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BEHAVIOR OF THE 5577Å AND 6300Å EMISSIONS DURING SUBSTORMS CONNECTED WITH RECURRENT SOLAR WIND STREAMS

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Abstract. The behaviour of the auroral emissions 5577Å and 6300Å and the ratio I_{6300}/I_{5577} during substorms occurred at the time of recurrent streams (RS) has been examined. The development of the substorm bulge is followed up. The variations of the emissions depending on the different locations of the substorm bulge with respect to the point of observation have been studied. Estimations of the particle precipitation spectra at the polar edge of the auroral bulge and inside it have been obtained. For the study, data from the All-Sky Imagers at Andøya Rocket Range (ARR), Andenes, Norway (69.3°N, 16.03°E) and at the Auroral Observatory, Longyearbyen, Svalbard (78.20°N, 15.83°E) from the observational season 2005-2006 have been used. Additional data concerning the solar wind parameters, IMF, the precipitating particles and the magnetic field are used from the WIND satellite and the IMAGE magnetometer network to determine the recurrent streams and the substorms during RS.

Introduction

It is known that the spectral characteristics of the aurora depend on the type of the solar wind flows (e.g. Hviuzova and Leontyev, 1997, 2001). The solar wind flows are different according to the state of the solar activity. During a solar minimum, the recurrent streams (RS) originating from coronal magnetic holes, characterized by a 27-day recurrence, are predominant (Pudovkin, 1996). During a solar maximum, most common are the sporadic flows associated with coronal mass ejections (CME) (Wang and Sheeley, 1994). Near the Earth they are observed as magnetic clouds (MC) (e.g. Burlaga et al., 1982).

The connection of the auroral spectral characteristics with different types of solar wind streams was studied by several authors (e.g. Hviuzova and Leontyev, 1997, 2001, Sivjee and Shen, 1997). Hviuzova and Leontyev, 1997, 2001 studied the emissions intensities ratio I_{6300}/I_{5577} that characterizes the hardness of the precipitating electrons spectrum. On the base of a large amount of data (aurora observations at the Loparskaya Observatory during 1970-1985) the yearly means of the of aurora intensity ratio were obtained. It was shown that during magnetic clouds aurora with enhanced mean ratio between the red auroral emission (6300 Å) and the green one (5577 Å) is observed. The precipitating electrons spectrum is extended to the soft electrons region. The spectral characteristics of the aurora observed during the passage of a recurrent stream are a result of the precipitation of more energetic electrons in the atmosphere and the lack of soft precipitating electrons (with energies <1 keV) (Hviuzova and Leontyev, 1997). The precipitating electrons spectrum is shifted to the higher energies. Sivjee and Shen, 1997 examined the auroral emissions during the solar magnetic cloud (MC) on October 18, 1995. This MC caused a strong magnetic storm (Dst~-100 nT). On the base of continuous spectroscopic measurements (about 10 hours) it was shown that a difference between the normal auroras and the magnetic cloud induced ones exists. This difference appears to the precipitations of electrons with an averaged energy of about 500eV, an event similar to the rare type A global red aurora.

In all these papers, the aurora spectral characteristics during long time intervals (during recurrent streams lasting several days, or magnetic clouds lasting tens of hours) were examined. In our paper, the dynamics of the intensities of the green 5577 Å auroral emission and the red 6300 Å one during substorms will be studied. In particular, the emissions intensities ratio I_{6300}/I_{5577} inside the auroral bulge and at its edge will be examined. In order to observe the motion of substorm bulge, to determine the auroras emissions polar edge of the bulge and inside it, we used data of high latitude stations. The Auroral Observatory in Longyearbyen is quite a high-latitude station (78.20°N, 15.83°E) and usually substorms are observed more equatorially, from stations at lower latitudes. However, the substorms sometimes reach higher latitudes, normally during high-speed recurrent streams of the solar wind, (e.g. Sergeev et al. 1979, Dmitrieva and Sergeev 1984, Despirak et al. 2008). We selected substorms observed during solar wind high-speed recurrent streams for our studies. A typical example of observation of a substorm during a recurrent stream: the substorm onset was at auroral zone latitudes, later it reached high latitude station and moved further to the pole. Thus, we observed the polar edge of the auroral bulge, when auroras were observed in the station zenith, and inside the bulge, when auroras moved further to the pole.

For this purpose the data from simultaneous measurements of the All-Sky Imagers at Andøya Rocket Range (ARR) and at the Auroral Observatory, Longyearbyen, have been compared with plasma and solar wind magnetic field data from the WIND satellite and data from the ground-based magnetic stations from the IMAGE network.

Data used

We used the following criteria for data selection:
1) Presence of 5577 Å and 6300 Å intensity measurements;
2) Presence of high-speed stream of the solar wind – a recurrent stream (this was controlled by WIND satellite data);
3) Presence of a substorm at the relevant station (controlled by the IMAGE magnetometers stations chain);
4) All-sky camera observations, presence of aurora and development of a substorm in aurora;
5) Clear sky (no clouds).

Data during two recurrent streams from the observational season 2005-2006 have been used: the recurrent stream on 2-9 November 2005 and the one on 23-28 January 2006. The measurements during 3 substorms at Andenes on 3 November 2005 and 4 substorms at Andenes and Longyearbyen on 26 January 2006 have been examined. Only 2 substorms at Andenes on 3 November 2005 and 2 substorms at Longyearbyen on 26 January 2006 satisfy our selection criteria.

Results

In Figures 1 and 2, the dynamics of the red and green lines and their ratio during the substorms on 3 November 2005 at Andenes is shown. These substorms developed during the recurrent steam on 2-9 November 2005, the solar wind parameters have the following values: Vx ~ -650 km/s, Bz ~ -4 nT. The upper panel shows the substorm development by chosen images of the red (up) and green (down) lines intensity taken from ASI. The edges of the row images are cut and they are centered towards the station. Data interpolation is performed to obtain the intensities in 467x467 equidistant points. North direction is marked by an arrow. The black point indicates the station zenith. The bottom panels show the course of the 5577 Å, 6300 Å emissions and their ratio I_{6300}/I_{5577} during the substorm development. For the emissions intensities and the corresponding ratio, data of the 5577 Å intensity in the station zenith and the 6300 Å intensity on the same geomagnetic line as the 5577 Å one are used. Black arrows point in the graphs to the moments presented in the images in the upper panels. The first substorm is observed from Andenes in 18:35:41 UT (Figure 1, upper panel). The auroral bulge reached zenith at 18:37:20 UT and after that went beyond the station, the latter staying inside the auroral bulge. The ratio I_{6300}/I_{5577} = 0.031 at the polar edge of the auroral bulge and I_{6300}/I_{5577} = 0.2 inside it.

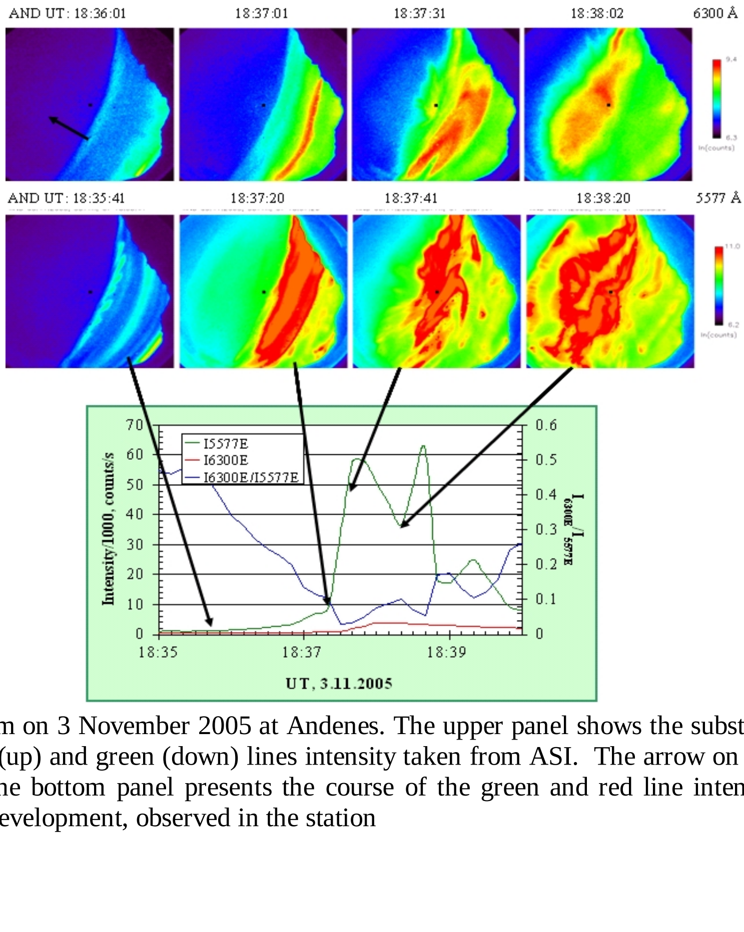

Fig. 1. The first substorm on 3 November 2005 at Andenes. The upper panel shows the substorm development by chosen images of the red (up) and green (down) lines intensity taken from ASI. The arrow on the left image points to the North direction. The bottom panel presents the course of the green and red line intensities and their ratio during the auroral bulge development, observed in the station

The second studied substorm is observed in 22:16:41 UT, the polar edge of the auroral bulge came in zenith in 22:17:11, after that the station stayed inside the auroral bulge (Figure 2, upper panel). The upper panel of Figure 2 shows the substorm development by chosen images of the red (up) and green (down) lines intensity taken from ASI. The arrow on the upper left image points to the North direction. The bottom panel presents the course of the green and red line intensities and their ratio during the auroral bulge development, observed in the station zenith. The ratio $I_{6300}/I_{5577} = 0.033$ at the polar edge of the auroral bulge and the average $I_{6300}/I_{5577} = 0.17$ inside it.

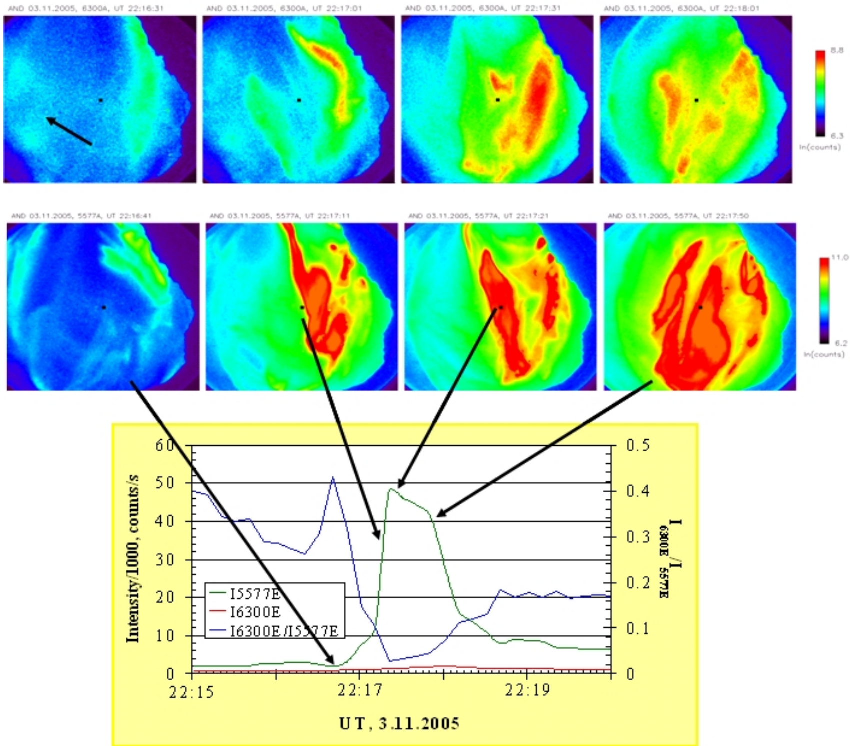

Fig. 2. Development of the second substorm on 3 November 2005 at Andenes by the all-sky imager (upper panel) and course of emissions intensities and their ratio in zenith (bottom panel).

During the examined substorms on 26 January 2006 at Longyearbyen, associated with RS, Vx ~ -600 km/s; -650 km/s, Bz ~ -8 nT. These substorms are examples of substorm observation at high latitudes (LAT=78.2°N) during a recurrent stream of the solar wind. The first substorm (not presented in the pictures) is observed from Longyearbyen at 17:17:21 UT, the polar edge of the auroral bulge reached the station zenith at 17:25:41 UT, further the zenith was inside the bulge. At the polar edge of the auroral bulge $I_{6300}/I_{5577} = 0.336$ and the average ratio inside it is $I_{6300}/I_{5577} = 0.581$. The ratio of the I_{6300}/I_{5577} values inside the bulge to the one at the polar edge of the auroral bulge is 1.73.
The development of the second substorm on 26 January 2006 at Longyearbyen is presented in Figure 3. In the upper panels, images of the 5577 Å showing the development of the auroral bulge are presented. The black point indicates the station zenith. The bottom panels show the course of the 5577 Å, 6300 Å emissions and their ratio I_{6300}/I_{5577} during the substorm development. For the emissions intensities and the corresponding ratio, data of the 5577 Å intensity in the station zenith and the 6300 Å intensity on the same geomagnetic line as the 5577 Å one are used. Black arrows point in the graphs to the moments presented in the images in the upper panels.The substorm is seen from the station in 21:02:40 UT. The polar edge of the auroral bulge is observed over zenith in 21:18:10 UT. $I_{6300}/I_{5577} = 0.095$ at the polar edge of the auroral bulge and its average value inside the bulge is 0. 232. The ratio of the I_{6300}/I_{5577} values inside the bulge to the one at the polar edge of the auroral bulge is 2.45.

Discussion and conclusions

The emissions intensities ratio I_{6300}/I_{5577} characterizes the hardness of the precipitating electrons spectrum (Rees and Luckey, 1974), we used this parameter to make a rough estimate of the electrons energy in the auroral arcs, observed in different parts of the auroral bulge – at the polar edge of the bulge and inside it. During the appearance of the substorm aurora near zenith, i.e. at the polar edge of the auroral bulge, the green line intensity sharply increased and the emissions intensities ratio I_{6300}/I_{5577} in all examined cases reached a minimum, thus testifying for the precipitation of more energetic electrons. Therefore, the precipitation of the most energetic electrons takes place at the polar edge of the auroral bulge.

The development of 4 substorms at Andenes and Longyearbyen by auroral emissions measurements has been studied. The minimum in the I6300Å/I5577Å ratio testifies for the most energetic electrons precipitated over the polar edge of the auroral bulge. It is obtained, that the average ratio I6300Å/I5577Å is about 2 times lower at the polar edge, that inside the auroral bulge.

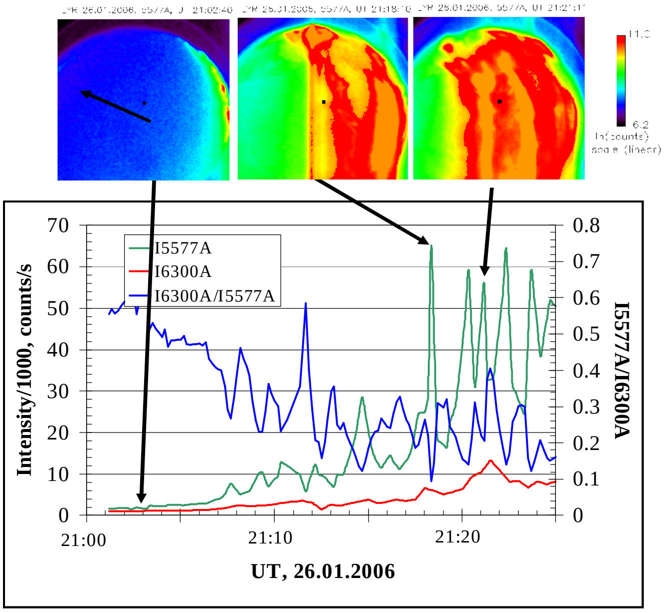

Fig. 3. A substorm at Longyerbyen on 26 January 2006. The upper panel shows the auroral bulge dynamics, expressed in the images of the 5577 Å emission intensity recorded by ASI. The development of the emissions and their ratio in zenith is presented in the bottom panel.

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