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DISTURBANCES OF AURORAL ELECTROJETS INDUCED BY IONOSPHERE HF HEATING

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Abstract. Disturbances of the auroral electrojets produced by the HF ionosphere heating are studied. The intensity and location of the ionosphere currents are deduced from data of the IMAGE magnetometer chain with 10 seconds time resolution. In the midnight sector the stabilisation of the equatorward border of the westward electrojet at the latitude of the heater is observed. In the evening sector heating in the region of the eastward electrojet leads to an increase of its current density with concurrent decrease of intensity of the westward electrojet occupying the region to the pole from the eastward one. Close temporal and spatial relationship of substorm intensifications to the region of ionosphere modification allows one to make a suggestion about the influence of ionosphere parameters (conductivity, polarisation electric fields) on the development of substorm. These results are evidence of the active role of E-region of the ionosphere in the generation of small-scale structure of ionospheric and field-aligned currents and leaves ground for disputing the ionospheric origin of multi-layer current structure observed during the substorm. The applicability of the calculations suggested infinite currents in east-west direction for cases of local current disturbances is also discussed.

A numerical modelling of the disturbances is presented. The modelling includes calculations of the disturbed electric field potential in horizontal inhomogeneous ionosphere, ionospheric and field-aligned currents, and magnetic disturbances on the ground. A case of voltage generator is considered. For this case the electric field in the ionosphere is mapped from the magnetosphere. Inhomogeneous background conductivity and electric field distribution has been constructed. The magnitude of the magnetic disturbances on the ground related with local area of enhanced conductivity makes about a few nT. The disturbances directly related with local heated area in the ionosphere can not explain experimental findings concerning the influence of the ionosphere modification on the substorm current system. A more sophisticated mechanism of the magnetosphere-ionosphere coupling including some positive feedback is needed for this.

Introduction

Recently, there has been shown the influence of the ionospheric HF heating on the substorm current systems [1]. The disturbances of the auroral electrojets may be related with the modification of ionospheric conductivity in the local area occurred during the heating. In that paper the behavior of a westward electrojet under the action of a long pulse of the pump wave has been studied. The present paper extends the study to the case of the eastward electrojet modification, we have also considered the modulated heating of the ionosphere.

To deduce the ionospheric current density from ground based magnetic measurements an algorithm proposed by Kotikov et al. is used [2]. It includes the separation of the disturbances into the variations from external (ionospheric currents) and internal (induction ones) sources, the calculation of west-east component current density based separately on H- and Z-component data of meridional magnetometer network. The detailed description of the method, its resolution and limitation can be found in [2]. The method allows one to calculate the electrojet fine structure and to infer the current system dynamics during a substorm development. We use IMAGE magnetometer network data with ten seconds time resolution. The meridional profile of stations is placed at around 200 km distance from the Tromsö heating facility. A few experiments during the Heating Campaigns in 1993 and 1998 have been analyzed. Peculiarities of auroral electrojet dynamics for different geophysical situations and for the cases of modulated and long pulse heating are derived. The applicability of the method proposed in [2] for longitudinally localized disturbances is verified. A small-scale current loop has been reconstructed with good spatial accuracy. The method gives the resolution of the order of 60 km.

It is generally believed that an ionosphere electron heating can produce magnetic disturbances on the basis of a few nT magnitude [3, 4, 5]. Stubbe and Kopka [6] reported about an artificial magnetic pulsation generation the amplitude of which had been 10 nT. The generation of disturbances during ionospheric conductivity enhancement has been studied in [3, 7, 8]. Maltsev et al. [7] have found an analytical solution for some kinds of conductivity inhomogeneities, for more general cases a numerical modelling should be used. The reflection of low frequency hydromagnetic waves by the non-uniform ionosphere has been studied by Glaßmeier [9]. A detailed description of the theory and presented results of the calculation are a good guide in the problem of the disturbance generation in the inhomogeneous ionosphere. Only an insignificant modification of the deduced equations should be done to use them for modelling of the disturbances for the case of the stationary electric field.

The case of voltage generator is conventional and simple estimations could be made for this approach. We try to compare these different events and we choose parameters for modelling which give the same distribution of the background electric field, ionospheric and field-aligned currents. The main aim of the modelling is to calculate magnetic disturbances on the ground related with a small-scale circular area of the enhanced conductivity inside a strong ionospheric current.

Behavior of the deduced ionospheric currents

EISCAT-Heating Campaign in November 1993 was devoted to the generation of the artificial magnetic pulsations [10], also a special experiment on effective generation of magnetic pulsations in the 1 Hz frequency range was carried out on November 19, 1998. During all these events the modulation of the pump wave in the ultra low frequency (ULF) range took place.

On November 15, 1993 the experiment started at 17.15 UT. The modulation frequency increased from 0.1 up to 3 Hz during 45 minutes, this duty cycle was repeated 5 times. The isocontours of the east-west current component are presented in fig.1. The experiment started under very quite conditions. The growth phase of the substorm lasted from 18.10 to 19.17 UT. One can notice an equatorward movement of the eastward electrojet during this time interval. The substorm expansive phase had an interesting specific feature: the significant poleward expansion of the westward electrojet was not accompanied by the same equatorward displacement of the currents moving eastward. The stabilization of the position of the electrojet equatorial border at the latitude of heating was reported by Kotikov et al. [1]. During the next intensification at 20.05 UT this effect is even more pronounced.

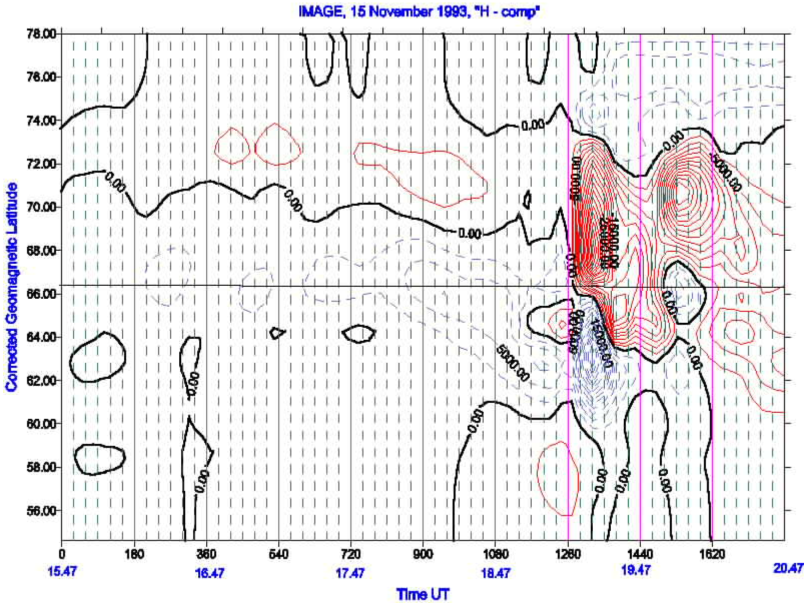

Figure 1. Isocontours of the ionospheric currents for November 15, 1993. The density of the eastward currents is shown with dashed lines, that of the westward ones - with solid lines. The horizontal line stands for the latitude of the heating.

The case of eastward currents heating takes place for November 16, 1993 event (is not displayed). The same modulation scheme as for November 15 is used for the experiment of November 16, 1993. During this event clear variations of the equatorial border position of the eastward electrojet and its intensity with a 45 min period were observed. On November 19, 1998? the modulation frequency changed every 5 minutes reaching 1, 2 and 3 Hz. This 15-min cycle of modulation was repeated 8 times. The current distribution for this event is not displayed either. Exactly at the starting time of the heating the eastward electrojet is focused at the

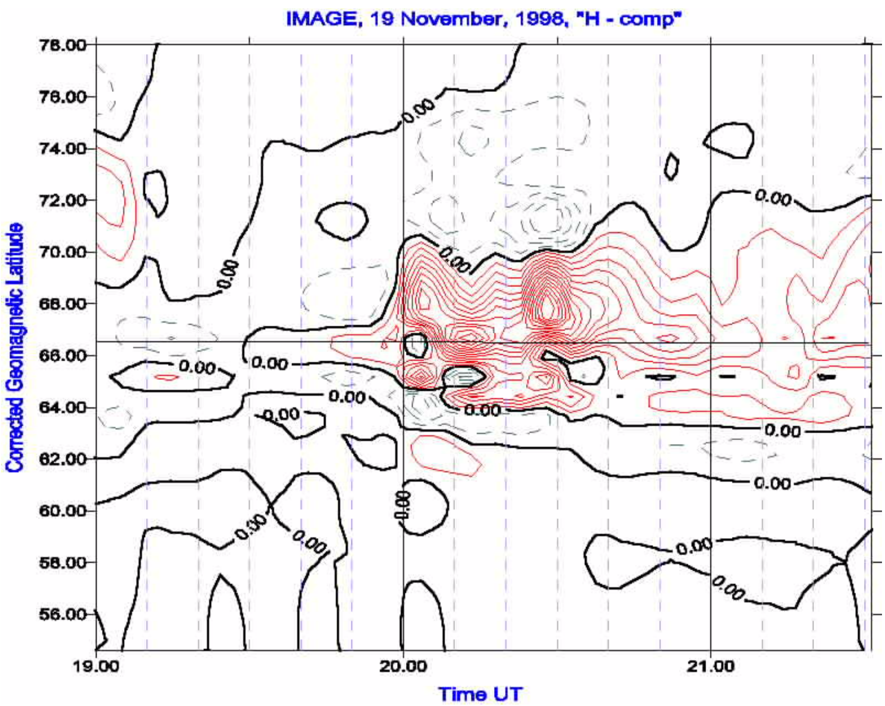

Figure 2. Current density for long pulse heating on November 19, 1998.

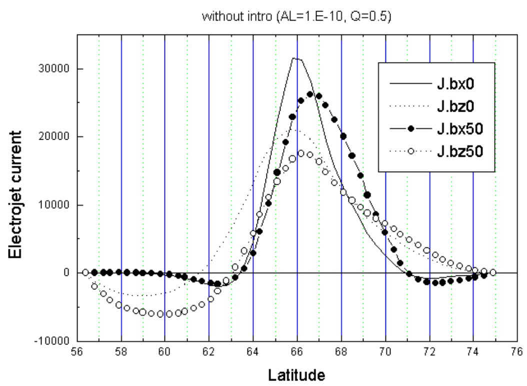

Figure 3. Ionospheric currents deduced from magnetic disturbances: undisturbed ones (J.bx0 and J.bz0) and with the current loop (J.bx50 and J.bz50)

latitude of the heating and its current density is increased.

In contrast to the modulated heating, a long pump wave pulse action produces more significant variation of the conductivity of the ionosphere [5]. This case is shown in the diagram of ionospheric current density for November 5, 1998 (fig. 2) when the heater was ON for 5 minutes and OFF for 5 minutes. This regime was used from 20.30 UT to 24.00 UT, and the heating was taking place in the region of a well-developed westward electrojet. One can observe a new feature in the current behavior: synchronism with the heating stratification of the electrojet. The current density is strongly decreased at the latitude of the heating. Cells of eastward currents are also seen inside the westward electrojet on November 5, 1998 (is not displayed). A similar heating regime as for November 5, 1998 was used during this experiment.

The question arises how to apply the method of current density calculations for the longitudinally localized disturbances? The infinite currents in the east-west direction are assumed in these [2]. For verification of the procedure we have calculated magnetic disturbances on the ground for the current loop of 50 km radius closed by an infinite jet. The latitude of infinite current is suggested to be equal to 66°, the altitude of the currents is assumed to be 100 km. From the calculated magnetic disturbances at the point corresponding to the IMAGE magnetometer chain geometry we had deduced ionospheric current structure and compared it with the current calculated for the case without current loop. The results of the verification are presented in fig. 3. Maximums of ionospheric currents deduced from H- and Z-components of the disturbances for the case with the loop shift to the north although their intensity slightly decreased. This result proved the applicability of the method of the current density calculations for the localized electrojet disturbances such as the ionosphere heating.

Modelling

The main ionospheric parameters included in the model are presented in Fig.4. We consider the polar ionosphere as a plane being homogeneous in east-west direction. The distribution of Pedersen conductivity is shown at the top diagram, the Hall conductivity is everywhere assumed to be 3 times higher than Pedersen one. Another important parameter for the modelling is the wave conductivity of the magnetosphere [7]. Glaßmeier [9] takes the value of wave conductivity to be equal to 0.05 S. This assumption gives a very high reflection coefficient of incident field-aligned currents. Oguti and Hayashi [8] found that the wave conductivity is approximately equal to the Pedersen one. In our modelling we suggest that it was equal to half the value of Pedersen conductivity. A potential drop across the auroral zone is given 60 kV. The distribution of the background electric field intensity calculated for these parameters is shown in the middle diagram. Note that this field has only a north-south component. The calculated profile of the field-aligned currents is presented in the bottom of the Fig.4.

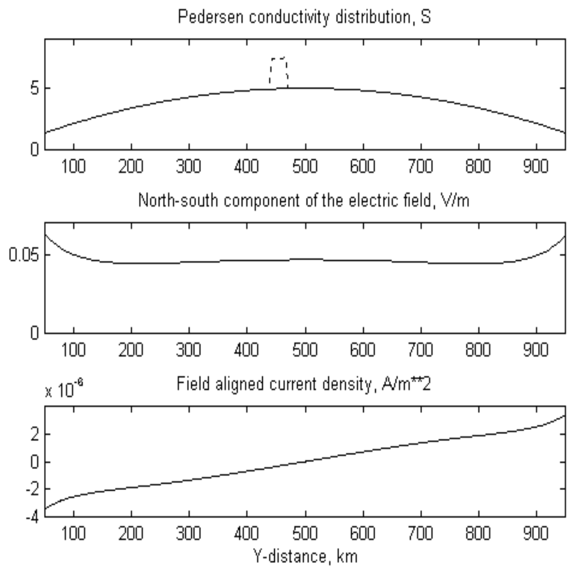

Figure 4. Ionospheric parameters accepted for modelling. The top diagram shows the conductivity distribution, in the middle panel electric field is displayed, the profile of the field-aligned currents is presented in the bottom.

The center of circle of enhanced conductivity with a 30 km diameter is placed 445 km from the southern boundary. Conductivities in this area are assumed to be increased by the factor of 1.5 from the background values. The calculation of the conductivity disturbances due to ionosphere heating [5] gives these values for the conductivity modification for the long pulse of the heating wave action. The disturbed conductivity profile is shown by the dashed line in the upper plot. The ionospheric electric field was calculated from the equation for potential for the disturbed conductivity of the ionosphere. The calculation was made on the grid 500×500 with 2 km distance between nodes. Also we calculated a disturbed ionospheric field, currents and magnetic disturbances on the

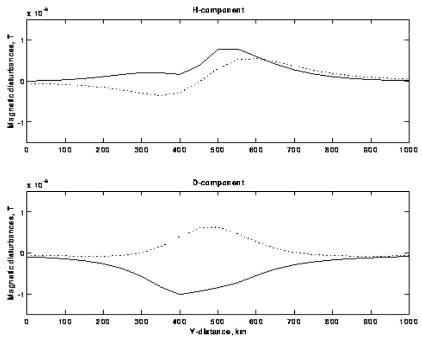

Figure 5. Calculated magnetic disturbances related with the local area of modified conductivity.

ground. Field-aligned currents are obtained as divergence of the ionospheric ones.

Fig.5 shows meridional profiles of the magnetic disturbances on the ground related with local area of enhanced conductivity.. At the top H-component disturbances are shown, D-component is plotted in the bottom. We have calculated two profiles of the disturbances: in the vicinity of the modified region (solid lines) and at the 200 km distance (dashed lines). The amplitude of the magnetic disturbances on the ground is about 1 nT near the disturbed region and decay fast as the distance grows longer. It is not enough to produce a noticeable variation of electrojets. To explain experimental results of the influence of the heating on auroral zone current system dynamics it is necessary to include in the model the magnetosphere-ionosphere interaction.

Summary

Experimental study shows that the heating is able to modify the current system in different sectors of auroral zone and at different substorm phases. The most pronounced peculiarity of this modification is the stabilization of the electrojet boarder position at the latitude of the heating. The heating in the region of the westward electrojet may produce a clear current of the opposite sign in a narrow latitude range. This current looks like a formation of two westward jets separated by the heated area. The current system modification during the heating may be explained by the disturbances of the existing ionospheric currents via the conductivity change in the heated region. We believe that this explanation is not complete. Only including the magnetosphere-ionosphere interaction with a positive feedback in the modified local area conductivity could provide a noticeable substorm current system. We think that the search of this feedback is very important for the understanding of the substorm generation. The experimental finding of the heating induced effects in the substorm current system gives a strong argument to the thesis about the active role of the ionosphere in the substorm development.

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