FIELD-ALIGNED AND IONOSPHERIC CURRENTS AND CONVECTION ELECTRIC FIELDS IN THE POLAR IONOSPHERE

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ABSTRACT/RESUME

A definite advantage of the *Swarm* mission compared to the Ørsted and CHAMP missions is the addition of instruments to measure the ionospheric convection electric field in addition to the magnetic field. In this study we investigate the relationship between the field-aligned and ionospheric currents and ionospheric electric fields in the polar regions. We demonstrate a newly developed tool to parameterize the field-aligned current pattern in combination with an ionospheric potential solver. The tool is used in an event study and the results compared to magnetic data from the Ørsted and CHAMP satellites and electric field observations from SUPERDARN.

1. INTRODUCTION

Field-aligned current (FAC) patters in the polar ionosphere can in general only be inferred from low altitude orbiting satellites on a statistical basis. Instantaneous values, or snap-shots of the FACs, can only be determined along the satellite track and the accuracy is normally limited by the infinite current sheet hypothesis. The Swarm mission, consisting of multiple satellites equipped with both high-precision magnetic field measurements as well as instruments to measure the ionospheric convection electric field, may however be able to estimate large-scale electric field and FAC pattern parameters on an instantaneous basis.
Here we demonstrate a newly developed tool, which can be used to investigate the relationship between field-aligned currents, ionospheric convection electric fields and ionospheric Hall and Pedersen currents. This comprise thus the first steps towards a simultaneous parameterized modelling of FACs, ionospheric currents and convection electric fields which is mutually consistent.

2. DATA AND METHOD

The modelling tool consists, in its current version, of three steps:

- A parameterization of the FACs, and a computation of the global FAC pattern in the polar region based on these parameters.
- A computation of the electric convection potential Φ and the ionospheric Hall and Pedersen currents in the polar region based on the FAC pattern and an empirical conductance model.
- A computation of the magnetic field due to the combined effect of the field-aligned and ionospheric currents. The magnetic field can be computed both at satellite altitude and on ground.

The computed magnetic and electric fields can then be compared to observations. The intent for future work is to close the circuit with a procedure resulting in an improved estimate of the FAC parameters based on the deviations between model and observations.

Here we demonstrate the tool by applying it to an event where the Ørsted and CHAMP satellites are crossing the polar regions simultaneously and at widely different local times. At January 3. both satellites cross the northern polar region around 01:40 UT and the southern polar region around 02:30 UT. During this period SUPERDARN measurements of the ionospheric convection electric field are also available, but unfortunately only with good coverage in the northern hemisphere.

3. FAC PARAMETRIZATION

The FACs are modelled by homogeneous current sheets extending from the ionosphere and outward along dipolar field-lines to 5 Re. Each sheet is determined by six parameters defining its cross section in the ionosphere: current density, width and magnetic latitude and MLT for each of the two ends of the sheets.

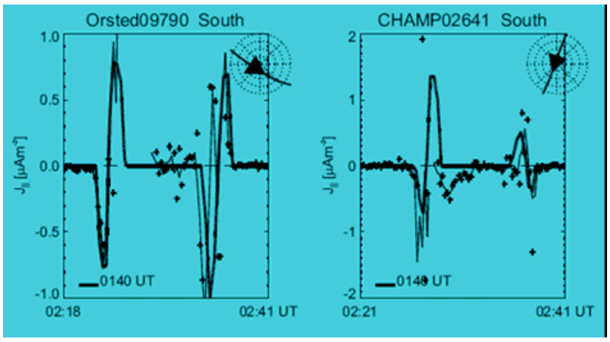

Figure 1: Field-aligned current densities determined along track assuming east-west oriented infinite current sheets (thin line) and the adopted parameterized current densities (thick line). The two panels show the crossing of the southern polar region by the two satellites.

The sheets are thus oriented roughly east-west, but one end can be at higher latitude than the other, enabling a

modelling of the statistically determined spiral-shaped current regions (e.g. Weimer, 2001 [1]).
Instantaneous large-scale FAC patterns are frequently more complicated than the statistical averages. Current sheets are often observed that are not immediately accounted for in the well established basic pattern consisting of region 1, region 2 and region 0 currents. Being used as a first step in the development of a new tool, the above mentioned event was selected for its relative simplicity and resemblance to the statistical average pattern.

The first estimate of the FAC parameters is derived from the derivative of the east-west magnetic component along the satellite tracks, using the traditional infinite current sheet assumption. Fig. 1 shows both the derived current intensities along the tracks (thin line and markers) and the adopted parameterized current intensity (thick line). The small insert at the top of each panel illustrate the satellite track. As a first approximation a simple region1/region2 structure is adopted in the parameterized currents.

Figure 2 shows the ionospheric cross-section of the adopted parameterized currents patterns. It consists of six current sheets: dayside and nightside region 1 and region 2 currents on the duskside, and nightside region 1 and region 2 currents on the dawnside. Since no measurements was made of the dayside region 1 and 2 currents on the dawnside the nightside currents have been extended a couple of hours into the dayside. In agreement with the observations by CHAMP and probably due to the negative B_y component of the interplanetary magnetic field during the event, the dusk- and dayside region 1 and 2 currents are extended across noon into the dawnside.. The width, intensity and location of each sheet were selected to match the profiles along track as shown in Figure 1. Finally the intensity of the currents was slightly adjusted to assure that no net current is flowing into or out of the ionosphere.

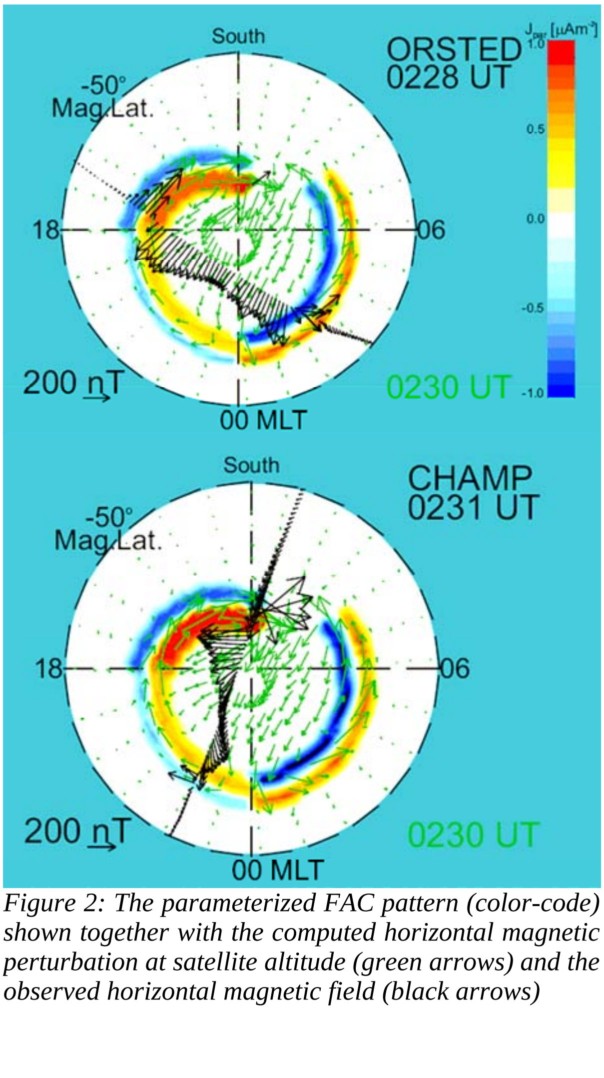

Figure 2: The parameterized FAC pattern (color-code) shown together with the computed horizontal magnetic perturbation at satellite altitude (green arrows) and the observed horizontal magnetic field (black arrows)

4. ELECTRIC POTENTIAL SOLVER

If the polar ionosphere is treated as a two-dimensional spherical shell, the electric potential Φ can be calculated from the field-aligned current pattern by equating the field-aligned current with the divergence of the horizontal Hall and Pedersen currents:

$$\nabla \cdot \underline{\underline{\Sigma}} \cdot \nabla \Phi = -J_{\parallel} \sin I \qquad (1)$$

$$\underline{\underline{\Sigma}} = \begin{pmatrix} \Sigma_{\vartheta\vartheta} & \Sigma_{\vartheta\lambda} \\ \Sigma_{\vartheta\lambda} & -\Sigma_{\lambda\lambda} \end{pmatrix} \qquad (2)$$

$$\Sigma_{\vartheta\vartheta} = \frac{\Sigma_P}{\sin^2 I}\ ; \quad \Sigma_{\vartheta\lambda} = \frac{\Sigma_H}{\sin I}\ ;\ \Sigma_{\lambda\lambda} = \Sigma_P \qquad (3)$$

where Σ_H is the Hall conductance, Σ_P is the Pedersen conductance, θ is the magnetic co-latitude, λ is the magnetic longitude and I is the magnetic field inclination angle (e.g. Kelley, 1989 [2], Raeder 2003 [3]). Thus the ionospheric Hall and Pedersen conductances play a crucial role, linking the magnetic and electric field observations.

Since no observations of the conductance are available we are forced to rely on models of these parameters. Here we use the empirical formulae incorporated in the global MHD model of solar wind – magnetosphere – ionosphere coupling, the so-called GGCM model described in [3] and implemented at the Community Coordinated Modelling Center (CCMC). The conductances were thus taken as model output from a run on request of the given event at CCMC. Fig. 3 shows the modelled Hall conductivity during the satellite crossing of the southern hemisphere. It is clear that both contributions from solar UV-radiation and contributions from auroral particle precipitation are included in the model.

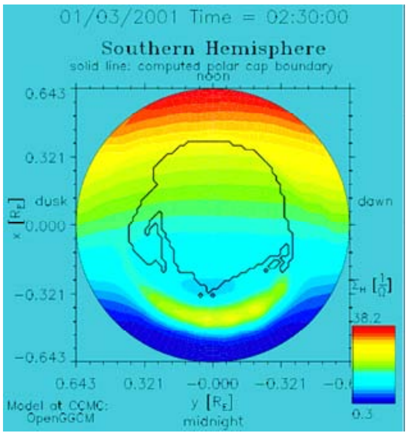

Figure 3: Ionospheric Hall conductance model determined from the open GGCM model.

Fig. 4 shows the electric potential computed from equation (1) using this conductance and the parameterized field-aligned current pattern shown in Fig. 2 as input. The well-known, slightly skewed, two-cell pattern is observed. Unfortunately SUPERDARN has no good coverage during this crossing.

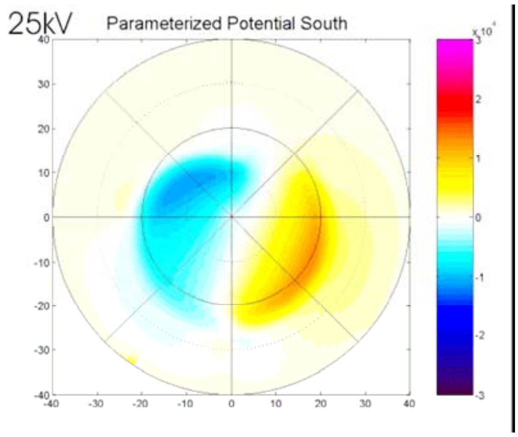

Figure 4 : Ionospheric electric potential computed from the parameterized FACs of Figure 2.

5. MAGNETIC FIELD COMPUTATION

The horizontal ionospheric currents can then be calculated as the product of the conductance tensor (eqs. 2-3) and the horizontal gradient of the electric potential. Combining this with the upward continued parameterized FACs provide a 3-D current system from which the magnetic perturbation can be calculated. Here we use the poloidal-toroidal decomposition method described in Engels and Olsen (1998) [4] and Vennerstrom et al. (2004) [5].

The computed magnetic field at satellite altitude is shown as green arrows in Fig. 2. These can then be compared with the Ørsted and CHAMP observations. In general there seems to be a nice coincidence, but there is definitely also room for improvement in an iterative procedure. Particularly one can note the underestimated magnetic fields in the polar cap far from the FACs and the differences in the north-south direction close to noon. It is important to note that both the FAC estimates but also the conductance estimate can be responsible for the discrepancies. The future *E*-field observations of *Swarm* are expected to be very helpful in distinguishing between these, but independent measurements of the ionospheric currents, such as ground-based magnetic field measurements or scalar field intensity variations at satellite altitude should also be incorporated.

6. THE WINTER HEMISPHERE

When the satellites passes the northern hemisphere, the polar region is almost in darkness, and the conductance is dominated by the contribution from the auroral emission as shown in Fig. 5.

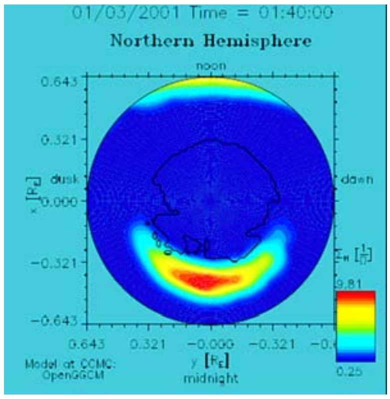

Figure 5: The GGCM model Hall conductance for the northern (winter) hemisphere

Following the same procedure as for the southern hemisphere, the CHAMP and Ørsted measurements are used to parameterize the FACs and the resulting magnetic perturbation and electric potential is computed. The magnetic perturbations are shown in Fig. 6 together with the CHAMP and Ørsted observations, and the electric potential is shown in Fig.7. Finally Fig. 8 shows SUPERDARN measurements of the ionospheric convection and the derived electric potential pattern for comparison. It is obvious that while the computed and observed magnetic perturbation compares reasonably well, the computed electric potential is far from the observed ones.

The CHAMP and Ørsted satellite data indicate that the region 1 and region 2 currents are of similar strength, and combined with the conductances shown at Figure 5 this leads to a 4 cell pattern, while the SUPERDARN measurements indicate a normal two-cell pattern.

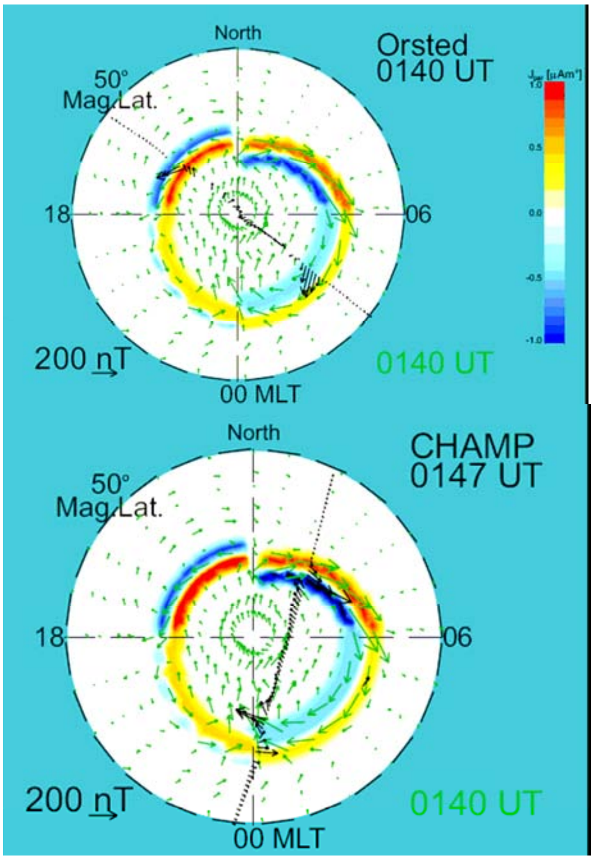

Figure 6: Same as Fig. 2, but for the passage of the northern (winter) hemisphere.

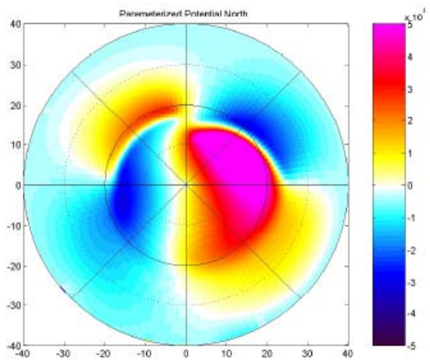

Figure 7: Ionospheric electric potential computed for the northern hemisphere based on the parameterized FAC pattern shown in Fig. 6.

There may be several reasons for this discrepancy :

- The used conductance model may deviate significant from the real ionosphere, particularly concerning conductance created by auroral precipitation. It could well be necessary to link the FACs and conductivity pattern in a consistent manner.
- The local FACs measured by CHAMP and Ørsted may not properly reflect the global FAC pattern.
- The used ionospheric model (i.e. equations 1-3) may be too simple.

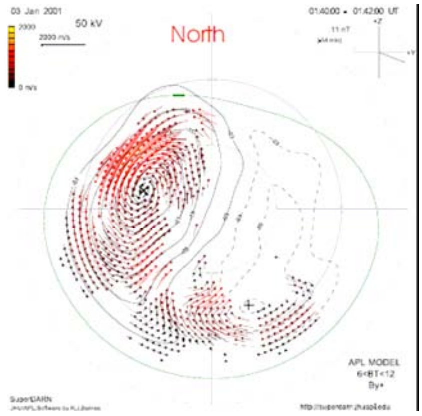

Figure 8: SUPERDARN measurements of the ionospheric convection and derived electric potential during the passage of the two satellites.(We acknowledge use of the SUPERDARN online archive)

7. SUMMARY

We have developed a modelling tool to parameterize the field-aligned current pattern in combination with an ionospheric potential solver. The tool is considered to be the first part of a new approach to investigate the large-scale electrodynamics of magnetosphere-ionosphere coupling based on a combination of electric and magnetic field measurements.

The modelling has been applied to a single event study with encouraging results, particularly during sunlit conditions. However, during winter conditions serious discrepancies between model predictions and observations have been identified. The results underline the crucial role played by the ionospheric conductivity, and indicates that it may be necessary to incorporate the empirical modelling of the conductance as an integrated, rather than independent, part of the modelling procedure.

8. REFERENCES

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