Variations of aurora emissions during substorms at Spitsbergen archipelago

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Spitsbergen photometer data from the 2005/2006 and 2007/2008 winter seasons have been used to study the variation of the auroral 5577 Å and 6300 Å intensity ratio during substorms. The substorm onset time and the further development were verified by ground-based data of the IMAGE magnetometers network and by data of the all-sky camera at Spitsbergen. Using WIND satellite data for the examined periods, the solar wind streams were revealed: recurrent streams from coronal magnetic holes and magnetic clouds. We considered the behaviour of the intensities I6300 and I5577 of the auroral emissions for 2 substorms observed during one recurrent stream and one magnetic cloud. It was shown that the precipitation of most energetic electrons occurs at the polar edge of the auroral bulge, and inside the bulge precipitation of less energetic electrons is observed. It was also shown that in front of the substorm auroras, a region of enhanced red emission of about 100 km width appears which can be related with a downward current.

Introduction

It is known that the solar wind flow can vary depending on the state of the solar activity. Thus, during a solar minimum, the recurrent streams (RS) originating from coronal magnetic holes, characterized by a 27-day recurrence, are predominant ([1], [2]). During a solar maximum, most common are the sporadic flows associated with coronal mass ejections (CME) ([4]). Near the Earth they are observed as magnetic clouds (MC) (e.g. [4]). The spectral characteristics of the aurora depend on the type of the solar wind flows. The connection of the auroral spectral characteristics with different types of solar wind fluxes was studied by [5], [6]. It was shown that during sporadic flows 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) [5]. The precipitating electrons spectrum is shifted to the higher energies. The yearly means of the aurora intensity ratios are presented. All these results were obtained by statistics, based on a large amount of data (aurora observations at the Loparskaya Observatory during 1970-1985). In our opinion, it is of major importance to follow up the dynamics of the auroral spectral characteristics during a substorm development. Moreover, it is known, that the substorm expansion depends on the conditions in the solar wind (e.g., [7], [8]), not only on the solar wind parameters values, as well as on the structure of the solar wind streams [9].

In this paper, the variations of the intensities of the green 5577 Å auroral emission and the red 6300 Å one will be examined. The dynamics of these emission intensities during two substorms, observed over the Spitsbergen archipelago at the time of a recurrent stream and during a magnetic cloud will be studied. Data from simultaneous measurements of the photometer and the all-sky camera installed at the Barenzburg Observatory, plasma and solar wind magnetic field data from the WIND satellite and data from the ground-based magnetic stations from the IMAGE network have been used.

Data

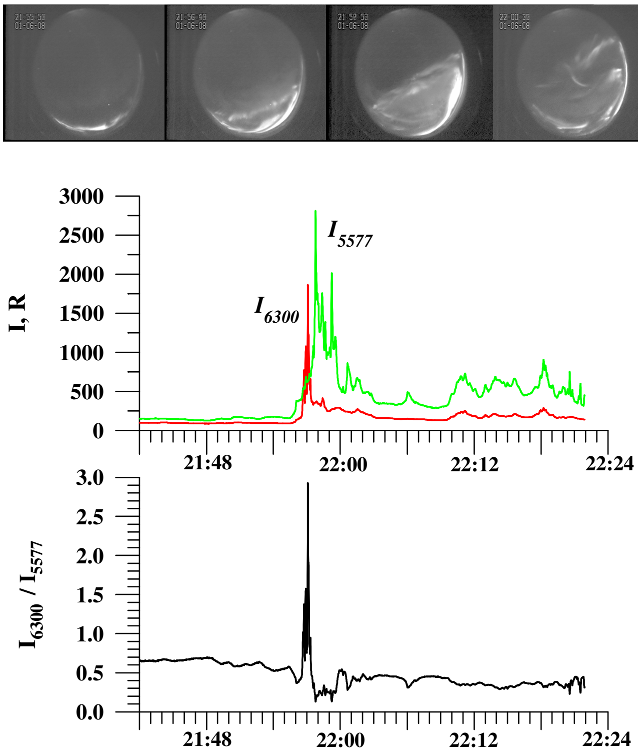
Spitsbergen PGI photometer data have been used to study the behavior of the auroral 6300 Å and 5577 Å emissions. The photometer has four channels for emission measurements: two channels for the 5557 Å and 6300 Å emissions directed towards the zenith and two channels for measurements of the 5577 Å emission directed under zenith angles of 30° and 60°. This work will employ only data from the two channels directed towards the magnetic zenith. The field of view angle of the device is 6 grads, the objective focus distance is 40 mm, and the sensitivity threshold is 4 R. Observations have been carried out continuously during two winter seasons – 2005/2006 and 2007/2008. The device time resolution is 1 s. The following spectral characteristics have been examined: the 5577 Å emission line intensity in zenith, the 6300 Å line intensity in zenith, and the ratio of these intensities I6300/I5577. The intensity ratio characterizes the hardness of the precipitating electrons flux. The variations of this ratio during two substorms observed at the Barenzburg Observatory have been studied.

By data of the all-sky camera at Spitsbergen, aurora observations, connected with substorm developments were verified. The sensibility maximum of the camera coincides with the green spectral region, and the part of the red spectral region in the registered glow is less than 10%.

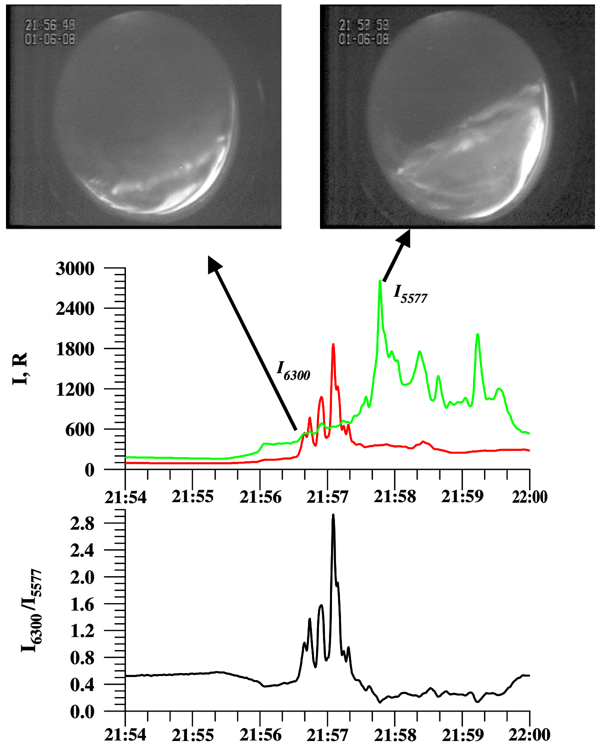
We have examined the periods of simultaneous observations of the WIND satellite, the PGI photometer and the all-sky camera at Spitsbergen. The substorm onset time and the further development were verified by ground-based data of the IMAGE magnetometers network. The solar wind conditions were determined from interplanetary medium parameters measured by the WIND satellite. All recurrent streams and magnetic clouds observed by WIND during 2005/2006 and 2007/2008 winter seasons (from November to February) were studied. As a result, two cases were selected: one recurrent stream on 4-9 January 2008 and one magnetic cloud on 24-25 December 2005. During the recurrent stream the substorm onset was at 21:55 UT on 6 January 2008. During the magnetic cloud the substorm onset was at 20:27 UT on 24 December 2005.

Results

Figure 1 shows the aurora dynamics and the variations of the 6300 Å and 5577 Å emissions intensities observed during the substorm from 21:56 UT on 6 January 2008. The upper panel of the Figure 1a presents the aurora development by data from the Barenzburg station (Spitsbergen) all-sky camera. The all-sky camera is oriented in such a way as the North direction is to the top of the image; the South is to the bottom, the East – to the right and the West – to the left. Note that Barenzburg is a quite a high-latitude station (LAT = 78°04'), and usually substorms are observed more equatorially, from stations at lower latitudes.



a)



b)

Figure 1. Behavior of aurorae by the all-sky camera and aurora emissions by the photometer during the substorm on 6 January 2008: a) from 21.42 to 22.24UT; b) from 21:54 to 22:00 UT. *The top panels shows the aurorae and the bottom panels show the intensities of the green line I_{5577}, the red line I_{6300}, and their ratio I_{6300}/I_{5577}.*

However, the substorms sometimes reach higher latitudes, normally during high speed recurrent streams of the solar wind, (e.g. [7], [10]). The case of 6 January 2008 appears an example of a substorm observation at high latitudes during a recurrent stream of the solar wind. By data of the all-sky camera (see Figure 1a, upper panel) aurora appears in the South of the frame at 21:55:50 UT when the first arc outburst was registered. Then the auroral arcs moved towards the zenith, reached the zenith at 21:57:50 UT and proceeded with its displacement northwards. At 21:57:50, the polar edge of the substorm auroral bulge was observed over the station, after which it displaced to the pole, and Barenzburg turned out inside the auroral bulge.

The two bottom panels (Figure 1a) present the photometer measurements: the upper graph shows the intensities of the green 5577 Å emission and of the red 6300 Å one, and the lower graph shows the emissions intensities ratio I_{6300}/I_{5577}. It is seen that during the substorm the following dynamics of the emissions ratio was observed: when the polar edge of the auroral bulge came into sight over the station (the aurora appeared into zenith), the average ratio was I_{6300}/I_{5577} =0.23; inside the auroral bulge the average ratio was I_{6300}/I_{5577} =0.44. At 21:56 UT a peak in the red line intensity I_{6300} was observed, and a little later, at 21:58 UT, a peak in the green line intensity I_{5577} was registered. It was at that moment that according to the all-sky camera data the aurora reached the zenith and accordingly, the photometer recorded a sharp increase of the green line intensity. In the bottom graph of Figure 1a, where the emission ratio I_{6300}/I_{5577} is shown, a sharp peak up to ~2.9, and after that – a sharp decrease down to ~ 0.1 are presented, respectively. This time interval is detailed in Figure 1b. The behaviour of the green and red line intensities and their ratio during the time from 21:56:40 UT to 22:00:00 UT are shown in the bottom panel of Figure 1b. In the upper panel of the figure, two frames of the all-sky camera are presented. The first frame corresponds to the moment when the photometer started to record the red emission peak (21:56:40 UT). In the all-sky camera frame this red emission is not seen because the camera registers mainly the glow in the green spectral range. However, the photometer data suggest that at that moment the red emission has been observed near the station zenith, since the photometer points to the zenith and its field of view is 6°. The red emission maximum was registered at 21:57:05 UT. The green emission maximum was observed about 21:57:45 UT, when the substorm aurora reached the zenith. This moment is shown in the second frame from the all-sky camera data in the upper panel of Figure 1b. Thus, peaks in the red and green line intensities displaced in the time from one another, were observed.

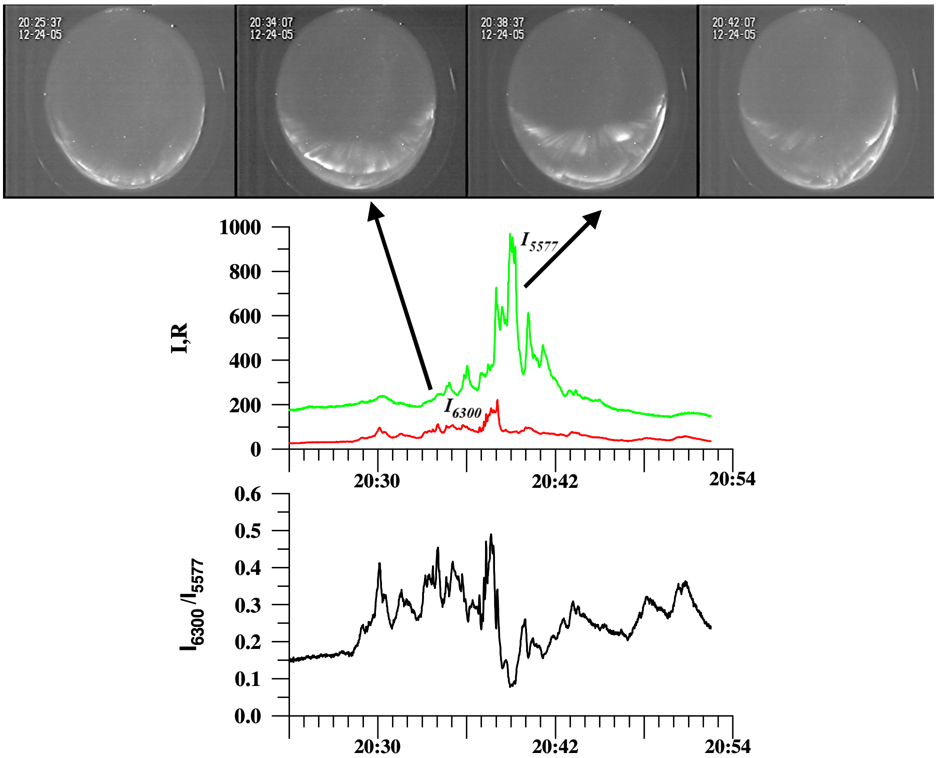


Figure 2. The top panel shows the aurorae by the Spitsbergen all-sky camera and the bottom panels display the intensities of the green line I_{5577} and the red line I_{6300}, and their ratio I_{6300}/I_{5577} during the substorm at 20:27 UT on 24 December 2005.

Figure 2 shows the aurora development and the dynamics of the red and green line intensities for the 24 December 2005 case. The substorm was observed at 20:27 UT, during the passage of a magnetic cloud. The upper panel of Figure 2 contains the all-sky camera data. The substorm began at 20:25:37 UT with an arc outburst, after that an aurora movement northwards was observed, however, the aurora didn't reach the zenith, just approached it and stopped moving, staying at several tenth of kilometers away from Barenzburg. The closest approach of the aurora to the zenith was at 20:38:37 UT, after that the aurora moved again in South direction and faded. Such an aurora development attests for a substorm development at lower latitudes, and only the polar edge of the substorm disturbances was observed over Barenzburg. It is seen (bottom graph in the lower panel of Figure 2) that at the maximal approach of the aurora to the zenith, the average emission ratio was I6300/I5577 =0.17. Besides, with the approach to the zenith, the increase of the red line intensity was observed earlier than that of the green line intensity. At 20:34:37 UT (the second frame of aurora in the upper panel of Figure 2) the red line intensity increased. At 20:38:37 UT (the third frame of aurora in the upper panel of Figure 2), when the aurora was closest to the zenith, the green line intensity sharply increased. Thus, in this case some softening of the precipitating electrons spectrum in front of the substorm auroral arcs was observed, as well (the emissions ratio I6300/I5577 =0.33).

Disscussion

A comparison is made between the dynamics of the red I_{6300} and the green I_{5577} line intensities and their ratios I_{6300}/I_{5577} during two substorms, the first of them connected with a recurrent stream of the solar wind and the second one - with a magnetic cloud. It was shown that during the appearance of the substorm aurora near the 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} which characterizes the hardness of the precipitating electrons spectrum, was ~0.2, thus testifying for the precipitation of more energetic electrons. The case of 6 January 2008, examined in the preceding part, is a typical example of observation of a substorm during a recurrent stream: the substorm onset was at auroral zone latitudes (Oulujärvi (OUJ) station, ~61° CGMLat), later it reached Barenzburg and moved further to the pole. Thus, Barenzburg turned out southwards of the polar edge of the bulge, i.e. inside the bulge. The emissions ratio for the aurora, observed inside the bulge, I_{6300}/I_{5577}~ 0.44, was a little higher than that at the polar edge. For the second case, 24 December 2005, the smallest red and green line intensities ratio was also observed near the polar edge of the bulge: I_{6300}/I_{5577}=0.17. Therefore, the precipitation of the most energetic electrons takes place at the polar edge of the auroral bulge. The value of the emission intensities ratio I_{6300}/I_{5577}, obtained in this paper, is in a good agreement with the result of [6] for this ratio during recurrent streams and is not in a such good agreement with the ratio obtained for the magnetic clouds ([6]). Possibly, this discrepancy as obtained because we examined a substorm, not typical for the magnetic clouds, not so intense, originating at auroral latitudes ~ 64.7° CGMLat. Usually substorms during magnetic clouds originate at low latitudes (~55-60° CGMLat) (e.g. [9]).

For the case of 6 January 2008, peaks in the red and the green line intensities, displaced in the time from one another, were observed. In front of the bright substorm arcs registered by the all-sky camera a region of red emission exists observed by photometer data. The width of this red emission can be evaluated, taking into account the fact that at the moment when the strong red emission is observed in zenith, the bright arcs are seen under an angle of ~45°. The width of the red emission region was estimated of about 100 km.

According to certain publications in front of the substorm auroral arcs, a region of a downward current was observed. It was revealed in different observations – by incoherent scattering radars [11], by the observation of the auroral hiss generation by Interball-2 and the Polar satellites [12], in the "radioaurora" observations [13]. According to the incoherent scattering radars observations, a region of decreased electron concentration (cavity, trough of the electron concentration) exists polewards from the aurora boundary at the height of the F-layer [11]. This diminishment of the electron concentration is interpreted as a downward current by the help of which the current system is closed: the region of the auroral arcs is a region of an upward current where the accelerated electrons move downwards, and polewards from the auroral arcs a region of a downward current is observed where the electrons move upwards along the force lines. By estimations of [11] the dimension of the downward current is ~90 km. As it is shown in the work of [12] this region of a downward current is directly related with the polar edge of the substorm aurora and can be considered a region of generation of the auroral hiss observed by the Interball-2 and Polar satellites. In our data (the PGI photometer and the all-sky camera measurements) the region of the downward current is displayed as a region of a red emission, situated in front of the substorm arc. In our view, this red emission can be provoked by energetic protons, moving down into the region of the downward current and is the result of the collisions of the accelerated protons with neutrals. This assumption can be further verified, for example by data of the FAST satellite.

Conclusion

The present work reveals on the basis of the analysis of the green I_{5577} and the red I_{6300} line intensities during two substorms that the precipitation of the most energetic electrons (I_{6300}/I_{5577} =0.2) happens at the polar edge of the auroral bulge. Inside the bulge, precipitation of less energetic electrons (I_{6300}/I_{5577} =0.44) is observed. It is also shown that in front of the substorm arcs, a region of a red emission with about 100 km width is observed which can be related with the downward current.

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