and SYMH indices) on Dec. 11 (*a*) and on Dec. 12 (*b*) are shown. The global precipitations were constructed according APM by using Dst and 5-min AL indices. The locations of the BAB and LOZ stations are marked by points. At the top of each pattern the magnetic activity and UT are shown. The numbers of vertical dashed lines on magnetic activity curves correspond to the time at which the precipitation patterns were calculated.

According to APM the BAB and LOZ observatories on Dec. 11 pass through different MLT sectors and zones. BAB located in the polar cap or at the poleward of SDP, and the LOZ placed in DAZ and AOP regions. At the time of SSC (1400 UT, pattern 1) we can see the typical noon-midnight form of auroral precipitation. Before of main phase of storm (1730 UT - pattern 2) the all precipitation zones shifted to pole, and during main phase (pattern 3) the equatorward expansion of precipitation zones was observed. In the nighttime sector the equatorward boundaries of the precipitation have shifted to lower latitudes, whereas the position of the poleward boundary depends weakly on the magnetic activity level. This effect was illustrated early by *Vorobjev and Yagodkina* (2007a). The pattern 3 (2100 UT) demonstrates the small asymmetry of auroral precipitation which typical for the auroral precipitation during the magnetic storms associated with the magnetic clouds (*Yagodkina et al.*, 2012).

Dynamic of auroral precipitation and magnetic activity variations on Dec. 12 are shown in Fig. 2b. During this period the series of substorms with typical AL distribution at long-lasting, steady depression of Dst were registered. Power of substorms increased sporadic. During |AL|- maximum the BAB station was located in the polar cap, and all boundaries have shifted to lower latitudes, the zones of precipitations expanded. During the expansion phases the typical noon-midnight distribution of auroral precipitation is observed. Before substorm growth and past of the recovery phases BAB was situated at the poleward edge of SDP. The LOZ station was situated in DAZ or AOP periodically.

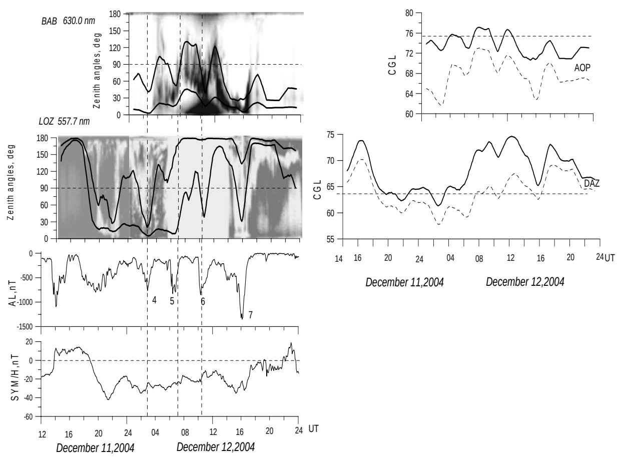

Fig. 3 The auroral luminosity registered by MSPs at BAB in 630.0 nm (the first panel) and at LOZ in 557.7 nm emissions (the second panel), the location of AOP and DAZ boundaries (white lines inside of the MSP records), AL- and SYM/H indices

Fig. 3 displays the auroral luminosities registered by MSPs at BAB in 630.0 nm (the first panel) and at LOZ in 557.7 nm emissions (the second panel), the location of AOP and DAZ boundaries (white lines inside of the MSP records), AL and SYM/H indices. The meridian scanning photometer at BAB registered aurora on Dec. 12 only. Along the vertical axis at the left panels the elevation angles of 0º and 180º correspond to the southern and northern horizon, respectively. From the right of panels the boundary dynamics of auroral precipitation in auroral oval (AOP – the first panel) and precipitation in DAZ (the second panel) are shown. Along the vertical axis at these panels the corrected geomagnetic latitude (CGL) are indicated. The boundaries were calculated from the APM. To determine the boundary locations as a function of the elevation angles, the altitude of aurora was adopted to be 120 km for green aurora and 250 km for red aurora. MSP scanned auroral luminosity from the southern to the northern horizon in the ranges 58°-71° CGL at LOZ and 62°-87° CGL at BAB.

December 11, 2004. Here we have optical data from MSP at LOZ only. As seen from Fig. 1 the magnetic storm began at about 1840 UT after southward turn of IMF Bz and the sharp magnetic bay in the AL index. According APM from 1400 UT to 1700 UT (Fig. 2a) the LOZ observatory located equatorward DAZ and MSP registered auroral luminosity near northern horizon. The equatorward displacement of the aurora occurred between 1700 UT and 2200 UT, the aurora shifted to equator up to about 60° CGL. The equatorward shift is associated with southward turn of IMF Bz and storm activity. During this time the SYM/H and the AL indices were minimum (Dst~-50 nT, AL~ -800 nT). From 1700 to 2400 UT the LOZ observatory is situated in the AOP or in the DAZ regions in the pre-midnight, midnight and post-midnight MLTs (Fig. 2a). In (*Vorobjev and Yagodkina*, 2005) it was shown that when the Dst index changes from positive to negative, the equatorward boundaries of precipitation shift toward lower latitudes. Auroral luminosity which located poleward DAZ precipitation is situated in region of AOP. The model boundary of auroral precipitation rather well describes the location of auroral luminosity at LOZ.

December 12, 2004. After 0000 UT one can see the series of substorms marked by the vertical dashed lines in Fig. 1. The AL indices variations demonstrate the development of magnetic substorms. We examined the auroral dynamic during the 4, 5 and 6 substorms. The substorm 7 was developing under northern turning of IMF Bz. Substorms under study took place in pre-noon, noon and past-noon MLTs. During quiet conditions, before growth phase, the BAB observatory was situated in the AOP region, LOZ was situated in DAZ.

During the first substorm marked number 4 the aurora at BAB and LOZ shifted to south horizon. The model boundaries of AOP (at BAB) and DAZ (at LOZ) indicate equatorward expansion to 62^0 and 58^0 CGL, respectively. At BAB from about 0000 UT to about 0300 UT the region of AOP is expanded, the equatorward boundary shifted to 62^0 CGL, the position of poleward boundary locates at about 72^0-73^0 CGL. In *Vorobjev et al.*, 2007b it was shown that all precipitation regions in the dayside sector synchronously shift equatorward not only during the growth phase also but during expansive phase. The largest shift to lower latitudes of the AOP region is observed at a maximum of the expansive phase and during the initial period of the recovery phase. At that time the region of SDP, located poleward of AOP, becomes very thin and/or disappears. In the near-noon hours the equatorward boundary of DAZ reaches the lowest latitudes during substorm recovery phase.

The magnetic activity increased and reached maximum about -767, 825 and 853 nT, respectively for 4, 5 and 6 substorms. The mean values of the Dst index in the considered periods varied insignificantly and not exceeding ~25 nT. During the every following substorm (5 and 6) the equatorward boundaries of AOP at BAB and DAZ at LOZ drifted to more high latitudes. According to APM the equatorward boundaries shifted to pole up to 68° and 64° CGL at BAB and LOZ, respectively. Displacement of poleward boundary at LOZ makes up about 10° CGL, from 63° to 73° CGL. As can see from Figure the discrete aurora at BAB located inside the AOP region. The model boundaries of auroral precipitation allow filling the gaps in the LOZ optical observations and the calculation boundaries rather well describe the location of auroral luminosity.

We investigated a distribution of the auroral intensities in green and red lines along the geomagnetic meridian in two time intervals on December 12: from 0623 UT to 0631 UT (pre-noon sector, the initial period of the recovery phase of substorm 5 in Fig. 3) and from 1130 UT to 1200 UT (after -noon sector, the recovery phase of substorm 6 in Fig. 3). Scans of the MSP system for the 557.7 and 630.0 nm emissions are shown in Fig. 4. The vertical dashed line indicates the zenith of BAB. The zenith angles were converted into degrees of corrected geomagnetic latitude (CGL) on the assumption that the altitudes of 557.7 and 630.0 nm emissions are 150 and 250 km, respectively and are pointed along the horizontal axes.

Fig. 4 illustrates the meridional profiles of the 630.0 nm (solid line) and 557.7 nm (dashed line) emissions and ratio of I_{6300}/I_{5577}. In Fig. 4a the typical distribution for the first interval is shown. In this interval the MSP at BAB registered auroras equatorward of zenith in the region of AOP. As seen from Fig. 4a the red luminosity band was located from about 66° CGL to 75° CGL and according to the model the boundaries which are shown in Fig. 3 filled the AOP region. The discrete auroral forms with intensity about 2-3 kR appeared inside the red band. The ratio $I_{6300}/I_{5577} >1$ corresponds to precipitation of soft electrons with average energy <1 keV (Judge, 1972). Fig. 4b for the second interval was constructed in the same format. The meridional profiles of the emissions are presented in 5 min. For this case the red band is more narrow and located about from 73° to 77° CGL. The green-line discrete forms were located in the middle of the narrow red band in the region of its maximum. The relationship between the emission intensities, $I_{6300}/I_{5577} \geq 1$, indicates that the discrete forms were caused by precipitation of relatively soft electrons with an energy of ≤1 (Judge, 1972).

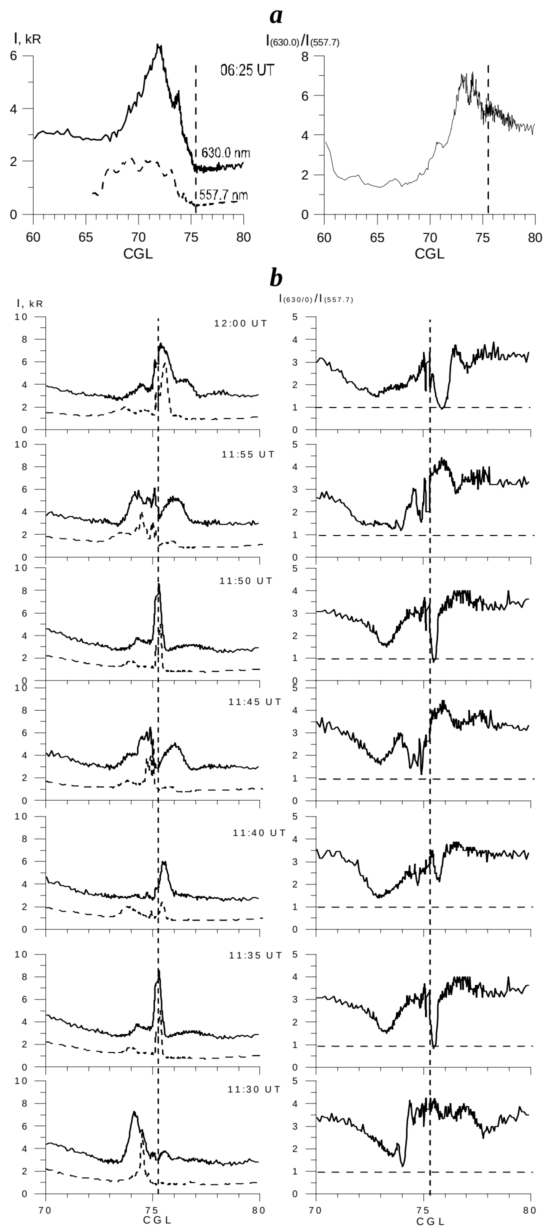

Fig. 4 The auroral intensities in green and red lines along the geomagnetic meridian

3. Conclusions

The data of the meridian scanning photometers (MSPs) at Barentsburg (BAB) and at Lovozero (LOZ) and the interactive Auroral Precipitating Model (APM) were used. It is shown the possibility of APM for characterization the boundaries of auroral luminosity. The discrete auroral forms at BAB appeared within the AOP (auroral oval precipitation). Auroral luminosity at LOZ was located in DAZ and poleward of DAZ, in AOP. Spectral auroral characteristics in the pre-noon and after-noon sectors at BAB were studied from MSP data. It is shown that in the pre-noon sector during the initial period of the recovery phase of substorm the red luminosity band filled the AOP region. In the after-noon sector during the recovery phase of substorm the red band is more narrow and auroral arcs were observed near the poleward edge of the red auroral band. The ratio I_{6300}/I_{5577} >1 in auroral forms testified of rather soft of precipitating electrons.

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