Usage of Statistic Substorm Model in the Magnetogram Inversion Technique

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Abstract. The 2D maps of distribution in ionosphere of the electric currents and electric potential are often calculated using global or high-latitude network of the ground-based magnetometers data and the magnetogram inversion technique, MIT, for their processing. However, this network is spatially inhomogeneous that leads to essential uncertainties at interpretation the results. In this connection, the authors of the present work try to use additional input information in MIT, to compensate partly the above uncertainties. The results of case study with such approach are given and discussed.

Introduction
Study of the large-scale systems of ionospheric and field-aligned currents and their dynamics is the traditional theme of research of the magnetospheric substorms, storms, and superstorms - of the space weather major manifestations. The basic empiric data for calculation of the named maps are obtained on the base of magnetic measurements onboard satellites and on the world network of the ground-based magnetometers. This paper is about the second named approach. The groundbased data are processed by using the magnetogram inversion technique, MIT. There are well-known three basic MIT variants – MIT, KRM, and AMIE [Mishin, 1980; 1990; Levitin et al., 1982; Kamide et al., 1981; Richmond and Kamide, 1988]. Three variants have important distinctions, but the completeness and accuracy of their outputs depends mainly on the same input data, and therefore is, in principle, of the same order. On the other hand, all the above algorithms of MITs are continuously improved, thus the named characteristics of each of them may be essentially different in the case studies and statistical studies [Kamide and Baumjohann, 1993; Mishin et al., 1997; 2001; 2011; Clausen et al., 2012; Gao, 2012].

In the present paper, we try to estimate in one case study the uncertainties, which are introduced in outputs of different MIT variants and of MIT-originial [Mishin, 1990, and references therein] by the inhomogeneous spatial distribution of the available network of the ground-based magnetometers in high latitudes of Northern hemisphere. This used network is the best and most utilized in magnetosphere studies. The data of the 09.01.2008 substorm, which was studied in the THEMIS program, are utilized.

Ground based magnetometers network
The main source of the MIT errors is the inhomogeneous placement of the used magnetometers on the Earth’s surface. The example is presented in Fig. 1, where 119 magnetometers, available for the event under consideration, are shown by black points. One can see two major holes in their distribution, both in dusk sector, one (major cavity) in higher geomagnetic latitudes $\Phi>70^\circ$, another one is mainly in subauroral zone. Our task is to make clear what influence on some basic MIT-outputs is created by this well expressed deficiency of the used magnetometers network.

Figure 1: The map of the magnetometers distribution in MLAT-MLT coordinates for two instants of UT (black points). Big hole in the magnetometers distribution in the dusk sector, $\Phi>70^\circ$, is shown by the shaded area of orange color. Red stars in this region marks the “artificial magnetometers”, which will be used (see text)
The methods, results and conclusion

MIT is complex of the programs, providing solution of basic equations and calculation of 2D-distribution in magnetosphere of electric currents, ionospheric and field-aligned, and electric potential. These maps serve by base to calculate series of electrodynamics parameters, see the above references.

The studied 09.01.2008 event was a weak substorm with the maximal AE-index ~ 430 nT. Some additional information about this substorm is given in the associated paper (V. Mishin et al., Dynamics of the polar cap boundary and the magnetic flux of the open tail lobes for two substorms, this issue)

MIT is based on two equations, which follow from Ohm’s law.

The basic equations of MIT are the following.

\[
\begin{align*}
\text{curl} (\Sigma \cdot \nabla U) &= -\Delta J \\
\text{div} (\Sigma \cdot \nabla U) &= j_z
\end{align*}
\]

Here, \(J(\theta,t)\) is the current function, obtained from ground-based magnetometers measurements, \(\Sigma(\theta,t)\) is the given tensor of the ionosphere conductance, and \(\text{curl}, \text{div}, \nabla, \text{and} \Delta\) are all 2D operators.

The equations are solved in our practice with the models of spatially homogeneous, or inhomogeneous conductance. In the present work the homogeneous model was used. Results are shown in Fig.2 by the data of two instants of growth phase. One can see, the ionospheric currents and FACs density are very weak. It means that the experiment is performed in extremely unfavorable conditions, i.e. with the a priori large relative calculation errors. Despite of it, some expected for typical substorm details can be found in the dawn sector. In EICs, the expected is the westward electrojet, WEJ, near midnight, with the center placed near the border, separating Regions 1 and 2 by Iijima and Potemra. In FACs, the important expected features are the three Iijima-Potemra’s borders, which all are clearly visible with the expected MLAT and MLT. In contrast to the dawn sector, the important expected details absent in the dusk sector, in the above mentioned hole of the spatial magnetometers distribution (Fig.1). In EICs, this important missing detail is the eastward auroral electrojet, EEJ, which is expected just in the above major hole. In the FAC density map, the most doubtful detail is almost total absence of the expected upward FAC in the same major hole of the R1 dusk sector.
Farther, we utilized the additional MIT-inputs, obtained by calculation of the magnetic fields components X, Y, Z in the points of above major hole, shown by the stars in Fig.1. The values X, Y, Z have been calculated by using the statistic substorm model by Mishin et al. [2001]. The results are given in Fig.3. More about method will be described elsewhere.

One can see in Fig. 3 that all the above mentioned expected, but missing, details of the ionospheric currents and FACs are restored by using the outlined method. It is not trivial result, which is evidence that the above mentioned missing details of the substorm considered are not contradiction to the conventional substorm model, but they can be created by deficiency of the available input data in dusk sector. This reasoning supports a reliability of the obtained MIT maps at least in the regions without of the holes: they seem to be reliable despite defects of the neighboring regions.

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