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Electromagnetic weather at 100 km altitude on 3 August 1986

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Abstract. The electromagnetic weather at high altitudes above the Earth's surface is determined by the transport of ionospheric plasma, which in turn is governed by the magnitude as well as the direction of the electric and magnetic fields. Different models [*Levitin et al.*, 1984; *Friis-Christensen et al.*, 1985; *Mishin*, 1990] have been proposed that allow an estimation of the electromagnetic parameters of the upper atmosphere, given a knowledge of the magnitude and orientation of the interplanetary magnetic field. Here we use one such model to estimate the global convection pattern and its temporal evolution during a pass of the Swedish satellite Viking over the northern polar cap. The model predictions are shown to agree well with the electric and magnetic fields measured along the satellite trajectory. The good agreement implies that the model can be used to reconstruct, with reasonable confidence, the large-scale distribution of electric and magnetic fields and their time-variation in the entire auroral ionosphere.

Introduction

In this paper, we briefly describe a model for estimating the electric and magnetic fields in the ionosphere, with the measured interplanetary magnetic field (IMF) as input. The results of this modelling are compared to actual measurements in the ionosphere. For the comparison we have chosen a pass of the Swedish satellite Viking on 3 August 1986. On this date a number of geophysically interesting phenomena took place in the ionosphere-magnetosphere system. These phenomena, and in particular their response to changes in the interplanetary medium, have been described and discussed extensively in the literature. The inter-hemispheric conjugacy of polar cap aurorae was investigated [*Craven et al.*, 1991] based on simultaneous images from the Viking and the Dynamics Explorer satellites. Magnetic field observations by Viking were interpreted as being due to the traversal of a complex current system and to solar wind plasma pressure changes at the magnetopause [*Erlandson et al.*, 1991]. Simultaneous observations by satellite and ground-based instruments were used to investigate the auroral luminosity band structure of polar cap aurorae [*Feldstein et al.*, 1992].

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Model description

The large-scale distribution of convection in the upper atmosphere (ionosphere) is conveniently represented by the electrostatic potential, Φ. At high latitudes Φ is mainly determined by the solar wind plasma and the IMF parameters. The velocity (v) and density (n) determine the "quasiviscous" convection part, and IMF B_y and B_z components determine the part of convection which is related to merging [*Friis-Christensen et al.*, 1985; *Feldstein and Levitin*, 1986; *Mishin*, 1990 and references therein]. The IMF B_y and B_z components vary more in time (over several hours) than the solar wind velocity and density. Therefore in the model by *Levitin et al.* [1984] the electric field potential Φ^m at the position (ILAT, MLT) and time (t) is represented by the relation

$$\Phi^m(\mathrm{ILAT}, \mathrm{MLT}, t) =$$
$$\Phi_0^m(\mathrm{ILAT}, \mathrm{MLT}) + \Phi_y^m(\mathrm{ILAT}, \mathrm{MLT}) \cdot B_y(t) +$$
$$\Phi_z^m(\mathrm{ILAT}, \mathrm{MLT}) \cdot B_z(t) \qquad (1)$$

where Φ_0^m(ILAT, MLT) describes the "quasiviscous" convection part, depending on n and v only. In the first approximation this term represents the "quasiviscous" convection for average values of n and v, namely, $n = 5$ cm^{-3} and $v = 450$ km/s. The other two terms represent the contribution to the convection arising from merging, assumed here to be linearly dependent on the B_y and B_z components. As a result the model gives the spatio-temporal distribution of Φ in the high-latitude region for both quiet and weakly disturbed intervals as well as for more disturbed intervals for which the arising electric fields are controlled by the "driven" mechanism of energy transfer from the solar wind to the ionosphere (the relation between Φ and IMF may be considered as linear).

The coefficients Φ_0^m, Φ_y^m, and Φ_y^m in the model were calculated on the basis of ground magnetometer data using the methodology by *Friis-Christensen et al.* [1985] and *Feldstein and Levitin* [1986]. The model is based on a statistical relationship between the magnetic field variations of the high-latitude ionosphere and those of the solar wind [*Levitin et al.*, 1982]. The model connects the ground magnetic field variations with the ionospheric (I) and the field-aligned ($j_{\|}$) currents, as well as with the ionospheric electric field (E) and its potential (Φ). Eventually the system of equations reduces to a second order differential equation for Φ which is then solved numerically. The unknown quantity in this equation is the potential Φ, while the ionospheric conductivity and the ground magnetic field variations are known quantities.

Once the potential is determined, the electric field is given by $\mathbf{E} = -\nabla\Phi^m$, the height-integrated ionospheric current by $\mathbf{I} = \Sigma\mathbf{E}$, and the field-aligned current by $j_{\|} = \nabla \cdot \mathbf{I}$, where Σ is the height-integrated ionospheric conductivity tensor. For comparison with measured data, the magnetic field variations at the position of Viking caused by the model current system (ionospheric as well as field-aligned currents) were calculated (see also *Dremuhina et al.* [1985]).

When developing a model of the above described type, inaccuracies will arise, connected with imperfections in the ionospheric conductivity model and the Earth's conductivity model (ionospheric currents induction effect) used in the analysis. The validity of the model becomes evident only after comparisons with experimental data. Possible reasons for discrepancy between the model and the data include the assumptions that the geomagnetic field lines are equipotentials, that the electric field is curl-free, etc. Comparisons of the model electric and magnetic fields and the model currents with satellite data from TRIAD, MAGSAT and COSMOS-184 [*Feldstein and Levitin*, 1986 and references therein] have shown that the model reasonably well describes the spatial dynamics of the current system in dependence on the IMF for smooth magnetospheric disturbances. Apparently, during these intervals the so-called driven mechanism of energy transfer from the solar wind to the magnetosphere prevails. The model is, however, not applicable to events characterized by strong magnetospheric disturbances when non-linear effects and local ionospheric conductivity variations play an important role. The virtue of the model is its capacity to determine the electromagnetic weather at high latitudes continuously, giving the dependence of the large-scale convection and the current systems on the IMF.

Model application and comparison with Viking observations

The electric field instrument on Viking measured the two spin plane components of the electric field [*Block et al.*, 1987; *Lindqvist and Marklund*, 1990.] One of these components is perpendicular to the magnetic field and often nearly antiparallel to the satellite's velocity (for the particular pass used here, they are anti-aligned to within 20 degrees). The other component is often nearly parallel to the magnetic field. The interplanetary magnetic field was monitored by the IMP 8 satellite, which recorded substantial variations. As a consequence, the ionospheric convection pattern changes considerably during the course of this event, as is demonstrated below. Figure 1 shows the modeled potential patterns in the beginning and in the middle of a Viking pass on 3 August 1986. Plasma flows along the isocontours of the potential. During the early part of the pass the whole polar cap is covered by a cell with clock-wise plasma circulation. After the IMF has turned southward a two-cell convection system, with antisunward flow in the polar cap, is established. Thus, in the beginning of the Viking pass the high-latitude plasma motion is confined to closed trajectories poleward of 75 degrees geomagnetic latitude. This means that the ionospheric ionization

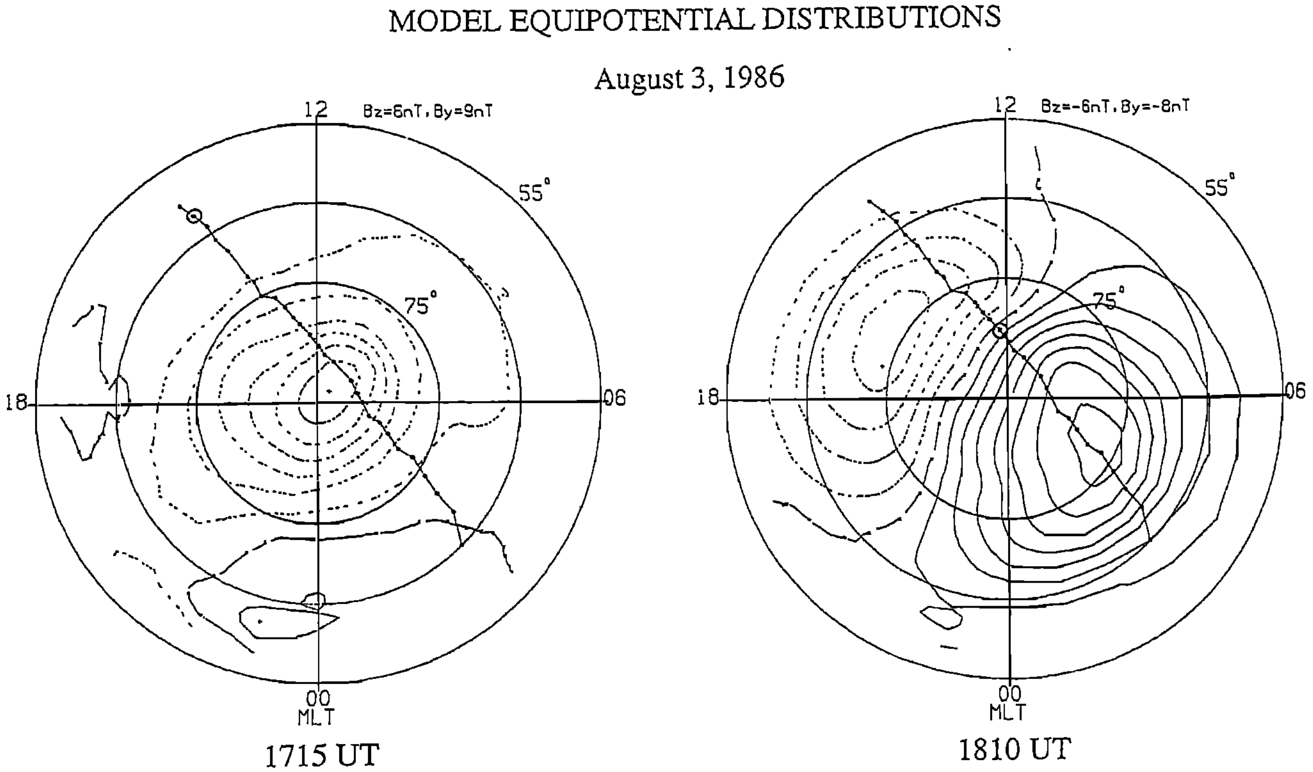

Figure 1. Ionospheric equipotential distributions at northern high latitudes at 1715 UT (left) and at 1810 UT (right). The contour separation is 10 kV. The polygonal line shows the projection of the Viking satellite trajectory to 100 km altitude. The dots indicate the satellite location every 5 minutes from 1710 UT to 1925 UT, and the open circle indicates the instantaneous position of Viking. The model results show that within less than one hour the potential distribution changed drastically. The coordinate grid is based on corrected geomagnetic latitude and magnetic local time. B_y and B_z are IMF components.

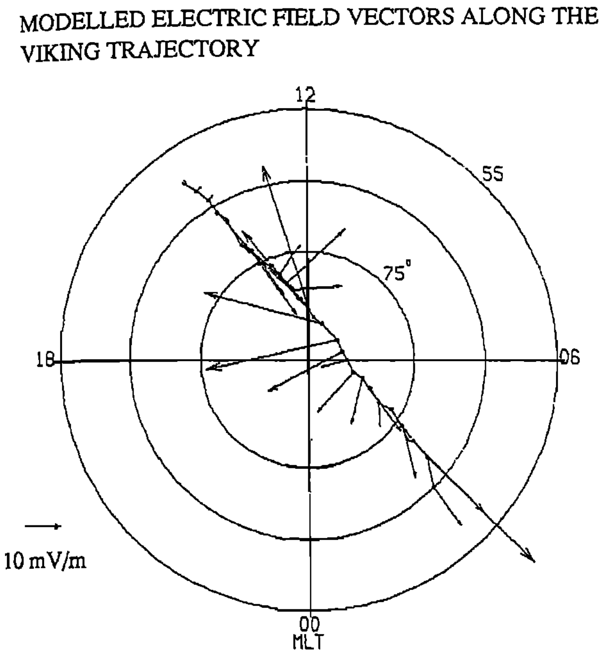
MODELLED ELECTRIC FIELD VECTORS ALONG THE VIKING TRAJECTORY

Figure 2. Horizontal (perpendicular to B) component of the model electric field along the Viking trajectory, plotted every 5 minutes. A 20-minute time delay between the measured IMF and the electric field response was assumed.

in the polar cap becomes fairly small because of the absence of plasma transport from lower latitudes. Near the middle of the satellite pass convective plasma transport into the polar cap from auroral and sub-auroral latitudes sets in. In this case, a higher degree of ionization of the polar cap ionosphere is expected.

Significant temporal changes in the convection pattern during the course of the satellite's traversal of the high-latitude region means that the electric field measured by the satellite changes as well. To verify the predicting power of the model, model potential patterns were calculated for each 5-minute interval. These were then compared to the satellite measurements from each correponding 5-minute interval. Figure 2 shows the modeled electric field along the satellite trajectory. The plasma convection velocity depends on the magnitude (and direction) of the electric field. With a typical magnetic field strength in the auroral region of 60 μT, the convection velocity is 1 km/s for an electric field of 60 mV/m. This is the speed with which plasma is transported into the polar cap on the dayside. In the night sector, where the electric field is weaker, about 20 mV/m, the plasma flows at a speed of roughly 300 m/s (at ionospheric altitudes).

The modeled electric field shown in Figure 2 has been projected onto the satellite's spin plane, to allow for direct comparison with the measurements. The result is found in Figure 3 (top panel) which shows a comparison between the modeled and the measured electric fields along the Viking trajectory. To make a quantitative comparison possible the measured electric field was "mapped" to 100 km altitude, using the assumption of a vanishing magnetic-field-aligned electric field between the two altitudes (Viking's altitude was approximately 10000 km).

Since the IMF is measured up-stream of the Earth, account must be taken for the time it takes the solar wind plasma, which carries with it the IMF, to travel from the IMP 8 satellite to the magnetopause, as well as the subsequent time for the change in the IMF at the magnetopause to influence the ionospheric convection pattern. The model calculations were performed with different delay times (ΔT), in the range 10-30 minutes. In Figure 3 (top panel) ΔT is 20 minutes. From the Figure we note that the agreement between the modeled and measured field is good. The correlation coefficient between the curves is $r = 0.88 \pm 0.07$ and the standard deviation is $\sigma = 15.5$ mV/m. The values of r decrease and those of σ increase for other values of ΔT.

Figure 3 (bottom panel) presents the variations along the orbit of the dawnward component of the magnetic field, measured by Viking (ΔB_d), and calculated from the modeled current systems (ΔB_d^m), respectively. ΔB_d was determined by subtraction of a "baseline," representing the magnetic effect of internal currents. This baseline was determined as the straight line from the measured field value at 1720 UT to that measured 1930 UT [*Erlandson et al.*, 1991]. The magnetospheric currents contributing to the remaining variations in B_d are mainly field-aligned. As in the case of the electric field, a delay time (ΔT) of 20 minutes was used. The Figure demonstrates that there is good agreement also between the modeled and the observed magnetic field variations along the Viking orbit.

Summary

In conclusion, the model has been shown to reasonably well predict the large-scale electric and magnetic field variations

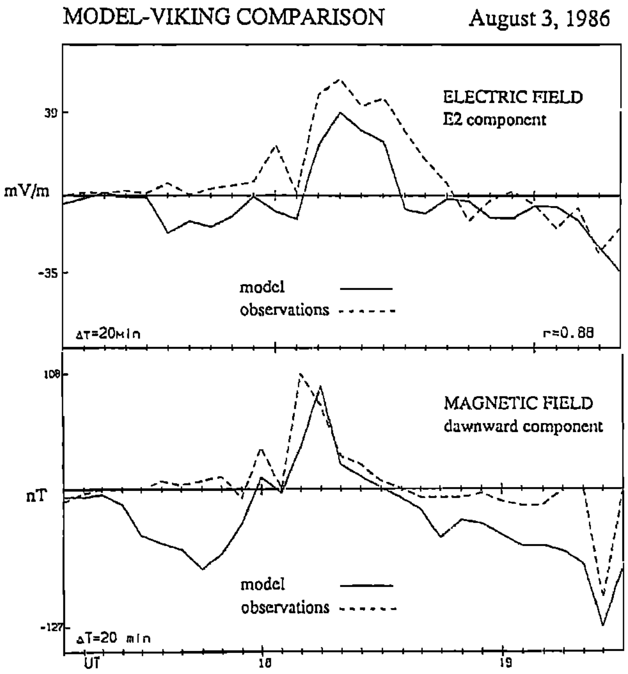
MODEL-VIKING COMPARISON August 3, 1986

Figure 3. Intercomparison of modeled (solid curve) and measured (dashed curve) electric field and magnetic field along the Viking trajectory. The electric field component plotted (top panel) is the one which is perpendicular to the magnetic field as well as to the satellite's spin axis. It is positive roughly towards dusk. The magnetic field component plotted (bottom panel) is the one which is perpendicular to the magnetic field as well as to the Sun direction. It is positive roughly towards dawn.

along the Viking trajectory. The agreement suggests that the model can be used to describe the temporal evolution of the electrostatic potential (convection), and the electric and magnetic fields in the entire high-latitude region. Thus, the electromagnetic weather in the high-latitude ionosphere, which is mainly determined by the state of the interplanetary medium, may be described by the model of the large-scale electric fields and currents [*Levitin et al.*, 1984] presented in this paper.

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