

DISTURBANCES OF NOVEMBER 19, 1998 HEATING EXPERIMENT OBSERVED BY SCANDINAVIAN GROUND-BASED COMPLEX

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Abstract. The EISCAT-Heating experiment on November 19, 1998 was carried out from 20.30 UT to 24.00 UT. The HF pump wave of 5.423 MHz in extraordinary mode (x-mode) had Effective Radiated Power (ERP) 900 MW. The heater was switched ON and OFF with 5 minutes repetition. Substorm intensifications are observed over Scandinavia before and during the experiment by UV imager on board POLAR spacecraft and ground based devices. We do not expect the ionosphere heating to be able to interfere into natural substorm development for this event. However after 22.00 UT the substorm active region is moved a few hundred kilometers to the north from Tromsø latitude and then far to the west. Approximately at the same time a regular structure is formed in the auroral absorption being periodic in space; the structure disappears 20 minutes after the ionosphere heating had stopped finished. The enhanced absorption regions are separated by the 50 km distance and stretched in south-east direction. We suggest that two modes of the initial disturbance development: continuous and bouncing ones exist at the same time. The intensity of the structure seems not to be phased by the heater ON/OFF. The ionospheric currents deduced from IMAGE magnetometer network data show a clear decrease of the westward current density during this time to the south of Tromsø latitude. The regions of the increased conductivity depress locally the magnetospheric convection and their distribution can be quite spatially stable. The clear connection of the enhanced absorption with the convection is discussed in terms of magnetosphere-ionosphere interaction enlarging the heating induced effects.

Introduction

The EISCAT Heating Facility is used for a long time for the ionosphere modification and different aspects of the experiments are extensively discussed in review papers [1, 2, 3]. Recently new results have been obtained demonstrating that the ionosphere modification can lead to disturbances in magnetosphere-ionosphere system [4, 5, 6, 7, 8]. Initial disturbances could, in principle, involve into their development the energy accumulated in the magnetosphere due to the coupling between the ionosphere and the magnetosphere and be strongly variable in their intensity, spatial and temporal scales. There are a lot of geophysical phenomena the generation of which is explained in terms of magnetosphere-ionosphere interaction. The search of similar phenomena originated from artificially modified ionosphere is a very interesting and complicated problem. The interest can be explained by the accounted for a possibility, firstly, to check our understanding of the magnetospheric processes, secondly, to increase the efficiency of active experiments. Difficulties are related with an alternative requirement to the natural disturbances. On the one hand the level of background activity should be significant enough to provide a process with positive feedback. On the other hand intensive natural phenomena control the disturbance development and mask the modification effect.

Most of high-latitude phenomena have a complicated spatial and temporal structure and their development should be well documented during the experiments. The natural disturbances sometimes look like small-scale and short-living ones from ground based observations but in reality they are a part of more extended ones which started a long time before. In this case the development of the localized disturbances is controlled by the global processes and the possibility to interfere into their evolution is insignificant. It should be recognized that monitoring of the general situation in the whole magnetosphere-ionosphere system is very desirable.

The modification with "colored" signals is usually used in the active experiments, the observation in natural disturbances of the spectral lines corresponding to modulation frequencies of the heating wave proves the artificial nature of the emissions at these frequencies [5, 6]. However this method could be ineffective for processes involving into themselves the magnetosphere-ionosphere coupling because of its strong influence on the resulting disturbances, their localization and duration. These disturbances are not either necessarily synchronized with the switching ON and OFF of the pump wave because the characteristic times of the positive feedback activation and fading may be long enough. Very strong arguments should be given in this case for evidence of their artificial nature.

The present paper is an example of such study and we try to present arguments for the significant role of the ionosphere heating and magnetosphere-ionosphere interaction in the development of the structured auroral absorption near Tromsø on November 19, 1998, but there are still some doubts left. The heating experiment with long pulses should be very effective for ionospheric conductivity modification in the E-region for the night time winter conditions [9]. The magnetospheric convection is manifested in the polar ionosphere as auroral electrojets deduced from ground based data of IMAGE magnetometer network. The development of the global activity is controlled by POLAR UV images in the northern hemisphere. The IRIS imaging riometer provides distribution of

auroral absorption showing a regular structure, periodic in space, and stable during more than 2 hours. The mechanism of localized precipitations, being a possible reason of this, is discussed in terms of an initial heating induced disturbance and its evolution including the magnetosphere-ionosphere interaction.

Experiment setup and data analysis

The EISCAT-heating experiment of November 19, 1998, time interval 20.30–24.00 UT, originally was aimed at the disturbed electron temperature measurements in the D-region [10]. The pump wave frequency of 5.423 MHz in x-mode was switched on and off every 5 minutes. The effective radiated power (ERP) was 900 MW. We expect strong disturbances of the ionospheric conductivity for nighttime winter conditions under action of long lasting heating pulses [9]. In this case the conductivity modification takes place in the E-region of the ionosphere due to the enhancement of the electron density here. The local conductivity disturbances under the convection conditions produce in turn the perturbation of the electric field, ionospheric and field-aligned currents. We consider them as initial disturbance in the magnetosphere-ionosphere system that may be able to activate positive feedback.

During the experiment the POLAR spacecraft crossed the northern polar cap and UV imager gave a picture of global substorm development. UVI displays (not shown here) with an approximate 11 minutes time resolution have been used for the interval of 19.03:50–23.17:45 UT. The ground-based aurora data of all-sky cameras of the Finnish Meteorological Institute have also been requested but the weather conditions were bad. Only two local substorm

intensifications around 20.00 UT and 20.30 UT can be recognized for the interval of the experiment. The data of POLAR UVI were not available after 23.18 UT.

The analysis of the consequent displays of the POLAR UVI with an approximate 11 minutes time resolution for interval of 19.03:50–23.17:45 UT shows a few substorm intensifications. The first break-up initiated far eastward from Scandinavia at 19.48 UT forms a clear WTS-like structure that is seen in the next frame (19.59 UT) over the northernmost part of Europe. A very similar development of the second intensification which started at 20.21 UT differs from the first one only in longitudinal and latitudinal dimension of the UV source region. After that the active region moves to the north from northern coast of Europe. Displays after 22.00 UT show a significant northern-west propagation of the substorm. The POLAR UVI data indicate that the heating experiment was carried out during a

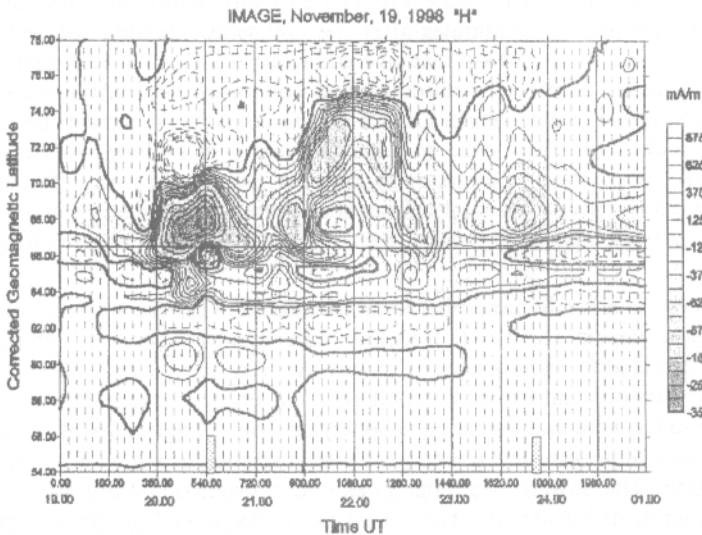


Fig.1. Isocontours of the east-west component of the ionospheric currents deduced from the IMAGE magnetometer data. The westward currents are shown by the solid lines, the eastward ones – by the dashed ones.

“classic” substorm and break-up manifestations should be sometimes observed by ground-based instruments arranged near the heating site. The IMAGE magnetometer network operates in Scandinavia and provides us with the information on disturbed currents in the region of interest. Stations being arranged almost along the meridian are suitable instruments for deducing intensity of the east-west component of the ionospheric current [11]. The variations of the current density and their location allow us to make conclusions about the disturbances as natural and man-made. November 19, 1998 may be characterized as a moderately disturbed day. The magnetic variations in H-component in Tromsø had 150 nT at their maximum. Near the local midnight a few localized substorm intensifications can be marked in magnetic records of the IMAGE magnetometer networks. Fig. 1 shows isocontours of the east-west component of the ionospheric current density deduced from the magnetic variation data with a 10-seconds time resolution for the extended time interval 19.00–01.00 UT. The method of the current calculations and its limitations are described in detail in [11].

The development of the westward electrojet started after 19.30 UT, and soon after one could see the first signatures of substorm intensification. In the contour plot they look like a fast poleward expansion of the ionospheric currents around 20.00 UT. Then the westward electrojet was quite stable until 20.25 UT, there could be mentioned slow southward drift of the currents. Just before the start of the ionosphere heating the next break-up over Northern Scandinavia occurs. During this intensification the behavior of the ionospheric currents could be recognized as a typical one for the break-up event [11]. The latitude range occupied an the electrojet expands to the north and south, the cells of the eastward current are connected with WTS associated field-aligned currents. Bright auroras for these break-ups are seen in all-sky displays of FMI through dense clouds. After 20.40 UT the active region shifts to the pole, but the current development shows clear signatures of substorms. An interesting feature of

southern electrojet border was noted by Kotikov et al. [8] for different events of the ionosphere modification. It is fixed near the latitude of the heating. In the present experiment only around 22.30 UT for a short westward currents are shifted insignificantly period to the south from Tromsø.

The imaging riometer (IRIS) at Kilpisjärvi operates at 38.2 MHz and produces 49 narrow beams. It gives the absorption of radio noise in the square of 240×240 km and allows us to deduce electron density distribution in the ionosphere. The distribution of the auroral absorption reconstructed from IRIS data is presented on fig.2. the images covered the time interval of 20.00 – 01.00 UT with a 5-minutes integration. Each plot shows an absorption projection at 90 km altitude for the square of 240×240 km centered at Kilpisjärvi. The absorption intensity is color coded, the scale is shown in the left bottom corner. For the analysis we also used data with a 1-minute integration time, but differences were not significant. Two substorm intensifications earlier registered in the POLAR's and magnetic data are also seen in the absorption distribution. Being rather localized in the longitudinal extent they started at 19.55 UT and 20.25 UT. The region of enhanced absorption after 21.31 UT moved northward and left the field of view of IRIS. After that a weak absorption is seen at the riometer images until 21.40 UT, when a clear structure is forming. The first patch of the enhanced absorption is stretched in south-east direction. Its intensity is inhomogeneous and the movement of "brightness" takes place inside this patch. The maximum of the intensity appears at the south-west edge and its shifts along this structure to the opposite edge. However this structure exists in the same area until 24.00 UT when the heater was OFF. Another patch is located at 50 km distance to the east and slightly to the north from north-west edge of the first enhanced absorption region. This patch is highly localized and does not show any stretching until the end of the heating when the first one decays. Signatures of the third patch are seen in the north-east part of the frame after 23.00 UT. We believe that there are two modes of the disturbance propagation: the continuous stretching of the absorption patch and the bouncing forming the new one. It should be noted that structure formation occurs after the displacement of the break-up region further from the heater. There is no clear correlation of the absorption intensity with the heating ON/OFF, but the structure exists in the course of the heating. After the end of the experiment the enhanced absorption decays for an hour but a more or less intensive structure is seen during 20 minutes. We suggest that observation of the small-scale regions of the enhanced absorption accounts for the electron precipitation initiated by the conductivity modification via heating and increased by positive feedback in the magnetosphere-ionosphere system. The initial heating induced disturbance is strongly changed by magnetospheric convection and is enlarged in space. The formed structure due to the self-consistent generation exists much longer than the repetition period of the pump wave, that is why the absorption intensity is not phased by the ON/OFF cycle of the powerful transmitter and disappears 20 minutes after the heater OFF.

Discussion

The heating experiment on November 19, 1998 seems to be valuable for a study of magnetosphere-ionosphere coupling. The first reason for this is the heating regime. Long lasting heating pulses rather effectively modify the ionospheric conductivity under condition of low electron density in D-region. This condition is satisfied for the winter nighttime ionosphere. One may expect a growth of the conductivity in the heated area by the factor of 1.5 [9]. The other reason is an excellent observational complex in Northern Scandinavia. The global geophysical activity being close to optimal one during this event is the third and main factor for the success of such study. We consider that a possibility to interfere into magnetosphere-ionosphere coupling exists either before the first substorm onset or after the end of the break-ups in the vicinity of the heater. In our case the substorm active region moves to the pole and then to the west before the observation of precipitation signatures. At the same time magnetic disturbances show a certain level of the magnetospheric convection of field tubes rising from the modified region. The regular structure of the auroral absorption has a clear anisotropy. Two dominant directions of the disturbance propagation do not change significantly for the entire experiment time. The south-east continuous propagation may be explained in the frame of Ionospheric Alfvén Resonator theory [12, 13]. Recently it has been applied to the ionosphere modification experiment [14]. It has been shown that resonance of Alfvén mode in the drift condition leads to formation of a periodic structure of Alfvén vortices with horizontal scale of 1 km. The amplitude of Alfvén vortex has an interesting feature – the hysteresis appears due to additional ionization produced by accelerated electrons.

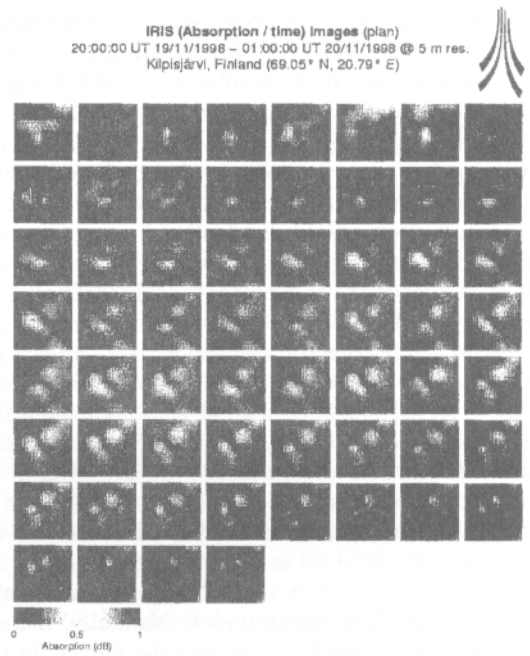


Fig.2. Distribution of the radio noise absorption deduced from the IRIS data.

The vortex formation can progress as an instability when the convection velocity exceeds a threshold value. The Alfvén vortex instability (AVI) may originate outside the heated area but near its boundary where the drift velocity is locally increased. The conditions for AVI triggering in the heating experiments are satisfied in two cases: the region of the enhanced conductivity is stretched along background electric field or the initial disturbance is sufficiently large [14]. We believe that the second condition was achieved on November 19, 1998 experiment and Alfvén vortices were formed near the southern boundary of modified region. The accelerated electrons produce here an additional ionization enlarging the enhanced conductivity region approximately in the direction of the background electric field. Evidently, the same movement of the locally enhanced electric field should be observed leading to the appearance of new Alfvén vortices and consequently to the disturbances propagation. It should be noted that convection is depressed inside the region of the enhanced conductivity and it may be a possible reason of the spatially stable absorption structure. Characteristic time of AV decay after decreasing of the local electric field has not been studied but in contrast to the nonlinear growth this process should be linear and much slower. We think that the bouncing mode of the disturbance propagation is also related with the convection. According to Sato and Holzer [15, 16] the field-aligned currents generated by the enhanced conductivity region are reflected from the opposite ionosphere and due to the drift they produce new regions equally separated in space where in appropriate conditions electron precipitations occur forming visible aurora. Although their basic assumption about the disturbance infinity in one direction is not valid in our case we suggest that general picture is very similar. The initial disturbance produces field-aligned currents of significant density propagating forth and back. During the propagation the field tubes drift and the reflected currents come to the ionosphere shifted in the direction of the convection. In November 19, 1998 experiment we observed two regions of enhanced absorption almost to the east from the initial disturbance region. Naturally, our suggestions are only qualitative and very preliminary. A more extensive study is needed including the numerical modeling of most significant points used for the interpretation. However, we believe that an interesting case of the activation of the magnetosphere-ionosphere interaction via the ionosphere electron heating has been found in November 19, 1998 experiment.

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