

GLOBAL IONOSPHERIC CONVECTION DURING SUBSTORM EXPANSION

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Abstract. The large-scale ionospheric convection patterns derived from the Assimilative Mapping of Ionospheric Electrodynamics (AMIE) procedure are used to examine the relationship between global convection and the substorm expansion. It is found that, after the onset of the substorm expansion when the AL index begins to decrease sharply, an isolated convection cell evolves near midnight. As the substorm progresses, this cell expands, gradually merging with the pre-existing dusk-side convection cell. When the pre-substorm expansion convection pattern is subtracted, the residual patterns show clearly a 2-cell convection configuration which first appears in the local midnight sector after the onset of the expansion phase and gradually intensifies in spatial size as well as in magnitude during the expansion phase. Such a configuration implies that the substorm-related ionospheric convection is mainly controlled by a magnetospheric process in the tail.

1. Introduction

Large-scale convection in the high-latitude ionosphere is strongly controlled by the interaction between the solar wind and the magnetosphere, mainly through reconnection processes at the dayside magnetopause as well as in the nightside magnetotail, and to a lesser extent through viscous-like processes along the magnetospheric boundaries [e.g., Cowley and Lockwood, 1992]. When the dayside plasma inflow is balanced by the nightside plasma outflow, one would expect a steady-state convection configuration to be reached. In reality, however, different time scales are involved in the different processes so that a truly steady-state convection hardly ever exists. The time scale for the dayside reconnection is essentially determined by the variations in the upstream solar wind and IMF. The time scale for the nightside process, on the other hand, depends not

only on the solar wind and IMF conditions but also on the intrinsically dynamic nature of the magnetosphere-ionosphere system itself. It is widely believed that part of the solar wind input energy is first stored in the magnetotail, and the sudden release of this energy causes substorms.

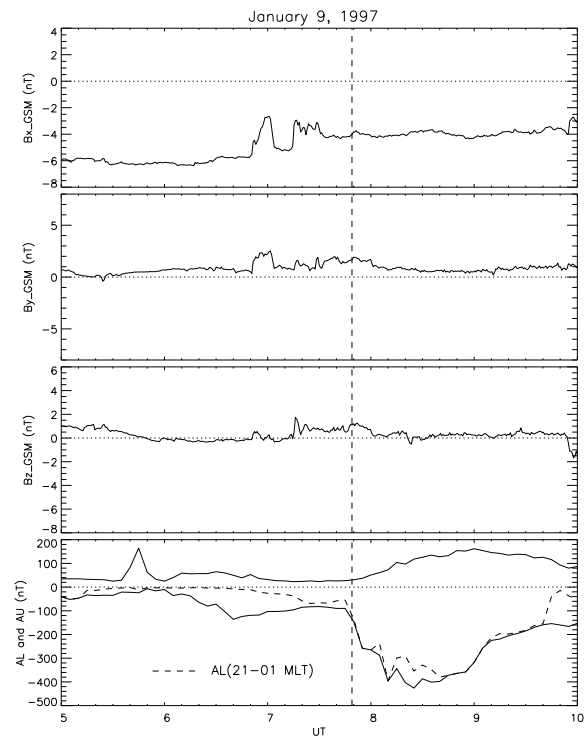


Figure 1. (from top to bottom) IMF B_x , B_y , and B_z components in GSM coordinates, and the AU and AL indices between 0500 and 1000 UT on January 9, 1997.

Consequently, there are two processes concurrently occurring during substorms: the one directly driven by the solar wind energy input controls the overall large-scale convection configuration while the one related to the magnetotail energy release contributes to the smaller-scale changes in the convection patterns. This two-component concept was proposed by *Kamide et al.* [1994]. To distinguish them quantitatively, one has to select events when an excellent global data coverage is available during well-defined substorms.

This paper studies the response of ionospheric convection during two isolated substorm events occurred on January 9 and 12, 1997, respectively. Global ionospheric convection patterns are derived using the Assimilative Mapping of Ionospheric Electrodynamics (AMIE) procedure [Richmond and Kamide, 1988]. Data inputs to AMIE for this study are the 1-min averaged ground magnetic per-

turbations recorded by a worldwide network of 123 magnetometer stations (among them, 88 were located in the northern hemisphere above 50° magnetic latitude for this study), and the global auroral images from the Polar UVI instrument. Height-integrated Pedersen and Hall conductivities in the ionosphere are estimated from a pair of Polar UVI images [e.g., *Lummerzheim et al.*, 1997] at about every 3 mins. Correspondingly, the AMIE convection patterns are derived in a 3-min time step.

2. Results

Event 1: January 9, 1997

The top three panels of Figure 1 show the B_x , B_y , and

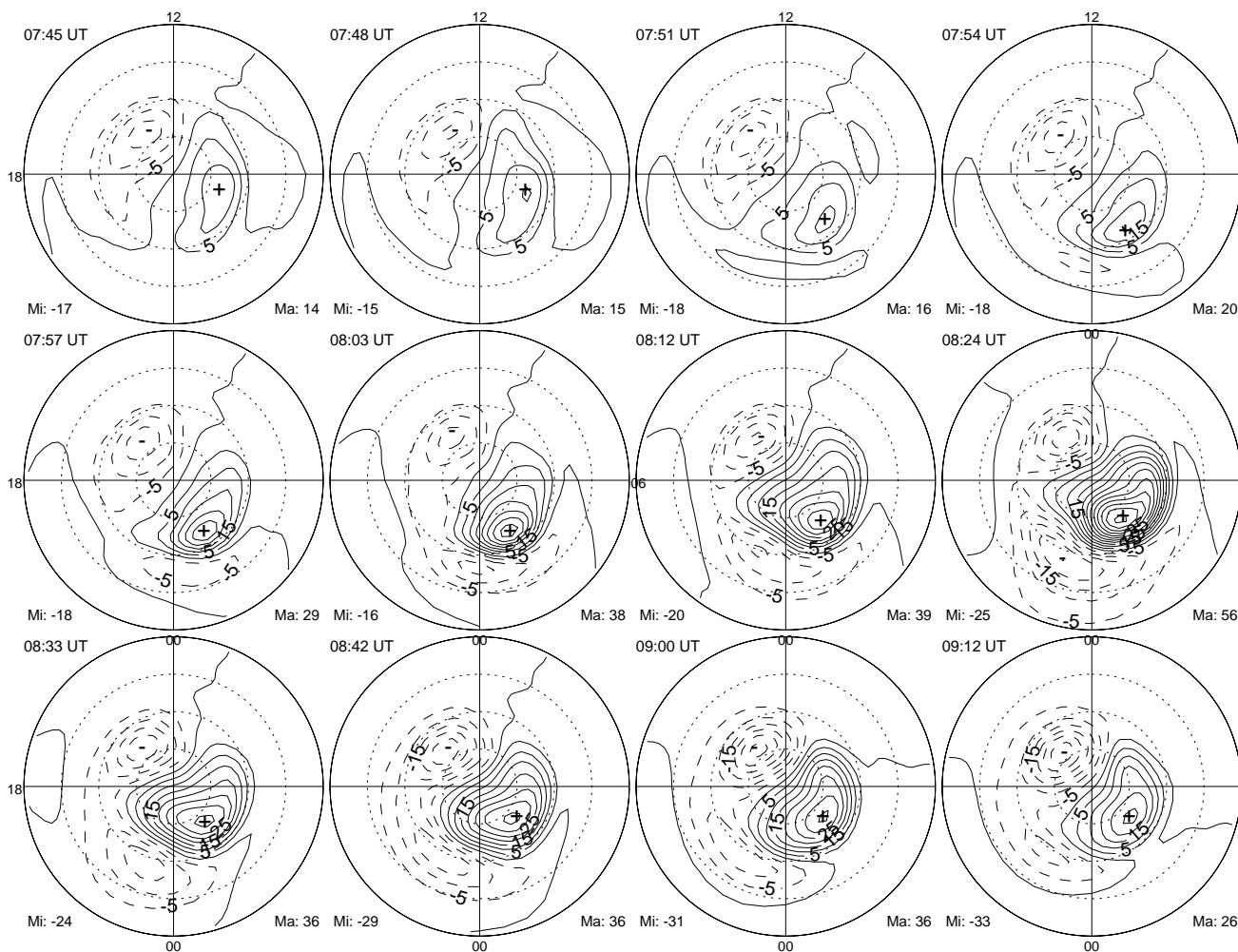


Figure 2. Selected ionospheric electric potential patterns in the northern hemisphere for 0745-0912 UT on January 9, 1997. The patterns are displayed in polar magnetic coordinates, with local noon on the top, dawn on the right side, and dusk on the left side. The outermost circle corresponds to 50° magnetic latitude. The dashed contours represent negative potentials and the solid contours positive potentials, and the contour interval is 5 kV. The extreme potential values are given underneath each pattern.

B_z components (in GSM coordinates) of the IMF measured by the WIND satellite, which was located at (78.3, - 60.7, - 2.6) R_E in GSE coordinates at 0700 UT on January 9, 1997. Note that the propagation time from the satellite location to the magnetopause has not been taken into account in this plot. During this 5-hr period, the IMF is relatively stable, and the magnitude of the IMF is about 5 nT. The bottom panel shows the AU and AL indices, derived from the north-south component of the magnetic perturbations recorded at 68 ground magnetometer stations located between 55° and 76° magnetic latitudes. For comparison, the dashed curve in the bottom panel is the AL index based on those auroral stations located only between 21 and 01 MLT, which therefore represents the westward electrojet near the midnight sector. The vertical dashed line marks the onset of the substorm expansion phase at

0749 UT, as indicated by the sudden enhancement of Pi2 pulsations observed by the Canopus magnetometer chain. This is a moderate substorm, with a minimum AL of about - 400 nT.

Figure 2 shows the representative patterns of ionospheric convection during the isolated substorm interval between 0745 and 0912 UT on January 9, 1997. Prior to the substorm onset at 0749 UT, the convection patterns are nearly steady, with a 2-cell configuration and a small cross-polar-cap potential drop of about 30 kV, which are consistent with the weakly northward IMF condition. After the onset, the convection configuration starts to change rather dramatically. The most noticeable feature is the development of an isolated negative cell in the midnight sector. As the substorm progresses, this cell intensifies not only in magnitude but also in spatial size.

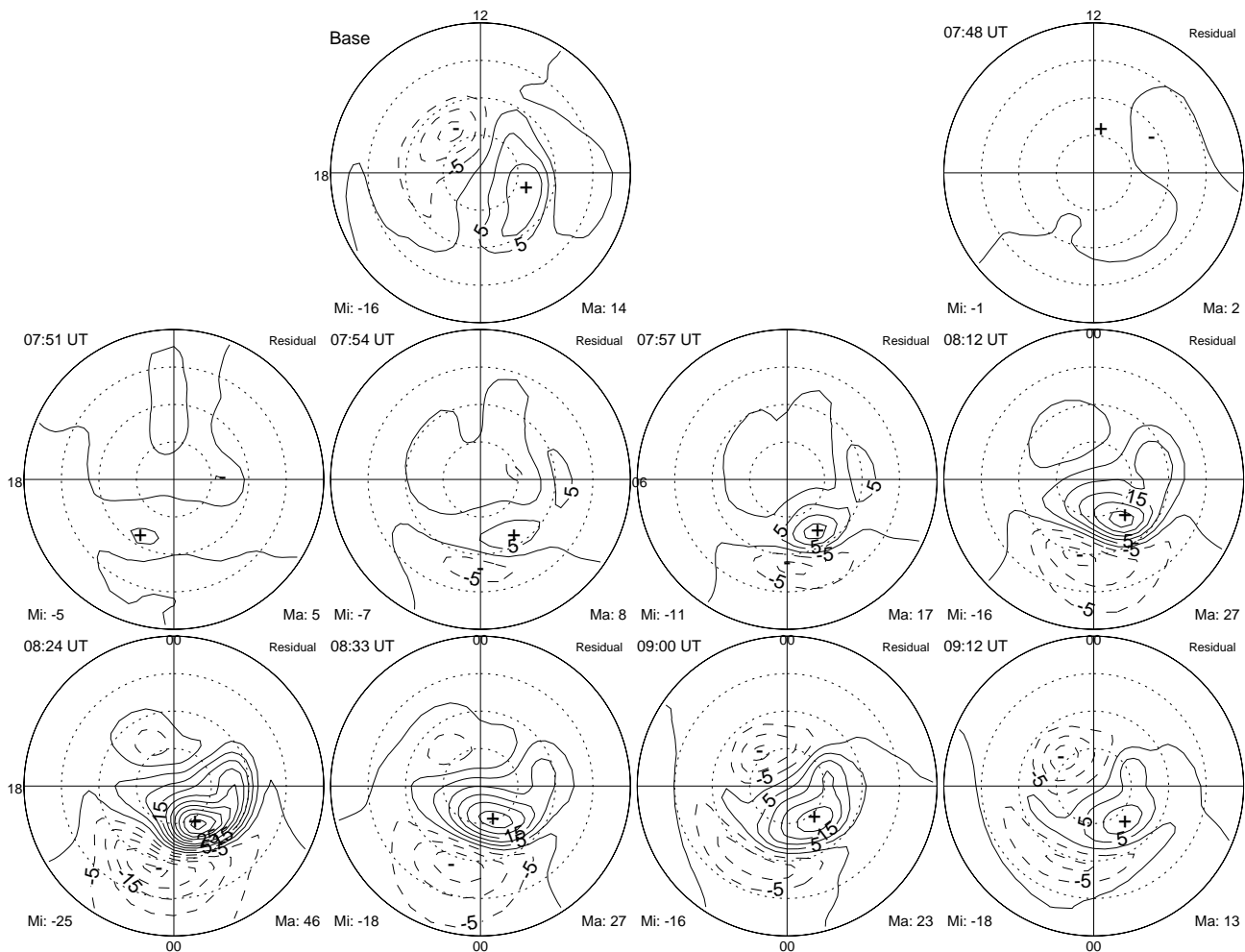


Figure 3. The steady base pattern and the residual electric potential patterns between 0748 and 0912 UT on January 9. The base pattern is the average of the patterns at 0745 and 0748 UT, prior to the substorm onset. The residual patterns are derived by subtracting the base pattern from the corresponding patterns shown in Figure 2.

Consequently, the nightside substorm-related cell gradually merges with the pre-existing duskside convection cell. During the recovery phase (after about 0830 UT), as shown in the bottom row of the patterns in Figure 2, the night-side cell diminishes, whereas the pre-existing duskside cell gradually enhances its magnitude.

Figure 3 shows the residual convection patterns, from which the averaged steady pattern prior to the onset of the substorm expansion phase has been subtracted. At 0754 UT (about 5 mins after the onset), a pair of convection cells evolve near the midnight meridian. They gradually intensify both in magnitude and in spatial size. By the end of the expansion phase at about 0824 UT, the twin convection cells have occupied the entire nightside region. During the recovery phase, these twin cells gradually diminish. At the same time, however, a negative cell emerges in the postnoon sector and intensifies. This is an very interesting phenomenon which has not been previously reported.

Event 2: January 12, 1997

Plotted in Figure 4 are the IMF B_x , B_y , and B_z components measured by WIND, as well as the AU and AL indices for the period of 0500-1000 UT on January 12, 1997. The WIND satellite was located at $(103.0, -54.7, -5.9) R_E$ at 0700 UT. The vertical dashed line marks the onset of

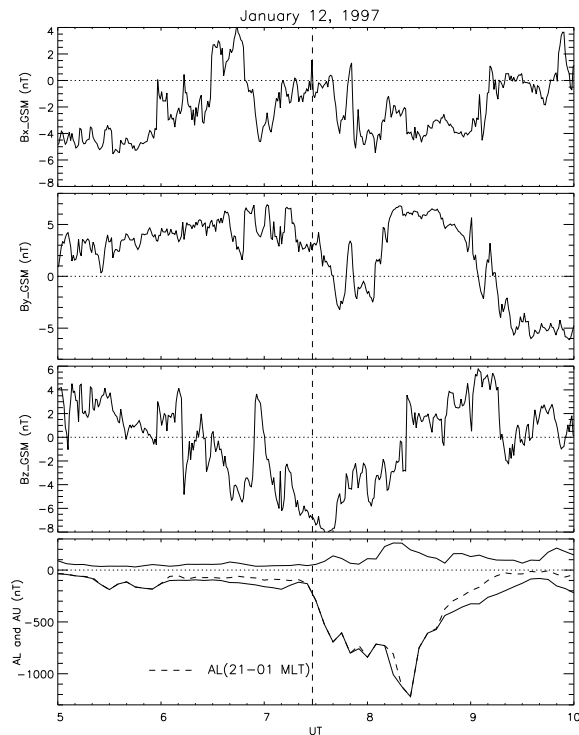


Figure 4. IMF B_x , B_y , and B_z components in GSM coordinates, and the AU and AL indices between 0500 and 1000 UT on January 12, 1997.

the substorm expansion phase at 0728 UT, based on the enhancement of the Pi2 pulsations observed by the Canopus magnetometer chain. Unlike the January 9 event in which the IMF is relatively stable, in this case all components fluctuated prior to the substorm onset, especially the IMF B_z changes from northward to southward about 30 mins before the onset. Taking into account the propagation time from the WIND location to the magnetopause (about 19 mins if a x-distance of $\sim 93 R_E$ and a bulk solar wind speed of 525 km/s are considered) and the ionospheric response time (about 12 mins on average [Ridley *et al.*, 1998]), such change in B_z is expected to affect the ionospheric convection during the expansion phase. This is a rather intense substorm, with a minimum AL of -1200 nT.

Figure 5 shows the representative residual patterns during the substorm. About 1 min after the substorm onset, a pair of convection cells emerge in the premidnight sector around 22 MLT. They intensify in magnitude as well as in spatial size during the expansion phase. Unlike in the previous case, there is another pair of convection cells that evolve on dayside of the dawn-dusk meridian during the expansion phase. This kind of 2-cell convection configuration on the dayside is associated with the southward turning of the IMF B_z , similar to that reported by Ridley *et al.* [1998]. During the substorm recovery phase from about 0830 UT to 0900 UT, the nightside substorm-related twin cells gradually diminish, while the negative potential cell in the postnoon sector gradually enhances. Note that the enhancement of the negative cell in the postnoon sector is not as monotonic as that in the previous case, which is probably due to the complication of the IMF changes during the recovery phase.

3. Summary and Discussion

In this study we have examined the global ionospheric convection patterns during two isolated substorms. We find that, in addition to the pre-existing 2-cell pattern, a separate convection cell evolves near local midnight after the onset of the substorm expansion phase. When the pre-substorm pattern is subtracted, the residual patterns show clearly a pair of convection cells emerge near the midnight sector and intensify not only in magnitude but also in spatial size as the substorm progresses, even when the IMF remains relatively stable. This implies that the substorm-related convection patterns are controlled by a magnetospheric process in the tail. Our findings are consistent with the two-component picture of Kamide *et al.* [1994].

One of the interesting features found in this study is the gradual decrease of the nightside convection cells accompanied by the increase of the negative cell in the postnoon sector during the substorm recovery phase. It seems that a theory analogous to the “current-shunting” hypothesis pro-

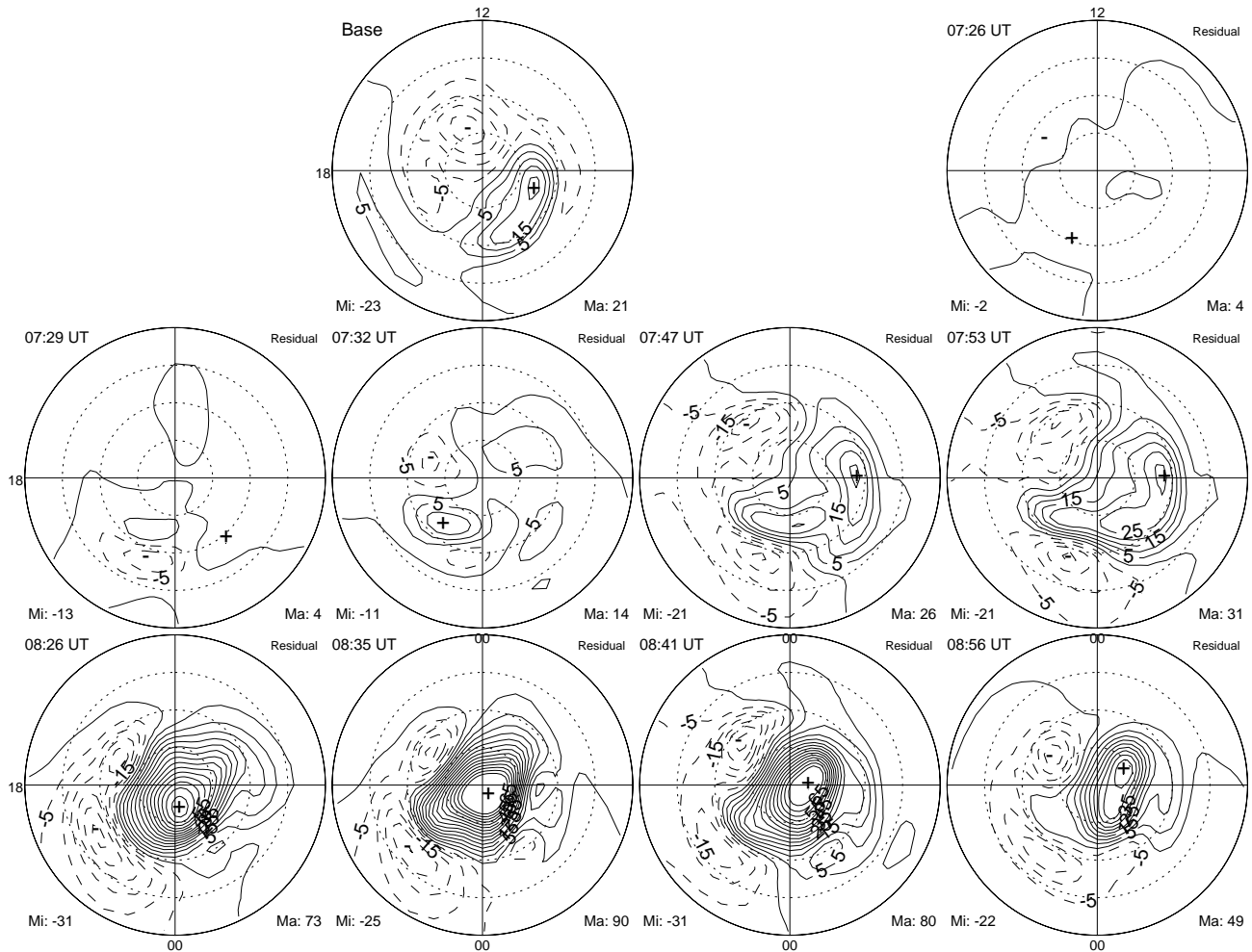


Figure 5. The steady base pattern and the residual electric potential patterns between 0726 and 0856 UT on January 12. The base pattern is again the average of the patterns prior to the substorm onset.

posed by *Siscoe* [1996] could be used to explain such a phenomenon. But in this case, the theory should work in the opposite way, that is, instead of transferring energy from the dayside to the nightside to trigger the substorm onset, energy is being released from the nightside to the dayside so that the recovery phase occurs.

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References

Cowley, S. W. H., and M. Lockwood, Excitation and decay of solar wind-driven flows in the magnetosphere-ionosphere system, *Ann. Geophysicae*, 10, 103, 1992.

Kamide, Y., et al., Ground-based studies of ionospheric convection associated with substorm expansion, *J. Geophys. Res.*, *99*, 19,451, 1994.

Lummerzheim, D., M. Brittnacher, D. Evans, G. A. Germany, G. K. Parks, M. H. Rees, and J. F. Spann, High time resolution study of the hemispheric power carried by energetic electrons into the ionosphere during the May 19/20, 1996 auroral activity, *Geophys. Res. Lett.*, *24*, 987, 1997.

Richmond, A. D., and Y. Kamide, Mapping electrodynamic features of the high-latitude ionosphere from localized observations: Technique, *J. Geophys. Res.*, *93*, 5741, 1988.

Ridley, A. J., G. Lu, C. R. Clauer, and V. O. Papitashvili, A statis-

tical study of the ionospheric convection response to changing interplanetary magnetic field conditions using the assimilative mapping of ionospheric electrodynamics technique, *J. Geophys. Res.*, *103*, 4023, 1998.

Siscoe, G., Possible global nature of substorm onset, in *Physics of Space Plasma (1995)*, Number 14, edited by T. Chang and J. R. Jasperse, MIT Center for Theoretical Geo/Cosmo Plasma Physics, Cambridge, MA, pp. 481, 1996.

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