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STRUCTURAL FEATURES OF AURORAL PRECIPITATIONS AND TOPOLOGY OF HIGH LATITUDE CURRENT SYSTEMS

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Abstract. Results of simultaneous Meteor-3M and auroral imager observations are used for study of features of auroral precipitations. It is taken into account that the threshold of auroral imagers does not exceed the brightening, which can be connected with plasma sheet electron precipitation without field-aligned acceleration. Accelerated electron fluxes are the sources of upward field-aligned currents. Values of such currents are estimated using Meteor-3M electron flux observations. Obtained values give the possibility to estimate transverse magnetospheric current supported by observed field-aligned currents.

1. Introduction

The problem of the determination of field-aligned current values continues to be one of the actual problems of the physics of the magnetosphere. Decades ago, direct measurements of magnetic field disturbances transverse to nondisturbed field lines gave the possibility to restore global picture of field-aligned currents (see Iijima and Potemra [1976a,b]). Numerous later works, including Iridium multi satellite observations, clarified this picture (see Anderson et al. [2000], Waters et al. [2001]). Nevertheless, the accuracy of such determinations is limited by the resolution of magnetometers installed on nonmagnetized satellites and by the necessity to use the one dimensional approximation for observed current sheets. As a consequence, real difficulties appear when the scale of field-aligned current structure in north-south direction is comparable with the scale of the structure in the east-west direction and multi layer current structures are observed (see Lukianova et al, 2001, Danov et al., 2006). The distribution of field-aligned currents can also be obtained using data of ground-based magnetic observations (see Mishin et al. [1991], Levitin et al. [1992], ets.). Limitations of the later technique are connected to comparatively large distances between ground based stations. At the same time, numerous results of particle flux observations on auroral satellites can also be used for the obtaining of values of field-aligned currents at least in the region of upward current. Such suggestion was used by Marklund et al. [1987], Cumnock and Blomberg [2004]) for the obtaining of global structure of magnetospheric convection using data of auroral imagers and particle satellite observations (KTH model).

In this paper we summarize arguments giving the possibility to use data of auroral particle fluxes for obtaining values of upward field-aligned currents. We discuss the acceleration of electrons by field-aligned potential drops and show that auroral electron observations in inverted V regions give comparatively accurate information about the value of upward field-aligned currents. We also use data of Russian satellite Meteor-3M to obtain the distribution of upward field-aligned currents along satellite trajectory and data of auroral imager for the evaluation of global values of upward currents.

2. Acceleration of electrons and observations of aurora

It is possible to show (see Antonova [2007], Kornilov et al. [2008] and references therein) that visible picture of polar aurora gives the distribution of upward field-aligned currents. Really, measured plasma sheet electron distribution functions in the first approximation can be fitted with comparatively high accuracy by isotropic Maxwellian distribution. Maximal energy flux of precipitating electrons in the case of absence of field-aligned potential drop is equal to

$$\varepsilon^* = n_0 T_e^{3/2} / (\pi m_e)^{1/2}, \qquad (1)$$

where n_0 is the electron density near the equatorial plane, T_e is the electron temperature, m_e is the electron mass. For n_0=0.5-1 cm^{-3} and T_e=0.5 keV, ε^*~0.3-0.6 erg/cm^{2}s. Such energy flux is close to a threshold of measurements of the auroral imagers of Polar and IMAGE satellites (~0.5 erg/cm^{2}c). This feature was first stressed by Vorobjev and Yagodkina [2008].Visually observed aurora of the I class of brightness requires 0.6 erg/cm^{2}c (Akasofu and

Chapman [1972]). The existence of field aligned potential drop leads to the increase of energy flux. The energy flux can be determined in accordance with the relation (see Antonova [1981])

$$\varepsilon^{ion} / \varepsilon^{*} = \frac{B_i}{B_a}\left[1 + \frac{U}{2T_e}\right]\left\{1 - \exp\left(\frac{-U}{T_e\left(B_i / B_a\right) - 1}\right)\right\} + + \exp\left(\frac{-U}{T_e\left(B_i / B_a\right) - 1}\right) \qquad (2)$$

where U is the energy obtained by electron in the field-aligned potential drop, B_i and B_a are values of magnetic field at the ionospheric altitudes and in the region of acceleration, respectively. The relation (2) has the form

$$\varepsilon^{ion} / \varepsilon^{*} = 0.5[1 + \left(1 + U / T_e\right)^2] \qquad (3)$$

if $\frac{U}{T_e\left(B_i / B_a - 1\right)} << 1$. Relations (2), (3) show that ~2-10 keV potential drop accelerating magnetospheric electrons leads to more than an order of magnitude increase of the energy flux value and to the appearance of II, III class of aurora. Accelerated magnetospheric electrons with energies 1-10 keV cannot create polar aurora of IV class. It is probably produced by accelerated till 1-2 keV dense (with density ~10^2-10^3 cm^{-3}) electrons of inospheric origin. Pitch-angle distribution of accelerated magnetospheric electrons is, as a rule, near to isotropic (shell type pitch-angle distribution) as field-aligned potential drops are situated comparatively far from the ionosphere (at heights larger than 5000 km) and electron temperature before acceleration is comparatively high. Accelerated electrons of ionospheric origin are very cold. Their acceleration leads to the formation of field-aligned particle beams.

Accelerated electrons produce upward field-aligned current. Field-aligned potential drop reflects electrons moving from the ionosphere. The contribution of ion current is, as a rule, much smaller than the contribution of electron current. Therefore the region in which quasistationary downward acceleration of electrons is observed is the region of upward field-aligned current.

Medium scale upward field-aligned currents are concentrated in inverted V structures. Magnetospheric electrons are accelerated in such structures by field-aligned potential drops. It is possible to select multiple inverted V structures using data of auroral satellites even in the case of comparatively low resolution. Extremely large electron fluxes are concentrated in thin auroral bright arcs. Such fluxes can be measured only in the cases of comparatively large satellite resolution or in the cases of rather oblique structure crossings. The contribution of thin bands of upward current connected to bright auroral forms into global distribution of field-aligned currents is not clear till now. However thin band of downward current with practically the same current density is observed parallel to upward current (see, for example, figure 3 in the paper Dubyagin et al. [2003]). Such feature gives the possibility to neglect in the first approximation the contribution of these thin current sheets in the integral field-aligned currents.

Relations (1)-(3) show that selecting inverted V structures as the regions where electron spectra have specific maxima it is possible to estimate values of upward field-aligned currents. It is necessary to take into account that particles with energies ~100 eV in the inverted V structures are secondary particles, which appear due to the scattering of primary particles and degradation of primary particle flux. Such particles are trapped between the magnetic and electrostatic barrier and does not transport upward field-aligned current.

3. Meteor-3M satellite observations

The satellite Meteor-3M was lunched December 10, 2002 to the heliosynchronous orbit with the altitude 1018 km and the inclination 99.63° by the rocket "Zenit" from the Baikonur cosmodrome. Measurements of auroral particle fluxes are made using the MSGI-5EI spectrometer (see Marjin et al. [2004]). The instrument includes the following sub-systems: high sensitive spectrometric module for low energy ion and proton measurements; high sensitive spectrometric module of low energy electron measurements; low sensitive spectrometric module for low energy electron measurements, and module for the measurements of integral flux of charged particles with the energies > 40 keV. The detection of low energy particles, energy-charge separation is realized by two kinds of spectrometric modules representing the cylindrical electrostatic analyzers, secondary electron multiplies of the type VEU-6 (low sensitive module) or VEU-7 (high sensitive module), charge-sensitive amplifier and the device for the formation of normalized pulses. The spectrometric modules measure differential energy spectra of low energy ions (protons) and electrons in the energy range from 0.1 to 20 keV. Dynamical range of the measurements of the ion channel is 10^3–10^8 particles/(cm2 · s · ster · keV). Dynamical range of the measurements of low energy electrons for the spectrometer MSGI-5EI is 10^3–$2 \cdot 10^9$ particles/(cm^2 · s · ster ·keV). Measurements of energy spectra of electrons and ions (protons) have two modes, controlled by external commands. The fast one is used for the study of space-time variations during the periods of geomagnetic disturbances. The time of measurements of energy spectra is 2 s, the number of energy channels is equal to 10. The second mode (the slow one) has the time of measurements of energy spectra of 10 s, but the number of energy channels is substantially higher and equal to 50. Batten gas discharge detectors realize the measurements of charged particles of medium energy. Dynamical range of the integral channel constitute 1–10^3 pulses per second. Measurements are realized in monitor regime independently on the regime of the work of spectrometer. The data base of the satellite Meteor-3M No 1 contains the values of particle fluxes with energy 0.1–10 keV and particle spectra.

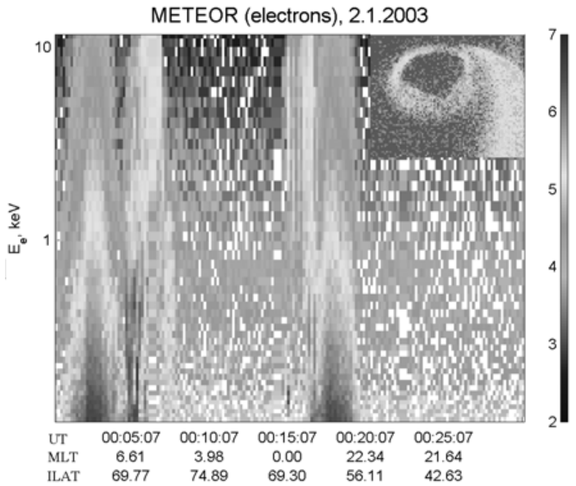

Figure 1. Results of observations of variations of electron fluxes by Meteor-3M satellite and position of auroral oval by IMAGE satellite for the event 2 January 2003.

Fig. 1 shows an example of auroral oval crossing. Satellite crossed the auroral oval and polar cap January 2, 2003 from 00:05 till 00:16 UT. Multiple inverted V structures are observed in the evening and morning parts of the oval. Right upper cone of the figure shows the auroral oval position obtained by IMAGE satellite (http://cdaweb.gsfc.nasa.gov/) for discussed event.

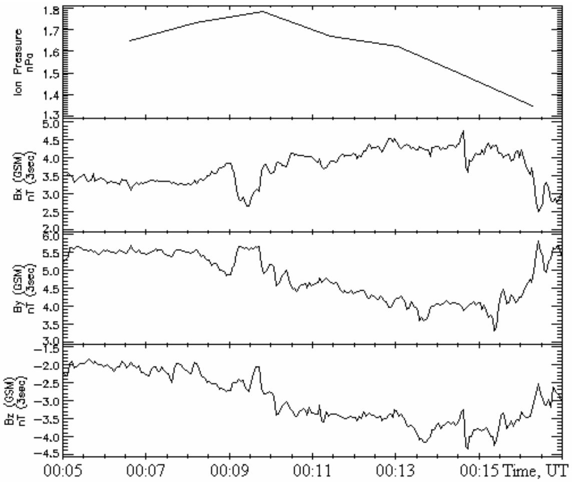

Figure 2. Parameters of the solar wind from the WIND satellite data base (http://cdaweb.gsfc.nasa.gov/)

The situation corresponds to comparatively quite conditions with geomagnetic parameters AE=77 nT, AL=-50 nT, Dst=-10 nT. Solar wind parameters (with corresponding time delay) are shown on Fig. 2. Solar wind dynamic pressure changes from 1.35 till 1.78 nPa, B_z IMF varies from -1.8 till -4 .2 nT, By varies from 3.4 till 5.8 nT.

Fig.3 shows the results of upward field-aligned current calculations. It was suggested that the main part of upward field-aligned current is concentrated in inverted V structures. Calculated integral values of upward field-aligned current constitute 0.11 A/m for evening crossing (upward part of Region 1 current) and 0.095 A/m for morning crossing (upward part of Region 2 current). Single crossing is difficult to use for evaluation of the integral Region 1 and Region 2 currents in the whole oval. However, it can be estimated using IMAGE picture. Such evaluations give ~$4\cdot10^5$ A. Obtained values are in a reasonable agreement with the results of field-aligned current measurements beginning with Iijima and Potemra [1976 a,b] and numerous results obtained later.

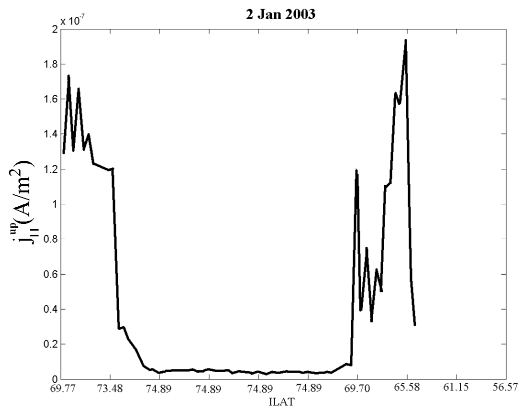

Figure 3. Results of upward field-aligned current calculations for the event 2 January 2003.

5. Conclusions and discussion

Obtained results demonstrate the possibility to calculate the upward field-aligned current density and the integrated over the band value of current using data of low orbiting satellite. Nevertheless, this method has a number of limitations. It can be applied to the upward current regions only, and only comparatively strong upward field-aligned currents can be observed. However, this method has strong advantages in comparison with traditional methods connected to the measurements of magnetic field distortion. Determination of current density by traditional magnetic methods includes the differentiation of magnetic data which introduce additional errors. It is very difficult to calculate current density in the case of multi layer structure when width of the layer is comparable with its length, when the measurements of electron flux in inverted V structures give the direct information about the upward field-aligned current density. Such information can be very useful for the verification of magnetic measurements in the case when it is possible to obtain field-aligned current values simultaneously with the particle flux data. It is necessary also to take into account that electron flux measurements give the information about upward field-aligned current in the case of absence rather sensitive magnetometers. Data of the electron particle fluxes is also possible to use for the verification of models obtaining values of field-aligned currents using data of ground-based magnetic observations.

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