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PECULIARITIES OF AURORAL EMISSIONS DURING SUBSTORMS

Veneta Guineva[1], Irina Despirak[2], Rolf Werner[1], Espen Trøndsen[3]

[1] Space and Solar-Terrestrial Research Institute, BAS, Stara Zagora Department, Stara Zagora, Bulgaria
[2]Polar Geophysical Institute, Apatity, Russia
[3]University of Oslo, Department of Physics, Oslo, Norway
e-mail: v_guineva@yahoo.com

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Abstract: *The auroral emissions 5577Å and 6300Å and their intensity ratio I_{6300}/I_{5577} during substorms have been examined. The development of the substorm bulge is studied by the behaviour of the emissions during the substorm movement towards North. Estimations about the nature of the particle precipitation spectra at the polar edge of the auroral bulge and inside it have been obtained. For the study, measurement 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) taken during the 2005-2006 observational season have been used.*
Additional data including 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 interplanetary conditions and the substorm development.
It is found out that the intensity emissions ratio is lower at the polar edge of the auroral bulge than inside it, which goes to show that the most energetic particle precipitation occurs at the polar edge of the substorm bulge.

ОСОБЕННОСТИ АВРОРАЛЬНЫХ ЭМИССИЙ ВО ВРЕМЯ СУББУРЬ

Венета Гинева[1], Ирина Дэспирак[2], Рольф Вернер[1], Еспен Трьондсен[3]

[1]Институт космических и солнечно-земных исследований, БАН, Филиаль Стара Загора
[2]Полярний Геофизический Институт, Апатити, Россия
[3]Университет Осла, Кафедра Физики, Осло, Норвегия
е-мейл: v_guineva@yahoo.com

Ключевые слова: *авроральные эмиссии, суббури, авроральная выпуклость, высокоскоростные потоки солнечного ветра.*

Резюме: *Исследовались авроральные эмиссии 5577Å и 6300Å полярных сияний и отношение интенсивностей I_{6300}/I_{5577} этих эмиссий во время суббурь. Получены оценки характера спектра высыпающихся частиц на полярном краю авроральной выпуклости и внутри выпуклости. Для исследований были использованы данные измерений all-sky камер в Анденесе, Ракетный Центр Андоя, Норвегия (69.3°N, 16.03°E), и Авроральной Обсерватории в Лонгербьене, Шпицберген (78.20°N, 15.83°E), сделанные в ходе сезона наблюдений 2005-2006 г.*
С целью определения межпланетных условий и контроля развития суббури были использованы дополнительные данные со спутника WIND и сети магнитометров IMAGE, в том числе, параметры солнечного ветра, межпланетного магнитного поля и магнитного поля Земли.
Было показано, что значения отношения интенсивностей эмиссий I_{6300}/I_{5577} меньше на полярном краю авроральной выпуклости, чем внутри нее. Это свидетельствует о том, что, высыпание наиболее энергичных частиц происходит на полярном краю авроральной выпуклости.

Introduction

Auroral observations have always played a fundamental role for the study of the solar wind-magnetosphere-ionosphere interaction during magnetic substorms. The auroral emissions behaviour during substorms is the result of a chain of subsequent phenomena connected to energy releases and changes in the near-Earth magnetospheric tail regions. All these phenomena, and in particular, the aurora spectral characteristics depend on the type of the solar wind flows (e.g. [1], [2]). The dynamics of auroral emissions during different types of solar wind streams was studied by several authors (e.g. [1], [2], [3]). In [1], [2] Hviuzova and Leontyev 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) [1]. The precipitating electrons spectrum is shifted to the higher energies. Sivjee and Shen examined the auroral emissions during the solar magnetic cloud (MC) on October 18, 1995 [3]. 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 due to the precipitations of electrons with an average energy of about 500eV, an event similar to the rare type A global red aurora.

In 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. The subject of our paper is to investigate the dynamics of the intensities of the green 5577 Å auroral emission and the red 6300 Å one during substorms (with duration from tens of minutes to 1-1.5 hours). In particular, the emissions intensities and their ratio I_{6300}/I_{5577} inside the auroral bulge and at its polar edge are examined. We used data from simultaneous measurements of the All-Sky Imagers (ASI) at Andøya Rocket Range (station AND) and at the Auroral Observatory, Longyearbyen (station LYR). In order to observe the substorm bulge motion, observations are needed, when the substorm onset is to the South of the station, the substorm bulge develops, its polar edge passes over the station and continue to move to the North. Thus, the polar edge of the auroral bulge is observed, when auroras appears in the station zenith, and inside the bulge, when auroras moves further to the pole. AND is situated at auroral latitudes (69.3°N, 16.03°E), and the substorm onset is usually at such latitudes. If the onset is over the station, it is not possible to determine the spectral characteristics relevant to the polar edge of the auroral bulge. Nevertheless, in a lot of cases the substorm can originate at lower latitudes. The Auroral Observatory in Longyearbyen is a quite high-latitude station (78.20°N, 15.83°E), usually substorms are observed more equatorially, and the polar edge of the bulge doesn’t reach and surpass the station zenith. However, substorms sometimes reach higher latitudes. Such an example is the case, described by Lester at al. [4]. Normally substorms develop or reach high latitudes during high-speed recurrent streams of the solar wind, (e.g. [5], [6], [7]). That is why we selected substorms observed during solar wind high-speed recurrent streams for our studies.

To determine the auroras emissions at the polar edge of the bulge and inside it, data from Andenes (AND) and at Longyearbyen (LYR) All-Sky Imagers measurements 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.

Instrumentation

The all-sky imagers (ASI) are positioned at Andøya Rocket Range (ARR), Andenes (AND) (69.3°N, 16.03°E) and in the Auroral Observatory, Longyearbyen, Svalbard (LYR) (78.20°N, 15.83°E). Both devices are identical. The all-sky imagers have 180° field of view. The used CCD cameras are monochromatic, 512x512 pixels, with 16-bit intensity resolution and up to 10 s time resolution. They are cooled to -25°C to increase the signal-to-noise ratio. Narrow band interference filters centred at 6300Åand 5577Å are used.

The 5577 Å and 6300 Å emissions are recorded automatically with 10 s time resolution. The raw data are in counts per exposure time (sec). The raw images are accumulated in the Oslo University.

Data used and selection criteria

We used the following criteria for data selection:

1) Presence of 5577 Å and 6300 Å intensity measurements, generation of a substorm to the South of the station and its further development;
2) Presence of a high-speed stream of the solar wind – a recurrent stream (controlled by WIND satellite data);
3) Confirmation of a substorm presence at the relevant station (controlled by the IMAGE magnetometers stations chain);
4) All-sky camera observations (controlling both: the presence of aurora and development of a substorm in aurora and the weather conditions);
5) Clear sky (no clouds).

Data from the observational season 2005-2006 have been used. 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 and 1 substorm at Andenes on 26 January 2006 satisfy our selection criteria.

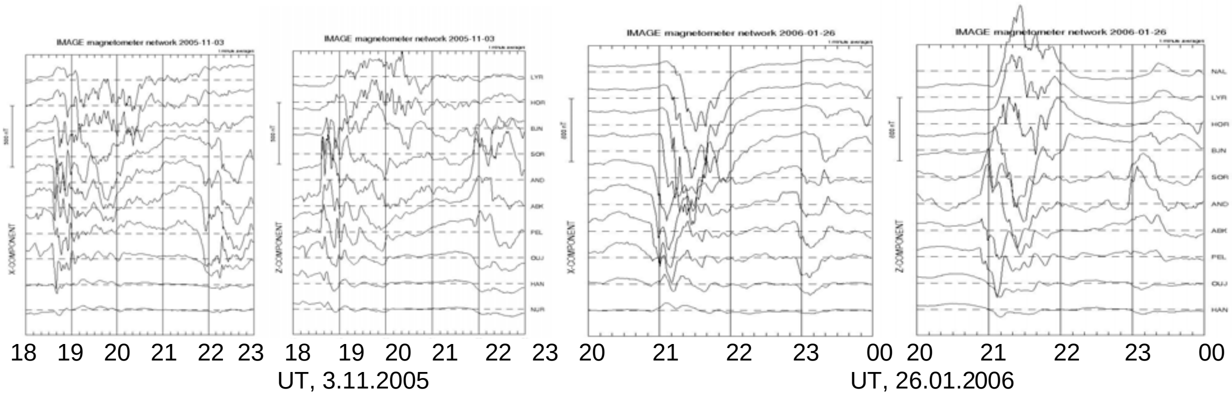

Fig. 1. Magnetic field X (left) and Z (right) components by IMAGE magnetometer chains for the examined substorms periods

Results

In Figure 1, the magnetic field X- and Z-components registered by IMAGE magnetometers stations chains are presented showing the substorm presence at AND and LYR for the examined cases.

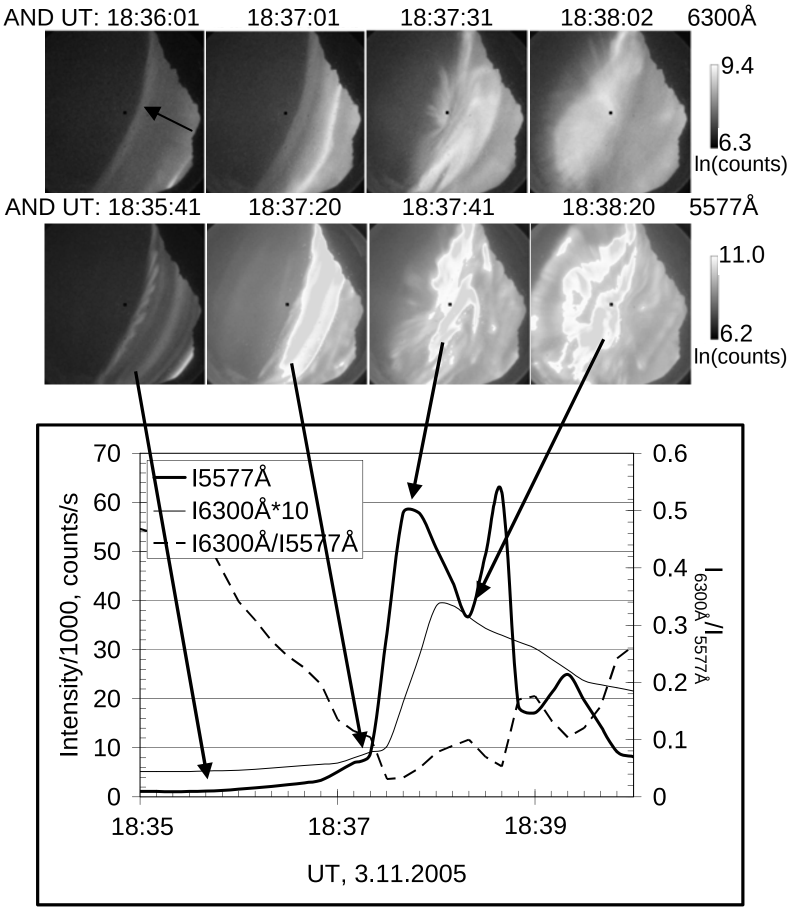

Fig. 2. The first substorm on 3 November 2005 at Andenes. The upper panel shows the substorm development by chosen images of the red (up) and green (down) lines intensity taken from ASI. The arrow on the left image points to the North direction. The bottom panel presents the course of the green and red line intensities and their ratio during the auroral bulge development, observed from the station

In Figures 2 and 3, 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 panels show the substorm development by chosen images of the red (up) and green (down) lines intensity taken from ASI. The edges of the raw 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 in the left upper image. The black point at the images center indicates the station zenith. The movement to North of the polar edge of the auroral bulge: its approaching and its passage through the station zenith is seen by the chosen images in both figures. 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 2, upper panel). The polar edge of the auroral bulge reached zenith at 18:37:20 UT and passed over it (18:37:41 UT, 18:38:20 UT) moving to North. After that the bulge edge went beyond the station, the latter staying inside the auroral bulge during the substorm expansion.

The polar edge represents a band in the North part of the substorm bulge, as it was noted by Zverev and Starkov [8]. This band comprises the arc fleshed first during the substorm beginning (usually the brightest one). We defined the borders of the polar edge and of the arcs inside the substorm bulge as the mean of the green line intensity during 2-3 hours of measurements (700-1000 values), plus one standard deviation of the mean. The minimal ratio I_{6300}/I_{5577} = 0.031 and the average one in the polar edge borders determined as described above, is 0.097. The average ratio I_{6300}/I_{5577} = 0.132 in the arcs identified in the described way inside the auroral bulge. The ratio of the average I_{6300}/I_{5577} value inside the bulge to the one at the polar edge of the auroral bulge is 1.36.

The upper panel of Figure 3 shows the second 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 second studied substorm is observed in

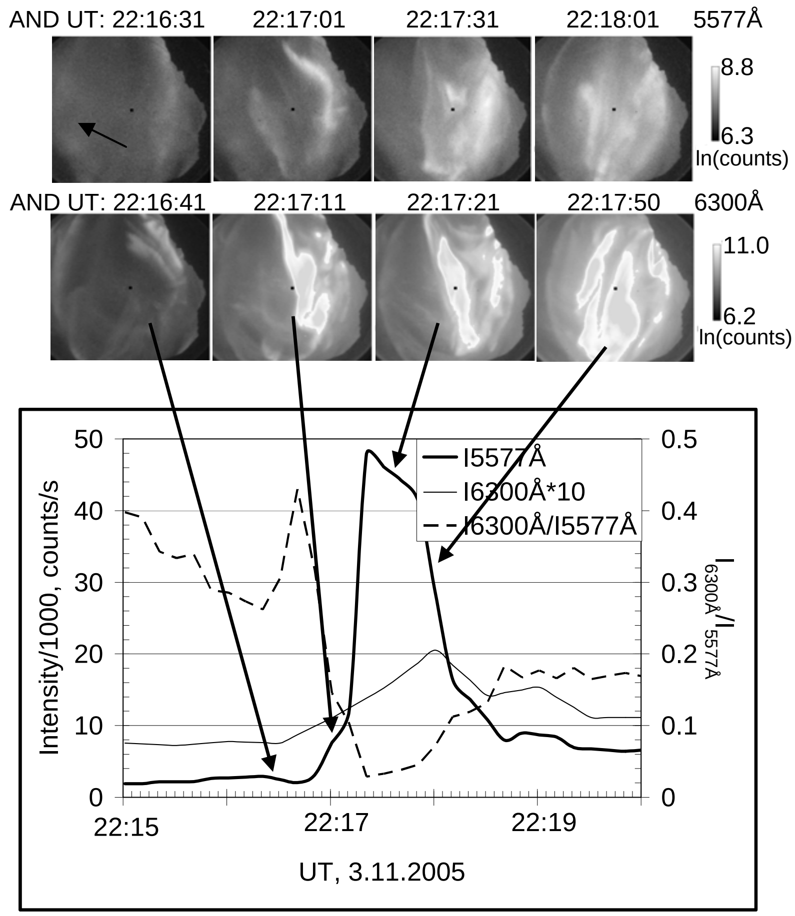

Fig. 3. Development of the second substorm on 3 November 2005 at Andenes by the all-sky imager (upper panel) and course of emissions intensities and their ratio in zenith (bottom panel)

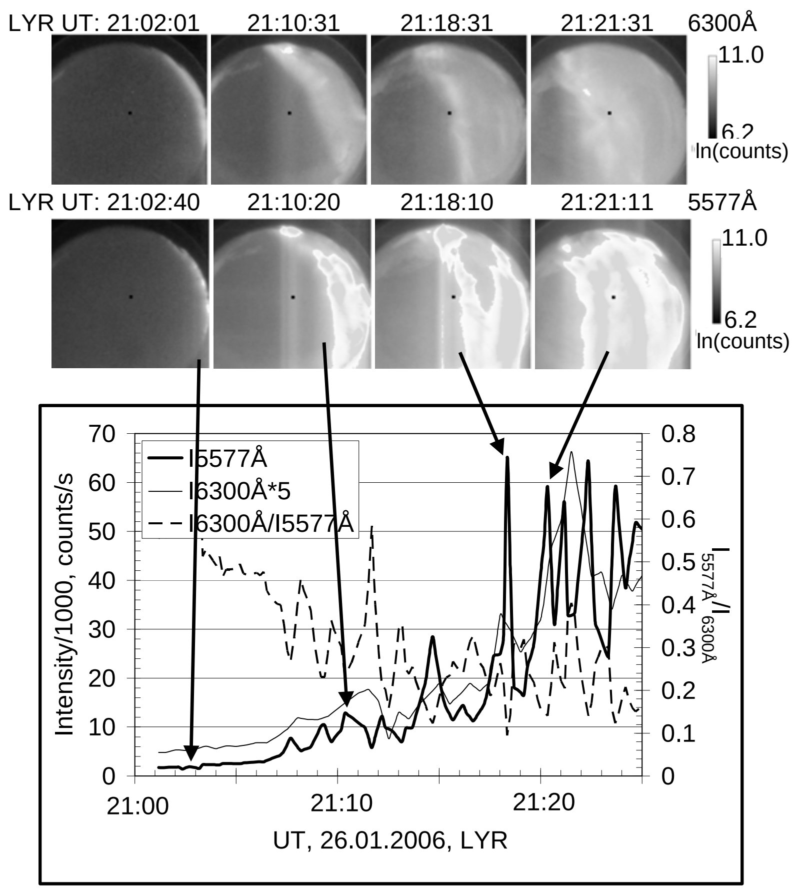

Fig. 4. A substorm at Longyerbyen on 26 January 2006. The upper panel shows the auroral bulge dynamics, expressed in the images of the 6300 Å and 5577 Å emission intensity recorded by ASI. The development of the emissions and their ratio in zenith is presented in the bottom panel

22:16:41 UT, the polar edge of the auroral bulge came to zenith in 22:17:11, and crossed zenith (22:17:21 UT, 22:17:50 UT) (Figure 3, upper panel, 5577Å intensity images). After that the station stayed inside the auroral bulge. 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 minimal ratio I_{6300}/I_{5577} = 0.029 and the average one at the polar edge of the auroral bulge is 0.109. The average I_{6300}/I_{5577} = 0.148 in the arcs inside the bulge. The ratio of the average I_{6300}/I_{5577} value inside the bulge to the one at its polar edge is 1.36.

The examined substorms on 26 January 2006 are associated with RS on 23-29 January 2006, when Vx ~ -600 km/s; -650 km/s, Bz ~ -8 nT.

The substorms at Longyearbyen 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 figures) 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 the minimal I_{6300}/I_{5577} = 0.336 and the average ratio is 0.438. The average ratio inside the bulge is I_{6300}/I_{5577} = 0.65. The ratio of the average I_{6300}/I_{5577} value inside the bulge to the one at the polar edge of the auroral bulge is 1.48.

The development of the second substorm on 26 January 2006 at Longyearbyen is presented in Figure 4. In the upper panel, images of the 6300 Å (up) and 5577 Å (down) showing the development of the auroral bulge are presented. The black point indicates the station zenith. The bottom panel shows 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 panel.

The substorm is seen from the station in 21:02:40 UT. The polar edge of the auroral bulge reached zenith in 21:18:10 UT and was observed over zenith in 21:21:11 UT. The minimal value I_{6300}/I_{5577} = 0.094 and the average one at the polar edge of the auroral bulge is 0.152. The average value in the arcs inside the bulge is I_{6300}/I_{5577} = 0. 208. The ratio of the average I_{6300}/I_{5577} value inside the bulge to the one at the polar edge of the auroral bulge is 1.37.

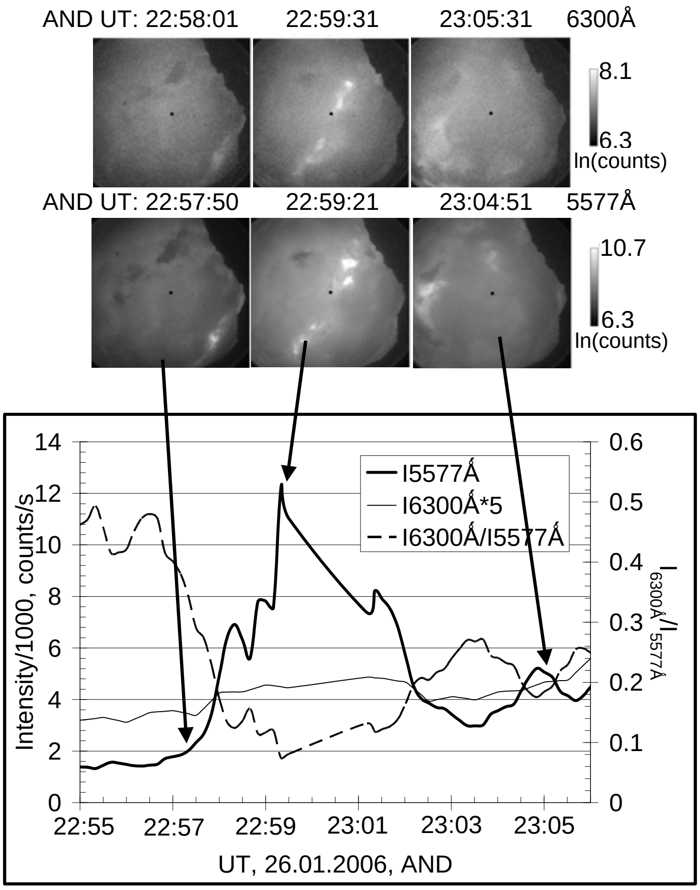

Fig. 5. A substorm development at Andenes on 26 January 2006, observed by the 6300Å (up) and 5577Å (down) images (upper panel) and the emissions intensities and their ratio in zenith during the same time period (bottom panel)

A substorm development on 26 January 2006 at Andenes is shown in Figure 5. The substorm is observed from the station in 22:57:50, the polar edge of the auroral bulge reaches zenith in 22:59:21 UT, in 23:04:51 UT the station is inside the suroral bulge (images in the upper panel of Figure 5). The corresponding course of the emissions and their ratio in zenith are presented in the bottom panel of Figure 5. The minimal value I_{6300}/I_{5577} = 0.073, the average one in the polar edge of the auroral bulge is 0.127 and in the arcs inside the bulge is 0. 197. The ratio of the average I_{6300}/I_{5577} value inside the bulge to the one in the polar edge of the auroral bulge is 1.55.

The emissions characteristics during substorm development concerning the examined cases are summarized in Table 1.

Discussion and conclusions

The emissions intensities ratio I_{6300}/I_{5577} characterizes the hardness of the precipitating electrons spectrum [9]. 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

Table 1. Basic emissions characteristics during substorm development, obtained for the examined cases

№	Station	Date	Onset (B)	Min (B)	Seen from	In zenith	Ratio edge min/time	Ratio edge mean	Bulge arcs mean	Mean ratio bulge to edge
1	AND	3.11.05	18:35	19:54	18:35:41	18:37:20	0.031 18:37:30	0.097	0.132	1.36
2	AND	3.11.05	22:13	22:40	22:16:41	22:17:11	0.029 22:17:21	0.109	0.148	1.36
3	AND	26.01.06	22:58	23:05	22:57:11	22:58:10	0.073 22:59:20	0.127	0.197	1.55
4	LYR	26.01.06	17:15	17:30	17:17:21	17:25:41	0.336 17:26:00	0.438	0.65	1.48
5	LYR	26.01.06	21:05	21:28	21:02:40	21:18:10	0.094 21:18:10	0.152	0.208	1.37

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 5 substorms at Andenes and Longyearbyen by auroral emissions measurements has been studied. The minimum in the $I_{6300Å}/I_{5577Å}$ ratio testifies for the most energetic electrons precipitated over the polar edge of the auroral bulge. It is obtained, that the average ratio $I_{6300Å}/I_{5577Å}$ is about 1.35 to 1.6 times lower at the polar edge, that inside the auroral bulge.

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