Satellite-based empirical models of ionospheric convection and field-aligned currents at high latitudes

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1. Introduction

Papitashvili et al. [1994] introduced a linear approach for the modeling of ionospheric electrodynamics (LiMIE). Besides ground geomagnetic data, this approach has recently been applied to ionospheric electrostatic potentials inferred from the cross-track ion drift velocities measured onboard of the DMSP satellites [Papitashvili and Rich, 2002] and to high-precision magnetic field measurements made onboard the Magsat and Ørsted satellites [Papitashvili et al., 2002]. In the LiMIE approach, the distributions of various ionospheric parameters consist of four basic elements. For example, the ionospheric electric potential $\Phi$ consist of: (a) the IMF-independent, two-cell background convection $\Phi_0$; (b) the lobe convection cell $\Phi_B$ controlled by the IMF $B_y$ component; (c) the merging two-cell convection $\Phi_{Bz<0}$ controlled by the IMF $B_z$ southward component; and (d) the near-pole, two-cell “reverse” convection $\Phi_{Bz>0}$ caused by the IMF northward component. We note that only three of these elements can coexist (combined together) simultaneously; the latter two elements replace each other depending on the IMF $B_z$ orientation.

2. High-Latitude, IMF-Dependent Patterns of Ionospheric Potentials and Field-Aligned Currents

Papitashvili and Rich [2002] and Papitashvili et al. [2002] show basic patterns of ionospheric convection and field-aligned currents, respectively. We present here the DICM and FACEM patterns (in pairs) modeled for the IMF $B_T = (B_y^2 + B_z^2)^{1/2} = 5$ nT and average solar wind conditions ($n = 5 \text{ cm}^{-3}$, $V = 400 \text{ km/s}$): for the northern and southern equinoxes (Figures 1 and 2), for the northern summer and southern winter (Figures 3 and 4), and for northern winter and southern summer (Figures 5 and 6). This organization allows interhemispheric comparisons of various high-latitude features (including the cross-polar potentials) to better understand underlying physics of the magnetosphere-ionosphere coupling.

Figure 1 shows that during equinox the potential patterns are very similar for all IMF clock-angles. The cross-polar, dawn-dusk potential drop $\Delta \Phi$ varies from 31 kV for the northern background convection to 88 kV for the southern $B_z < 0$ pattern. Overall, the southern and northern patterns are very similar suggesting that during equinox, the magnetosphere-ionosphere coupling supplies the magnetospheric potential almost equally to both the northern and southern polar ionospheres. The IMF $B_y$ effect on the high-latitude convection is clearly seen when $B_z = 0$ (middle row); it adds or subtracts additional potentials to the background pattern in each hemisphere according to the corresponding IMF azimuthal component direction. The negative dusk cell still dominates and causes significant asymmetry in the hemispheric patterns for the same sign of $B_y$ component; however, the $B_z$-controlled patterns become almost symmetrical in the northern and southern polar caps for opposite signs of the IMF azimuthal component. The reverse, dusk-dawn potential for $B_z = +5$ nT (top row) reduces significantly the overall background potential patterns, making the resulting distributions weak and undistinguished. However, an increase in either $B_{y-}$ or $B_{y+}$ content results in the standard-like, two-cell patterns. This suggests that the global convection is still the standard-like, two-cell type, even if the reverse, sunward flow is added to the day-side of the background pattern for $B_z = +5$ nT.

Figures 3 and 5 show the DICM patterns for northern summer/southern winter and for the northern winter/southern summer conditions, respectively. The dusk convection cell for positive (negative) IMF $B_y$ has 2–6 times more voltage than the dawn cell during all seasons in the northern (southern) hemisphere; the convection cells are nearly equal in voltage for the opposite $B_y$ polarities. This effect has been shown for summer by Crooker and Rich [1993]. The “summer-to-summer” and winter-to-winter”
comparisons reveal that the combined effect of the viscous and reconnection processes produces a smaller cross-polar potential drop in one hemisphere: $\Delta \Phi = 74$ kV (94 kV) during summer (winter) in the northern hemisphere and $\Delta \Phi = 83$ kV (115 kV) in the southern hemisphere. Similar asymmetry is seen from the “summer-to-winter” comparisons; the cross-polar potentials are 10–20% larger in winter. Therefore, we conclude that the “summer-to-winter” ratio of about 0.85 is clearly obtained only from the combined background (IMF $\sim 0$) and reconnection ($B_z < 0$) patterns; the $B_y$-controlled lobe reconnection may show similar ~20% increase in winter, but the latter results are yet inconclusive.

The IMF clock-angle dependence in the FACEM model is shown in Figures 2, 4, and 6 for $B_T = 5$ nT over the northern and southern polar regions. The maps show all expected features of the high-latitude ionospheric FAC systems. The R1/R2 system is a dominant feature even in the dark, winter hemisphere. The equinox patterns are very symmetric between hemispheres, showing almost no differences in the current intensities. The field-aligned currents are much stronger in the sunlit polar cap.

3. Conclusions

The new DMSP-based model of ionospheric convection shows that the cross-polar potentials show a weak seasonal effect; the potential drops generally increase from summer to winter by ~10–15%. There is also a persistent dawn-dusk asymmetry in the standard, two-cell convection patterns against the noon-midnight meridian. The dusk cell dominates in the background potential patterns causing a recognizable asymmetry in all subsequent patterns when the IMF $B_z$ or $B_y$-controlled patterns are added. For FACEM, the presented results seem to be in general agreement with our understanding of the global FAC patterns. As seen in the figures, the total currents are about symmetrically distributed between the two hemispheres during equinox, while the summer currents are ~1.35 times stronger than the winter currents. This is in good agreement with our recent findings [Christiansen et al., 2002].

Although our results may suggest that the difference in the cross-polar potentials could be caused by the limited accuracy of our modeling, we also may hypothesize that some differences could be caused by the interhemispheric asymmetry of the three-dimensional R1 current system providing a feedback to the dayside reconnection as suggested by Papitashvili and Rich [2002].

We believe that all currently available ground- or satellite-data based ionospheric convection models, somehow parameterized by the IMF strength and direction, show comparable responses of the high-latitude ionosphere on changes in the IMF and solar wind near the Earth’s orbit. However, the LiMIE approach used for construction of the ground magnetometer-based DMI and IZMEM models and now satellite-based models DICM and FACEM is the only approach that explicitly describes the background (IMF-independent) convection patterns for both polar regions and all seasons. Furthermore, the results presented in this study justify a need in developing a unified approach for the modeling of high-altitude ionospheric convection and field-aligned currents from various sources (i.e., ground magnetometers, radars, digisondes, and satellite observations) allowing seamless data assimilation in various “space weather” applications.

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WWW Reference – http://www.sprl.umich.edu/mist/limie.html

References


Figure 1. Contour plots of the DMSP-based IMF-dependent high-latitude ionospheric convection patterns modeled for northern (left panel) and southern (right panel) equinoxes. The dial plot in the center of each panel shows the background convection for IMF = 0; other eight dial plots are organized according to the IMF “clock-angle” vector $B_T = (B_y^2 + B_z^2)^{1/2} = 5$ nT. The numbers at lower corners of each dial show the MIN/MAX potentials, marked by symbols “−” and “+” at the plots, respectively. The zero potential contours are plotted as a dash-dot line; the contour intervals for the positive and negative cells are 5 kV.

Figure 2. Maps of field-aligned currents for $B_T = 5$ nT organized by the IMF clock angle for northern (left panel) and southern (right panel) equinoxes. The central plots are the patterns for $B_T = 0$. The total hemispherical currents (top numbers, MA) and the minimum and maximum current densities (lower numbers, $\mu$A/m²) are marked at the bottom corners of each polar subplot. The upward currents are plotted in blue (negative) and downward currents – in red (positive). The FACs $\text{min/max}$ density locations are identified by “−” and “+” symbols, respectively.
Figure 3. Same as in Figure 1 but for northern summer (left panel) and southern winter (right panel).

Figure 4. Same as in Figure 2 but for northern summer (left panel) and southern winter (right panel).
Figure 5. Same as in Figure 1 but for northern winter (left panel) and southern summer (right panel).

Figure 6. Same as in Figure 2 but for northern winter (left panel) and southern summer (right panel).