FINE STRUCTURE OF THE PARTICLE PRECIPITATIONS DURING SUBSTORM DEVELOPMENT AT HIGH LATITUDES

Veneta Guineva[1], Irina Despirak[2], Rolf Werner[1]

[1]Space Research and Technology Institute – Bulgarian Academy of Sciences
[2]Polar Geophysical Institute (PGI), RAS, Apatity, Russia
e-mail: v_guineva@yahoo.com

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Abstract: *The fine structure of the particle precipitations during substorms was studied by data of aurora observations at 2 high latitude stations – Barentsburg (Russia) and Longyearbyen (Norway). The intensities ratio $I_{6300Å}/I_{5577Å}$ which is considered as a characteristic of the hardness of the precipitated electrons spectrum was used to estimate roughly the electrons energy in the arcs observed in different parts of the substorm bulge – at its polar edge and inside it. Simultaneous data from the zenith photometer and TV camera in Barentsburg, data from the all-sky imager in Longyearbyen and IMAGE magnetometers chain data were used. The following spectral characteristics were examined: the green line intensity $I_{5577Å}$ in zenith, the red line intensity $I_{6300Å}$ in zenith and their ratio $I_{6300Å}/I_{5577Å}$. It was shown that the ratio $I_{6300Å}/I_{5577Å}$ for arcs inside the bulge is higher than the one for arcs at the polar edge of the bulge. This indicates that the most energetic electrons were observed at the polar edge of the auroral bulge.*

ТЪНКА СТРУКТУРА НА ПОТОЦИТЕ ИЗСИПВАЩИ СЕ ЧАСТИЦИ ПРИ РАЗВИТИЕ НА СУББУРИ НА ВИСОКИ ШИРИНИ

Венета Гинева[1], Ирина Деспирак[2], Ролф Вернер[1]

[1]Институт за космически изследвания и технологии – Българска академия на науките
[2]Поляpен Геофизически институт (ПГИ), РАН, Апатити, Русия
e-mail: v_guineva@yahoo.com

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Резюме: *Тънката структура на потоците изсипващи се частици при суббури е изследвана по данни от наблюдения на авроралните емисии от 2 високоширотни станции – Баренцбург (Русия) и Лонгиербиен (Норвегия). Отношението на интензивностите $I_{6300Å}/I_{5577Å}$, което може да се разглежда като характеристика за твърдостта на спектъра на изсипващите се електрони, е използвано за груба оценка на енергията на електроните в дъгите, наблюдавани в различни части на авроралната изпъкналост – на полярния ѝ край и във вътрешността ѝ. Използвани са данни от едновременни измервания от зенитния фотометър и TV камерата в Баренцбург, данни от all-sky камерата в Лонгиербиен и данни от верига магнитометри от мрежата IMAGE. Разгледани са следните спектрални характеристики: интензивността на зелената линия $I_{5577Å}$ в зенит, интензивността на червената линия $I_{6300Å}$ в зенит и тяхното отношение $I_{6300Å}/I_{5577Å}$. Показано е, че отношението $I_{6300Å}/I_{5577Å}$ е по-високо за дъги в авроралната изпъкналост, отколкото за дъги на полярния край на изпъкналостта. Това е индикатор, че най-енергетичните електрони се наблюдават на полярния край на авроралната изпъкналост.*

Introduction

The intensities of the separate optical emissions are related to the energy and flux of precipitating electrons in the corresponding energy band. The ratios of various atoms and molecules intensities in the upper atmosphere can serve as a characteristic of the energy of the precipitating particles causing the aurora [1]. Different emissions ratios were used to estimate the characteristic energy of the precipitating electrons spectrum, for example, the ratio of the red line intensity to the green line intensity $I_{6300Å}/I_{5577Å}$, the ratio of the red line intensity to the blue line intensity $I_{6300Å}/I_{4278Å}$, the ratio $I_{3371Å}/I_{4278Å}$, etc. [e.g. 2, 3].

In some papers, to estimate the hardness of the precipitating electrons spectrum, the ratio of the red line intensity to the green one $I_{6300Å}/I_{5577Å}$ was used. The 5577 Å intensity depends on the average fluxes in 108-120 km height range (2-7 keV energy range) [4], and the 6300 Å intensity – to the average fluxes in the 180-250 km height range (5.10^{-3} – 5 eV energy range). So, a lower value of the ratio $I_{6300Å}/I_{5577Å}$ corresponds to higher energy of the precipitating particles. In the papers [5, 6] the spectral characteristics of auroras during different types of solar wind fluxes were investigated by means of this emissions ratio. It was shown that during magnetic clouds and other non-stationary flows auroras with enhanced mean ratio $I_{6300Å}/I_{5577Å}$ were observed [6]. The spectral characteristics of the auroral emissions during high speed recurrent streams result of hard electrons precipitations in the atmosphere and of a lack of soft electrons (<1keV) precipitations [5]. It should be noted that all these results were obtained based on large statistics. But in these papers there was not carried out a differentiation on various types of emissions, for example, during substorms. During substorm development the precipitating electrons spectrum becomes harder. In our view, it will be interesting to trace the dynamics of the spectral characteristics of the auroral emissions during substorm development.

In our work we use the emissions intensity ratio $I_{6300Å}/I_{5577Å}$ as a rough estimate of the energy electrons in the auroral arcs observed in the different parts of the substorm auroral bulge – at the polar edge of the traveling to the pole bulge and inside it. It is known that during substrorms the auroral bulge – an area occupied by bright, short-lived arcs - forms [7]. Substorm development scheme was described in detail in a number of papers. In the pre-substorm phase the arcs of the auroral oval move to the equator, the polar cap region broadens, the arcs of “the polar cap aurora” disappear [8, 9]. The substorm expansion phase begins with the flash of one arc, usually the most equatorial one between the existing discrete auroral arcs (break-up). A westward traveling surge forms, after that the auroral bulge area expands in all directions, mainly toward the pole, to the West and to the East [9, 10]. The auroral bulge development is not continuous, but consists of separate microsubstorms [11, 12]. Microsubstorms develop in different longitudinal sectors and last 5-10 minutes. In every microsubstorm a movement of the auroral emissions to the pole is observed, but it doesn’t happen continuously, and consists of individual activations – outbursts of new arcs poleward of the previous ones [13]. Further, during the recovery phase, the bright discrete arcs at the polar edge degenerate into irregular strips and fade, the auroral bulge as a whole begins to shrink, its polar edge moves to the equator and, the South one – to the pole [8, 9].

It was established that at the polar edge of the bulge usually discrete auroral emissions occur [14] that corresponds to higher energy particles. But a comparison of the particles energies in the arcs at the polar edge of the bulge and in the arcs inside the bulge has not been implemented. There is a work, in which the dynamics of the polar boundary of the auroral oval during substorms was studied and it was shown that most energetic particles were observed at the polar edge of the luminosity band [15]. But the fine structure of the particle precipitations in the auroral bulge wasn’t investigated in detail.

The subject of our study is to compare the energies of the precipitating electrons in auroral arcs at the polar edge of the auroral bulge and inside it. For this purpose, observations of the auroral emissions at two stations – Barentsburg and Longyearbyen were used. To determine the presence of substorms and the phases of their development data from the all-sky imagers of both stations and data from magnetic stations chain IMAGE were used.

Data used

Data of aurora observations at 2 high latitude stations situated in Svalbard – Barentsburg (78.093°N, 14.208°E), Russia and Longyearbyen (78.20°N, 15.83°E), Norway were used for the study. Usually substorms are observed more equatorially, at lower latitudes, but sometimes, mostly during high speed recurrent streams in the solar wind, the disturbances reach higher latitudes, as well [16, 17]. These high latitude stations were chosen with a view to have the possibility of more precise monitoring of the substorm movement from South to North and determination of the polar edge of the auroral bulge.

The dynamics of the red and green line emissions in the auroral arcs during substorms was analysed. Measurements of the zenith photometer and the TV all-sky camera at Barenzburg during the winter season 2007-2008 and of the all-sky imager (ASI) at Longyearbyen from the 2005-2006 observational season were used.

The following data selection criteria were applied:

- observation of auroras by the TV camera in Barentsburg or enhanced activity in the auroral emissions 5577 Å and 6300 Å registered by the all-sky imager at Longyearbyen;

- presence of simultaneous measurements of the photometer and the TV all-sky camera (for Barentsburg);
- presence of a substorm at the relevant station (controlled by the IMAGE magnetometers chain);
- substorms reached the station zenith and passed beyond it were examined;
- clear sky (no clouds).

As a result 3 cases were chosen: 2 cases of substorms by Barenzburg data (6 January 2008 and 16 December 2007) and 1 case by Longyearbyen data (26 January 2006).

The development of 2 substorms is presented in detail.

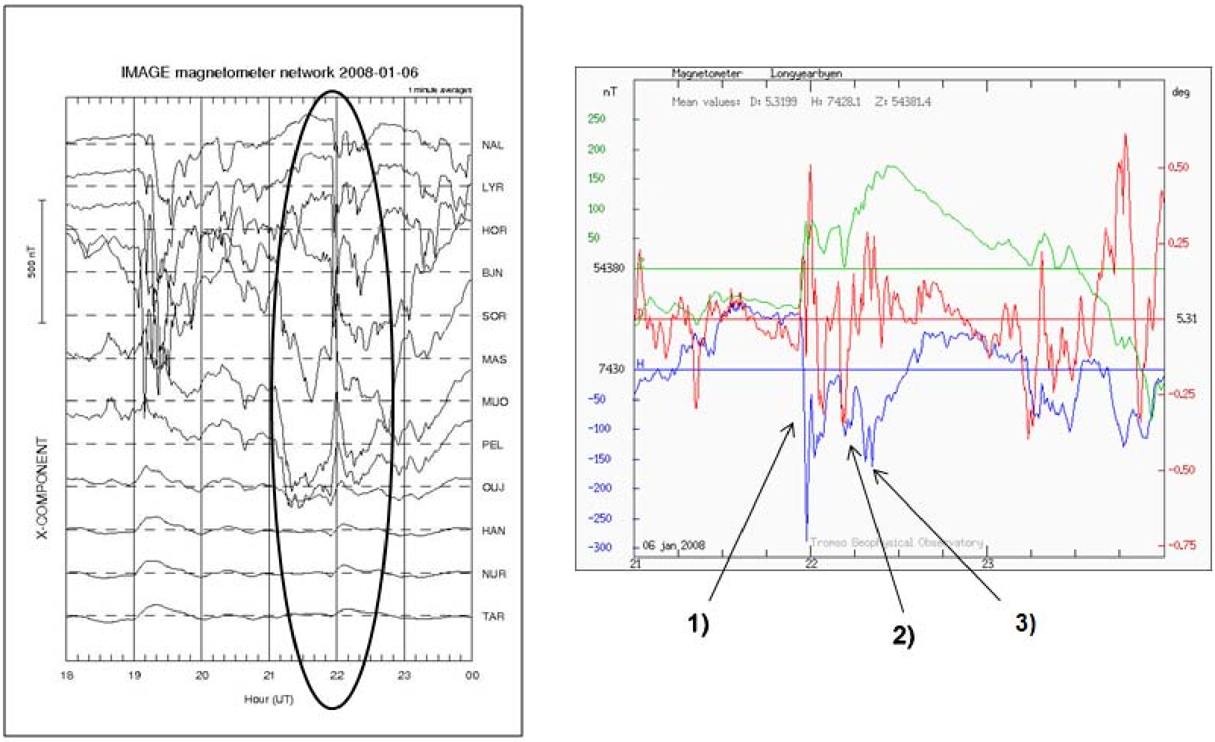
Results

For every case the following spectral characteristics were studied: the intensity in zenith of the green line $I_{5577Å}$, the intensity in zenith of the red line $I_{6300Å}$, and these emissions intensities ratio $I_{6300Å}/I_{5577Å}$.

Case 1: 6 January 2008

The 6 January 2008 case is a typical example of high latitude substorm: the substorm began at low latitudes, in the auroral zone (Oulujärvi station (OUJ), ~61°CGMLat), the disturbance reached Barentsburg and moved further to the pole. Thus Barentsburg lied for some time to the South from the polar edge of the substorm bulge, namely inside the auroral bulge. In fig.1 the magnetic field components variations registered by the magnetic stations chain IMAGE (fig.1a) and at Longyearbyen station (fig.1b) are shown. In fig.1a it can be seen how the substorm spread went from the onset at Oulujärvi (OUJ) to the high latitude stations Longyearbyen and Ny Ålesund (LYR, NAL). The variations of all magnetic components at Longyearbyen are presented in detail in fig.1b. The microsubstorms are marked by arrows 1), 2), 3) and they were registered in 21:56, 22:09, 22:17 UT, respectively.

In fig.2 the auroras dynamics and the intensity variations of the red and green line emissions during the substorm observed from 21:56 UT on 6 January 2008 are shown. In the upper part the all-sky camera data are presented. In the bottom part of fig.2 the zenith photometer data are given – the emissions intensities $I_{6300Å}$ and $I_{5577Å}$ and their ratio $I_{6300Å}/I_{5577Å}$. The all-sky camera is oriented so that North is upward in the pictures, South – downward, East – to the right and West – to the left. By

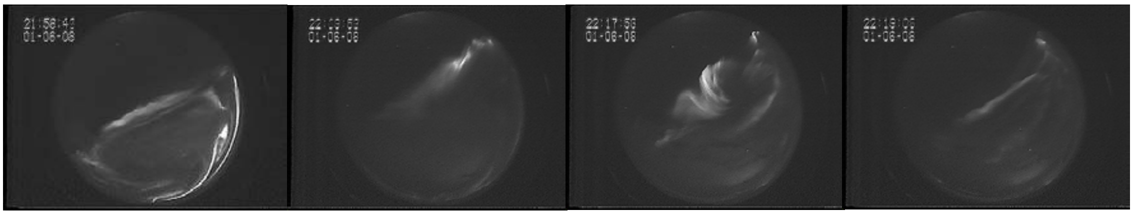


a) b)

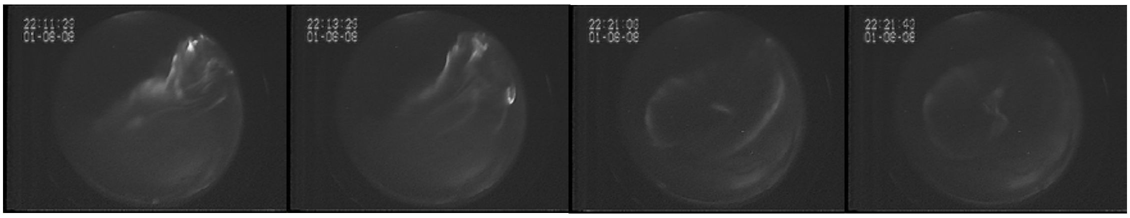
Fig. 1. Magnetic field measurements on 6 January 2008. a) (on the left) Variations of the X-component of the magnetic field by the meridional chain TAR – NAL of IMAGE stations for 18 – 24 UT on 6 January 2008. The examined substorm on 21:56 UT is marked by an oval; b) (on the right) The variations of the magnetic field components H, D and Z registered at Longyearbyen. The microsubstorms are pointed out by arrows 1), 2), 3) in 21:56 UT, 22:09 UT, 22:17 UT, respectively.

Barentsburg all-sky camera data the substorm began with the outburst of an equatorial arc in 21:55:50 UT, further auroras moved to zenith, reached zenith in 21:57:50 UT and continued their spread to the North.

In fig.2a the TV all-sky camera images in which arcs at the polar edge of the bulge were registered in zenith, are presented. The first image (21:58:40 UT) refers to the peak №1 in the green line intensity by data of the photometer directed to zenith (fig.2c). In this moment, by the TV all-sky image an arc corresponding to the polar edge of the substorm bulge, developing over Barentsburg, was observed. The second image (22:09:58 UT) represents the moment, when an auroral arc was observed in the camera zenith, corresponding to the polar edge of a microsubstorm which developed in another longitudinal sector. By photometer data this is peak №2 of $I_{5577Å}$ (in fig.2c). In the third and



a)



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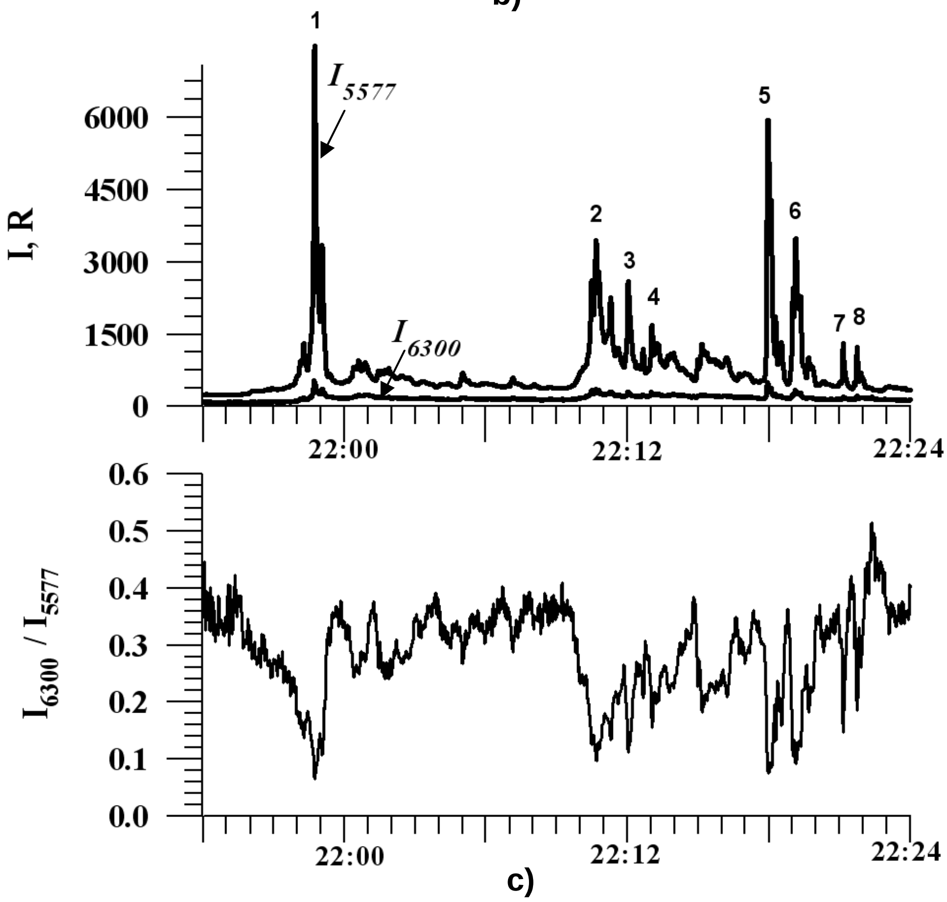


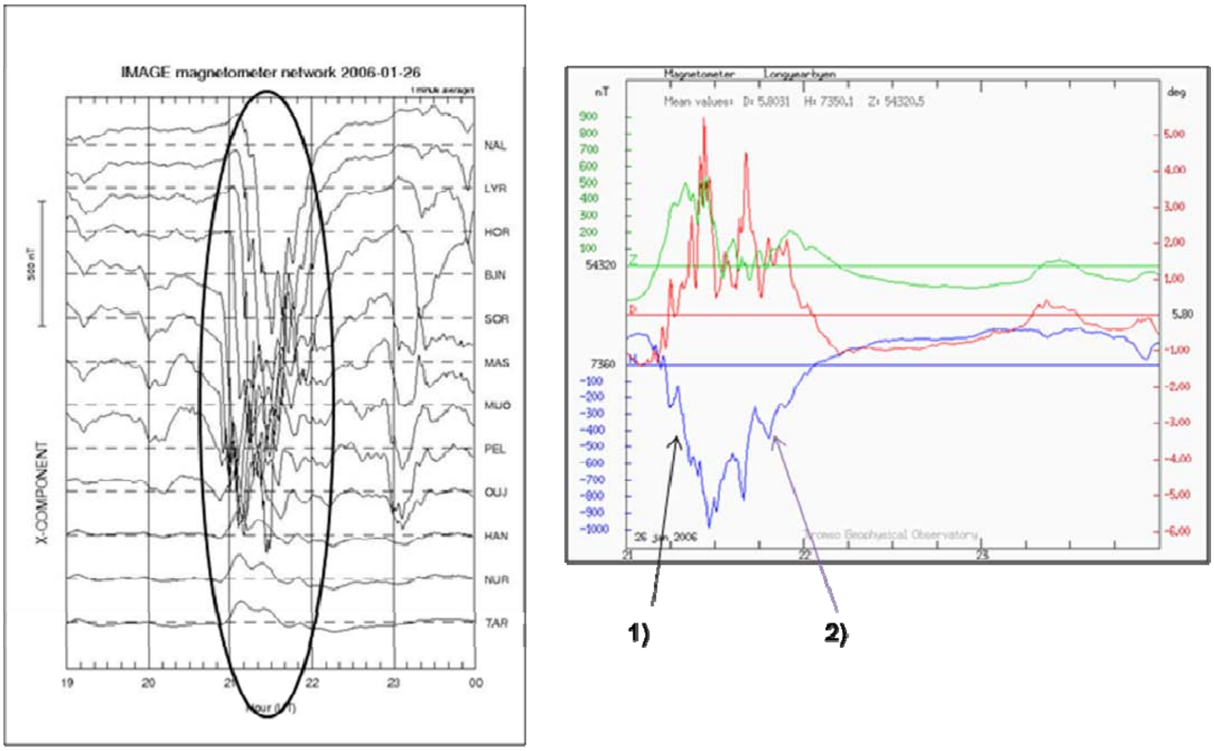
c)

Fig. 2. a) and b) Auroras dynamics by data of the TV all-sky camera and c) variations of the emissions $I_{6300Å}$ and $I_{5577Å}$ and their ratio $I_{6300Å}/I_{5577Å}$ by zenith photometer data during the substorm on 6 January 2008. Fig.2a – images with arcs in zenith, connected to the polar edge of the auroral bulge of microsubstorms in different longitudinal sectors (1, 2, 5, 6 by photometer data in fig.2c). Fig.2b – images with arcs in zenith, related to the inside part of the bulge (3, 4, 7, 8 by photometer data in fig.2c).

fourth images (22:17:50 UT and 22:19:05 UT) an auroral arc, connected with the polar edge of another microsubstorm was observed in zenith. By photometer data, this arc is expressed by intensity maxima №5 and №6 in fig.2c. In fig.2b images, registered in 22:11:25 UT, 22:13:20 UT, 22:21:02 UT and 22:21:40 UT are shown. In these images arcs, generated inside the substorm bulge were observed in zenith. By photometer data the maxima №3, №4, №7 and №8 of $I_{5577Å}$ in fig.2c correspond to these arcs. The mean emissions ratios are $I_{6300Å}/I_{5577Å}$ ~ 0.09 and $I_{6300Å}/I_{5577Å}$ ~ 0.18 for the arcs at the polar edge of the bulge and for the arcs inside the bulge, respectively.

Case 2: 26 January 2006

The substorm on 26 January 2006 was observed during a high speed recurrent stream. It is known that during high speed recurrent streams the disturbances can reach high latitudes [e.g. 16]. The substorm disturbance began at auroral latitudes (Oulujärvi station (OUJ), ~61°CGMLat), subsequently reached Longyearbyen and traveled forward to the pole. The substorm propagation can be traced after fig.3a in which the x-component of the magnetic field registered by a chain of magnetic stations from the IMAGE set is presented, including lower latitudes than the substorm onset at Oulujärvi (OUJ) to the high latitudes stations Longyearbyen and Ny Ålesund (LYR, NAL). In fig.3b the variations of the magnetic field components at Longyearbyen are shown. The microsubstorms registered in 21:10 UT and 21:47 UT are pointed out by arrows 1) and 2), respectively.



a) b)

Fig. 3. Magnetic field measurements on 26 January 2006. a) (on the left) Variations of the X-component of the magnetic field by the meridional chain TAR – NAL of IMAGE stations for 19 – 24 UT on 26 January 2006. The examined substorm on 21:10 UT is marked by an oval; b) (on the right) The variations of the magnetic field components H, D and Z registered at Longyearbyen. The microsubstorms observed in 21:10 UT, 21:47 UT are pointed out by arrows 1) and 2), respectively.

The auroras dynamics and the intensity variations of the red emission $I_{6300Å}$ and the green one $I_{5577Å}$ as well their ratio $I_{6300Å}/I_{5577Å}$ are presented in fig.4. In the upper part of the figure chosen ASI images are shown, in fig.4a – with arcs of the red line emission, and in fig.4b – with arcs in the green line emission, observed in the station zenith. In the bottom part of the figure the intensity variations $I_{6300Å}$ and $I_{5577Å}$ in zenith and their ratio $I_{6300Å}/I_{5577Å}$ are drawn (fig.4c). By Longyearbyen all-sky imager measurements the substorm began to the South in 21:14 UT, after that the auroral arcs moved gradually to the North, reached zenith in 21:14 UT and continued traveling to the pole. The first image in fig.4b corresponds to the moment when the polar edge of the bulge reached the station zenith, an auroral arc was observed in zenith. Image 5 in fig.4b corresponds to the moment, when the polar edge of another microsubstorm, developing in other longitudinal sector was observed in the station zenith.

Images 2, 3 and 4 refer to moments, when arcs related to the inside of the auroral bulge were observed in zenith.

The mean values of the emissions intensities are $I_{6300Å}/I_{5577Å}$ ~ 0.17 and $I_{6300Å}/I_{5577Å}$ ~ 0.28 in the arcs at the polar edge of the bulge and inside the bulge, respectively.

In all examined cases of substorms we found that the emissions ratio $I_{6300Å}/I_{5577Å}$ is about 2 times higher in the arcs inside the auroral bulge than in the arcs at the polar edge of the bulge.

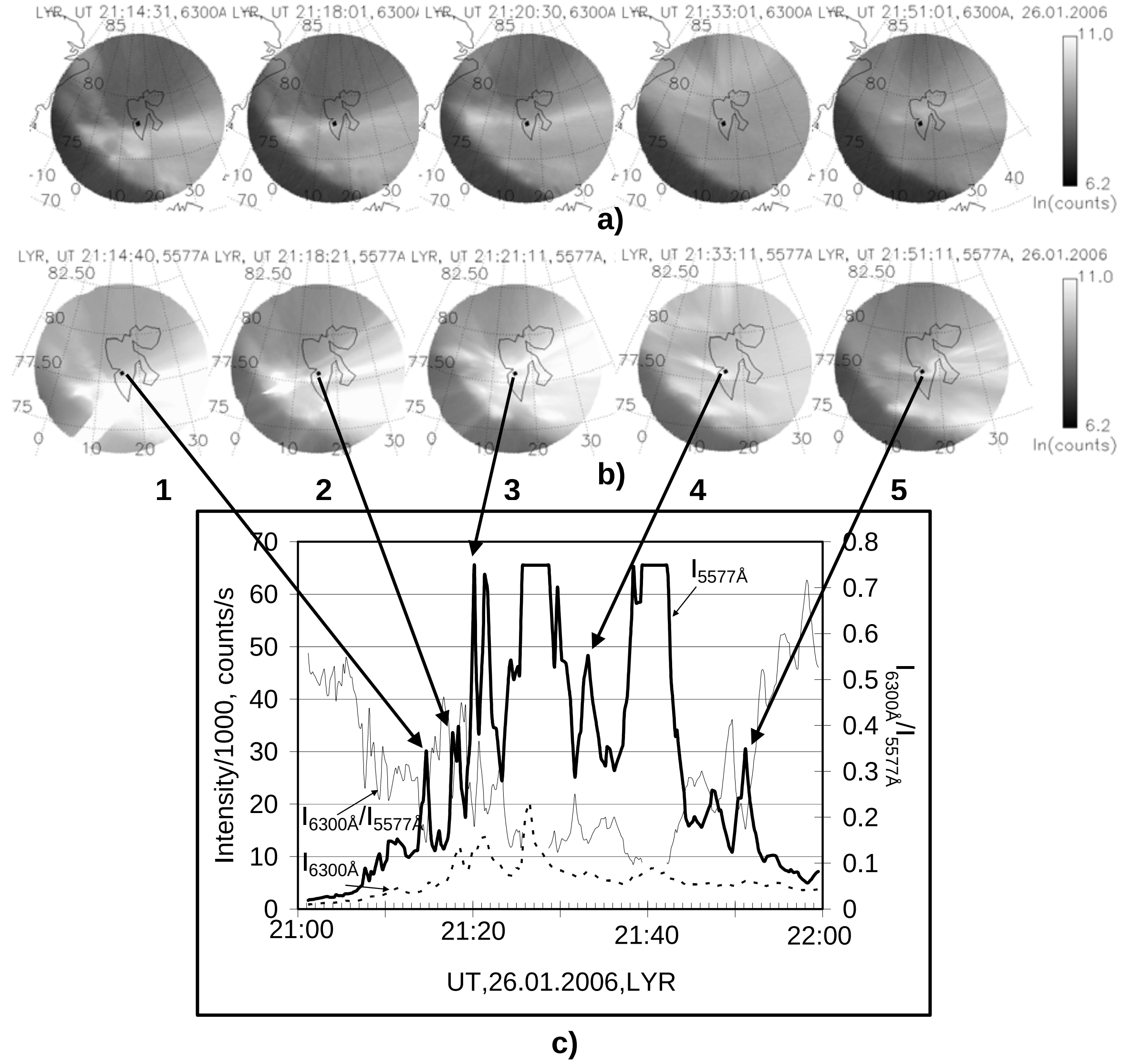


Fig. 4. Aurora dynamics by the red (a) and green (b) emissions images of the all-sky imager during the substorm on 26 January 2006. Images 1 and 5 – arcs in zenith, connected to the polar edge of the microsubstorms in different longitudinal sectors; images 2, 3, 4 – arcs in zenith inside the bulge. In the bottom (c) the intensity variations of the emissions $I_{6300Å}$ and $I_{5577Å}$ and their ratio $I_{6300Å}/I_{5577Å}$ are shown.

Discussion

In our work the dynamics of the intensities of the red and green lines ($I_{6300Å}$ and $I_{5577Å}$) and of their ratio $I_{6300Å}/I_{5577Å}$ during 3 substorms was examined. Two of the substorms occurred during high speed recurrent streams of the solar wind. The obtained values of the emissions ratios are in good coincidence with the results in [5] in which the spectral characteristics of the auroral emissions related to recurrent streams in the solar wind were studied. Our result is somewhat lower than the obtained in [5] one ($I_{6300Å}/I_{5577Å}$ ~ 0.4) suggesting that the spectrum of precipitating electrons during substorms becomes harder. Moreover, we have to take into account, that in [5] the spectral characteristics of the auroral emissions were averaged over a long time period. And in our work the emissions ratio in individual arcs was compared.

We compared the auroral emissions ratio in different regions of the auroral bulge – at the polar edge and inside it. The emissions ratio $I_{6300Å}/I_{5577Å}$ in the arcs inside the auroral bulge was obtained to be about 2 times higher than in the arcs at its polar edge. The emissions ratio characterizes the hardness of the precipitating electrons spectrum [1]. Therefore, the most energetic particles are observed at the polar edge of the auroral bulge. Our result agrees with the result of Zverev and Starkov [15] in which it was shown that the most energetic particles were observed at the polar edge of the luminosity band and the particles energy decreased towards the equator.

Conclusions

In order to compare the characteristics of the electrons precipitating at the polar edge of the auroral bulge and inside it, the dynamics of the auroral emissions during substorms observed over Svalbard, was studied. It was shown that the emissions ratio $I_{6300Å}/I_{5577Å}$ in the arcs inside the auroral bulge was higher than in the arcs at the polar edge of the bulge. From this it follows that the precipitations of most energetic electrons occur at the polar edge of the auroral bulge.

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