Variations of the auroral emissions and the absorption at 38.2 MHz during substorms associated with a recurrent stream of the solar wind

Guineva V.[1], Werner R.[1], Trondsen E.[2], Honary F.[3], Marple S.[3]

[1] Solar-Terrestrial Influences Institute, Bulgarian Academy of sciences, Stara Zagora Departmnent,Stara Zagora, Bulgaria ,v_guineva@yahoo.com
[2]University of Oslo, Department of Physics, Norway, espen.trondsen@fys.uio.no
[3]Lancaster University, Department of Communications Systems, UK, f.honary@lancaster.ac.uk, s.marple@lancaster.ac.uk

The opportunity for simultaneous multi-instrument observations by different instruments, as well by sets of instruments of the same kind, nowadays is a precondition for an extensive research of the ionosphere phenomena. For this study, simultaneous ground based observations' data of the OI 5577 Å and 6300 Å emissions, the absorption at 38.2 MHz and the magnetic field have been used from the following instruments: the All-Sky Imager (ASI) and the magnetometer, positioned at Andøya Rocket Range (ARR), Andenes (69.3°N, 16.03°E), and the Imaging Riometer for Ionospheric Studies (IRIS) at Kilpisjärvi, Finland (69.05°N, 20.79°E).

The behaviour of the auroral emissions, the ratio I_{6300}/I_{5577} and the absorption at 38.2 MHz during 3 substorms occurred during a high speed recurrent stream has been examined. Variations of the emissions and the absorption at 38.2 MHz, related to the different locations of substorm bulge have been studied. Estimations of the particle precipitation spectra in the polar edge of auroral bulge and inside auroral bulge have been obtained. The correlation between the 5577 Å and 6300 Å emissions and the absorption at 38.2 MHz has been examined.

Introduction

The importance of the auroral processes as part of the plasma-physical processes in the Universe contributes to the interest to their investigation [1]. The auroral disturbances, as well as the magnetospheric ones are related to the solar wind (SW) and the interplanetary Magnetic Field (IMF). The changes in the solar wind reflect in the auroral processes, in particular in the behaviour of the auroral emissions and the absorption at 38.2 MHz. But different types of solar wind exist, differing from each other by their origin, characteristics and duration [2]. Basic structures in the solar wind are the high speed recurrent streams (RS) from magnetic holes [3], and the sporadic flows, connected to coronal mass ejections, usually observed near Earth as magnetic clouds (MC) [4]. The regions of interaction of RS and MC with the undisturbed solar wind are CIR (corotating interaction region) and SHEATH. Depending on the phase of the solar wind cycle different types of SW flows prevail: RS during downward course of the solar activity and the solar cycle minimum [5] and MC during the solar cycle maximum [6]. The spectral characteristics of aurora depend on the different solar wind types. They were studied by Hviuzova and Leontiev during stationary SW flows (RS) [7] and during sporadic ones (MC) [8]. But a differentiation of the cases of auroral emissions during substorms and in quiet conditions during the studied SW flows wasn't made.

In the present work, a study of the auroral 5577 Å (green) and 6300 Å (red) emissions and the absorption at 38.2 MHz giving information about the precipitating electrons ranging from 10 to 100 keV during 3 substorms in the time of a recurrent stream is implemented.

Observational instruments and data used

For this study, simultaneous measurements from all-sky imager (ASI), riometer and magnetometer have been used.

The All-Sky Imager (ASI) is positioned at ARR, Andenes (69.3°N, 16.03°E). It records automatically the 5577 Å and 6300 Å emissions with 10 s time resolution from a 180° field of view in a 512x512 matrix. The row data are processed in the Oslo University.

The Imaging Riometer for ionospheric Studies (IRIS), situated at Kilpisjärvi, Finland (69.05°N, 20.79°E), measures the absorption of cosmic noise at 38.2 MHz by 49 beams (7x7 area) every second. This absorption corresponds mostly to ionisation by electrons with energies in the range 10÷x100keV and deposition heights centered at about 90 km. The database is organized by the Lancaster University.

The Andenes Magnetometer (69.3°N, 16.03°E) measures the magnetic field components every second. They are accumulated and processed at the Tromsø Geophysical Observatory, University of Tromsø, Norway.

Additional satellite and ground based data contributed to the study, as well. Data from WIND and DMSP satellites are used to monitor the interplanetary conditions and the auroral particles precipitation. Data by all-sky camera at Andenes and IMAGE magnetometers network are used to verify substorm onset time and further development. Substorm westward electrojet development was defined by the MIRACLE system.

Results

A recurrent high speed stream is selected according to the criteria given in [17], lasting from 2 November to 9 November 2005.

During the recurrent stream (RS), several measurements of the 5577Å and 6300Å intensities have been carried out by the all-sky imager (ASI). For this study, one measurement night, 3-4 November 2005, was chosen. On 3 November (the most disturbed day in November 2005), 2 intensive substorms occurred. The onset and development of the substorms were verified by ASI data, as well as by the Andenes magnetometer data, by the all-sky camera data, by the

IMAGE network magnetic field data and by the ionospheric equivalent current estimates of MIRACLE system. In Fig.1, from up to down, the ASI and IRIS keograms and the magnetic field components at Andenes for the period 3-4 Nov. 2005 are presented. ASI and IRIS keograms were constructed for one and the same geomagnetic meridian, passing through the center of the field of view of IRIS (103.62°E). The two substorms, beginning at 18:36 UT and 21:52 UT as they were identified by the magnetic field data are clearly expressed in the keograms by the enhancement of the 6300 Å and 5577 Å emissions and the absorption at 38.2 MHz. They spread all over the instrument fields of view.

In Fig.2, 3, the course of the auroral emissions and the absorption during both substorm developments is presented. The 5577 Å intensity is taken for the Andenes station coordinates (69.3 N, 16.03 E), and the 6300 Å intensity – for the same geomagnetic coordinates as the 5577 Å one. The intensities ratio $I_{6300Å}/I_{5577Å}$ is used as a measure of the hardness of the precipitating electrons energetic spectrum. The absorption course is presented by the central IRIS beam. The absorption at 38.2 MHZ is directly connected to the precipitating electrons with energies in the range 10-100 keV. On the substorm beginning, 5577 Å and 6300 Å emissions, and the absorption sharply increase and stay enhanced during the substorm development in comparison with the time before the substorm beginning. The correlation between the emissions intensities and the absorption is studied. Regardless of the conditions, a good correlation is obtained between 5577 Å intensity and 6300 Å one (correlation coefficient R>0.7) during all examined periods. The correlation between the absorption and the emissions is not always so good. This is

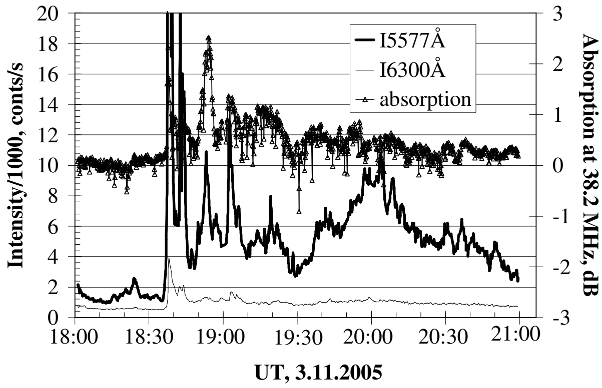

Fig.2. Course of the 5577 Å and 6300 Å emissions intensities and the absorption at 38.2 MHz from 18:00 to 21:00 UT, 3.11.2005 when the first examined substorm onset and development occurred.

due to the different electrons energy related to these phenomena and the changes in the precipitating electrons energy spectrum. The correlation between the absorption and the emissions is worse during substorms, when the energy spectrum of the precipitating electrons is shifted to the higher energies.

First substorm

The first substorm onset was in 18:36 UT and its expansion lasted to 19:42 UT. In the upper panel of Fig.4, images of 5577 Å emission from ASI, presenting some basic moments of the substorm development, are shown. The North direction is 60° anticlockwise from the vertical one. The times of the images are marked below them. The substorm onset was seen from Andenes station in 18:36:11 UT (left upper image). It moved towards Andenes (central and right upper images). The substorm began at Andenes in 18:37:20 UT, when the polar edge of the auroral bulge reached zenith (left bottom image), after that the substorm movement northward continued and the station zenith stayed inside the auroral bulge (two examples are the bottom central and right images). The emissions and their ratio around the substorm beginning

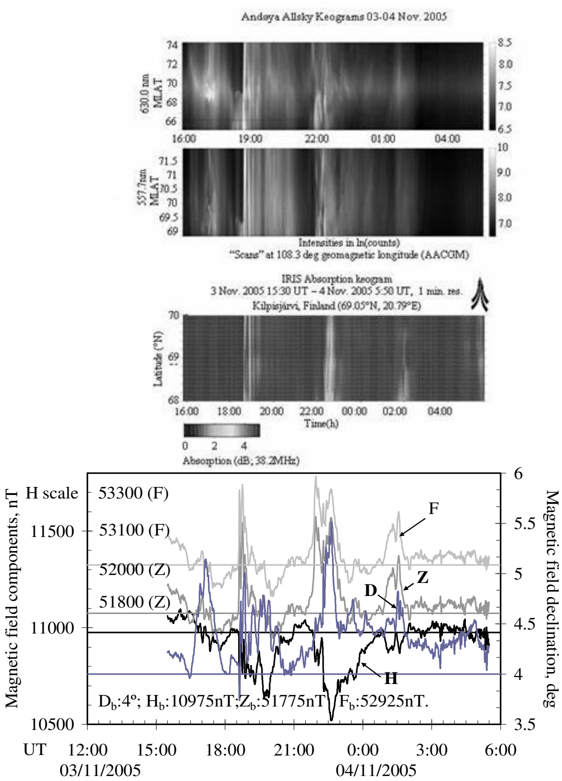

Fig.1. ASI keograms (up), IRIS keogram (further down), and the magnetic field components at Andenes (bottom) for the examined period during the RS. The two substorms, beginning at 18:38 UT and 21:52 UT are clearly expressed in the keograms by the enhancement of the 6300 Å and 5577 Å emissions and the absorption at 38.2 MHz in the substorm times.

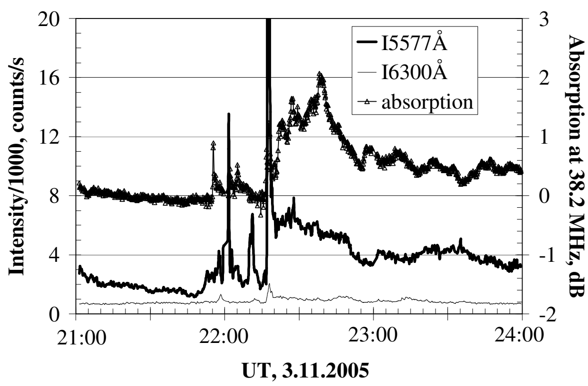

Fig.3. Course of the 5577 Å and 6300 Å emissions intensities and the absorption at 38.2 MHz from 21:00 to 24:00 UT, 3.11.2005 when the second examined substorm onset and development occurred.

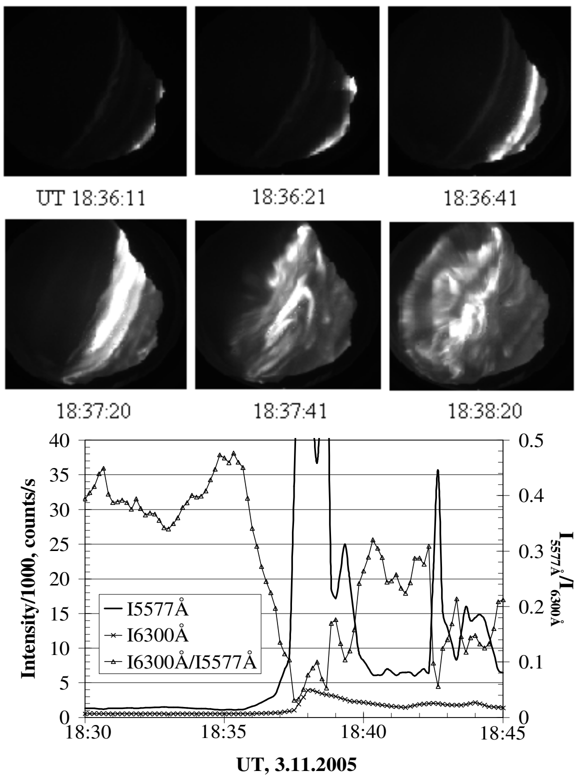

Fig.4. First substorm beginning.
Upper panel: chosen images of 5577 Å emission from ASI: substorm at lower latitudes seen from Andenes (upper row of images), subtorm beginning, the polar edge of the auroral bulge reaches the Andenes station (bottom left image), the station zenith is inside the auroral bulge (bottom center and right images). North direction is 60° anticlockwise from the vertical one. Bottom panel: course of the 5577 Å and 6300 Å emissions intensities and the ratio $I_{6300Å}/I_{5577Å}$ during the time of the substorm beginning.

time are presented in more details in the bottom panel of Fig.4. A sharp increase of the intensities is observed when the polar edge of the auroral bulge reached the station zenith. In the same time, the intensities ratio sharply decreases, reaching minimal value of 0.03. The $I_{6300Å}/I_{5577Å}$ ratio stays low inside the bright arc at the polar edge. Its average value is 0.078. During the substorm expansion, up to 19:42 UT, the average ratio is 0.2. In the period before the substorm beginning the average $I_{6300Å}/I_{5577Å}$ ratio is 0.42.

Second substorm

Before the second intense subsorm, a weak substorm developed at lower latitudes. The onset of the weak substorm was in 21:52 UT. The first two rows of the upper panel of Fig.5 show some images of the 5577 Å green emission during this weak substorm development. It was registered first in 21:52:10 UT. After it moved to the North, but only the polar edge of the auroral bulge hardly reached the Andenes station (e.g. the image in 22:02:11 UT). This substorm didn't develop further to the North. The onset of the second intense substorm was in 22:16 UT and its expansion was up to 22:40. Several images of the green line emission shown in the second two rows of the upper panel of Fig.5 present the substorm development. The substorm was registered first by ASI in 22:16:41 UT. It reached Andenes in 22:17:21 UT, after that propagated to higher latitudes and the station turned out to be situated inside the auroral bulge. In the bottom panel of Fig.5, the course of the emissions and their ratio for the discussed period is presented in more details. The average ratio before the weak substorm beginning, from 21:01:20 to 21:50, is 0.407. In the bright arc at the polar edge of the auroral bulge registered during the weak substorm the 5577 Å intensity sharply increases, and the $I_{6300Å}/I_{5577Å}$ ratio has a minimum. The minimal emissions ratio at the polar edge of the auroral bulge is 0.06 and its average value inside the bright arc is 0.102. The emissions behaviour is the same during the second intense substorm. In the bright green arc the $I_{6300Å}/I_{5577Å}$ ratio reaches a minimum of 0.033. The average value of the ratio inside the arc is 0.092. The average $I_{6300Å}/I_{5577Å}$ ratio during the substorm expansion up to 22:40 is 0.17.

Discussion

The variations of the red 6300 Å and green 5577 Å emissions and their ratio $I_{6300Å}/I_{5577Å}$ are studied during substorms: before the substorm beginning, at the polar edge of the auroral bulge and inside the auroral bulge, during a high speed recurrent stream. Two intensive substorms and a weak one are examined, occurred in the evening period (18:00 UT – 24:00 UT) on 3 November 2005.

As the all-sky imager is not calibrated, the obtained emissions intensities and ratios are relative, but comparing the results, obtained in the different cases: before the substorm beginning, polar edge of auroral bulge, auroral bulge, we can retrieve an absolute value. The highest $I_{6300Å}/I_{5577Å}$ ratio is obtained during the periods before the substorm beginning (0.42 and 0.407). This means, that during these periods, the electron spectrum is softer. Most energetic precipitating electrons are found over the bright arcs at the polar edge of the auroral bulge (average ratios 0.078, 0.102, 0.092). This ratio is about 4 times lower than the one before the substorm beginning. Inside the auroral bulge, the obtained emissions ratio is 0.2 and 0.17. These values are about 2 times higher than the ones at the edge of the auroral bulge and testify for a softer electron energy spectrum.

Conclusions

The auroral emissions and the absorption at 38.2 MHz during 2 intensive substorms and a weak one occurred when a recurrent stream passed by the Earth are examined.

The correlation between the emissions and the absorption is studied. Good correlation (R>0.7) is obtained between 5577 Å intensity and 6300 Å one during all examined periods regardless of the conditions.

The $I_{6300Å}/I_{5577Å}$ ratios before the substorm beginning, at the polar edge of the auroral bulge and inside the auroral bulge are found to be related as 4:1:2.

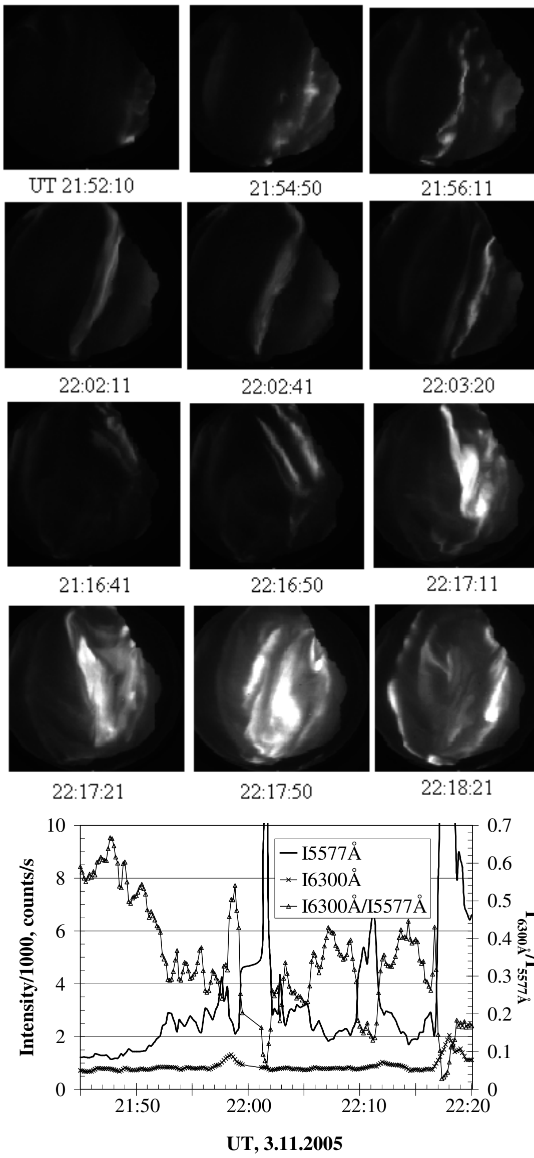

Fig.5. Second substorm beginning.
Upper frame: images of 5577 Å emission from ASI. The two upper rows present the development of the weak substorm seen from Andenes. It hardly reached the station. The polar edge of the auroral bulge was over zenith in 22:02:11 UT (the left image of the second row). The second two rows of images illustrate the development of the second intense substorm. The bottom left image presents the substorm beginning at Andenes. After this time the station stayed constantly inside the auroral bulge during the substorm development.
Bottom frame: course of the 5577 Å and 6300 Å emissions intensities and the ratio $I_{6300Å}/I_{5577Å}$ during the substorm beginning.

Acknowledgments:

The study is part of a joint Russian -Bulgarian project "The influence of solar activity and solar wind streams on the magnetospheric disturbances, particle precipitations and auroral emissions" of PGI RAS and STIL-BAS under the program for fundamental space research between RAS and BAS.

Data access has been provided under the Project "ALOMAR eARI" (RITA-CT-2003-506208), Andenes, Norway. This Project received research funding from the European Community's 6th Framework Program. We are thankful for the data originated from (IRIS), operated by the Department of Communications Systems at Lancaster University (UK) in collaboration with the Sodankylä Geophysical Observatory, and funded by the Particle Physics and Astronomy Research Council (PPARC).

The authors are grateful to Truls Lynne Hansen of the Tromsø Geophysical Observatory, University of Tromsø, Norway, for providing magnetometer data.

We thank to J.King and N.Papitashvilli at Perot Sys., NASA GSFC and CDAWeb for providing ACE, WIND and magnetometer set data. The DMSP particle detectors were designed by Dave Hardy of AFRL, and data obtained from JHU/APL.

REFERENCES

[1] B. Hultqvist. "On the importance of auroral processes in the Universe", *Journal of Atmospheric and Solar-Terrestrial Physics,* 2008, doi:10.1016/j.jastp.2008.03.023

[2] M. Neugebauer. "Measurements of the properties of solar wind plasma relevant to study of its coronal sources", *Space Sci. Rev,.* vol.33, 1982, p.127

[3] A.S.Krieger, A.F.Timothy, E.C.Roelof. "A coronal hole and its identification as a source of a high velocity solar wind stream", S*ol. Phys*., vol.23, 1973, pp.123-128

[4] L.F.Burlaga, L.Klein, Jr.Sheeley, D.J.Michels, R.A.Howard, M.J.Koomen, R.Schwenn, H.Rosenbauer. "A magnetic cloud and a coronal mass ejection", *Geophys. Res. Lett.,* vol.9, 1982, pp.1317-1320

[5] Y.-M.Wang, N.R.Sheeley, Jr. "Global evolution of interplanetary sector structure, coronal holes, and solar wind streams during 1976-1993: Stackplot displays based on solar magnetic observations", *J. Geophys. Res.*, vol.99, 1994, pp.6597-6608

[6] D.F.Webb, R.A. Howard. "The solar cycle variation of coronal mass ejections and the solar wind mass flux", *J. Geophys. Res.*, vol.99, 1994, pp.4201-4220

[7] T.A.Hviuzova, S.V.Leontiev. "Spectral characteristics of the auroral emissions connected with high speed streams of the solar wind from coronal holes", *Geomagn. And Aeronomy,* vol.37, 4, 1997, pp.155-159 (in Russian)

[8] T.A.Hviusova, S.V.Leontiev. "Spectral characteristics of the auroral emissions connected to non-stationary solar wind flows", *Geomagn. And Aeronomy,* vol.41, 3, 2001, pp.337-341 (in Russian)

[9] Georgieva K., Kirov B., Obridko V., Shelting B., Atanasov D., Tonev P., Guineva V., Data Base of Geoeffective Solar Wind Structures, Geomagnetic Indices, and Atmospheric Dynamics Parameters, Proceedings of the International Conference "Fundamental Space Research. Recent development in Geoecology Monitoring of the Black Sea Area and their Prospects", Sunny Beach, Bulgaria, September 22-27, 2008, P.175-179.