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COMMENT ON "IONOSPHERIC CONVECTION RESPONSE TO CHANGING IMF DIRECTION" BY KNIPP ET AL.

M. Lockwood
Rutherford Appleton Laboratory, Chilton, UK

and S.W.H. Cowley
Blackett Laboratory, Imperial College, London, UK

In their paper, Knipp et al. [1991] present some very interesting data concerning the evolution of the pattern of high-latitude ionospheric convection in response to changes in the orientation of the interplanetary magnetic field (IMF). The purpose of this comment is to note the relevance to this work of some other studies, both experimental and theoretical, which were not cited by the authors. The paper shows flow "snapshots" produced by the AMIE technique. We wish to point out that the results presented are strongly supportive of the Expanding/Contracting Polar Cap (ECPC) convection model.

Generally, reconnection at the dayside magnetopause and in the geomagnetic tail will proceed at different rates and the ionospheric flow pattern will not be in steady state. The concepts involved in the ECPC convection model were first outlined by Russell [1972], who sketched the ionospheric flows for the expansion and growth phases of substorms. The flow patterns were evaluated quantitatively by Siscoe and Huang [1985], assuming for simplicity a circular polar cap. Siscoe and Huang considered the convection for wholly unbalanced dayside reconnection, i.e. with no tail reconnection, which is an idealised description of a growth phase. Lockwood and Freeman (see review by Lockwood and Cowley [1988]) generalised this to show examples of patterns for which both dayside and nightside reconnection are taking place, but at different rates.

A number of recent observations have supported this ECPC convection model. Its use has allowed the main features of satellite passes during various substorm phases to be modelled (e.g. Moses et al. [1989]). However, the observations which are of most relevance here were made using the EISCAT radar, with simultaneous IMF data for just sunward of the bow shock from the AMPTE-UKS and -IRM satellites [Etemadi et al., 1988; Todd et al. 1988; Lockwood et al. 1986, 1990]. These observations showed that dayside auroral flows responded to both northward and southward turnings of the IMF on time scales of only a few minutes. The delay of the initial response after the IMF change reached the magnetopause was found to be a minimum of only about 2 min. in the early afternoon sector and to increase to near 15 min. near dawn and dusk. After the initial response, the flow speed evolved over a period of about 5-10 min. The response times are the same as those deduced for the corresponding Hall currents from magnetometer data by Nishida [1968]. Lockwood et al. [1990] showed that these response times were well explained by the ECPC convection model and deduced that the convection pattern must be thought of as the sum of two patterns, driven by dayside and nightside reconnection and corresponding to the DP2 and DP1 current systems, respectively.

In the light of this work, let us now consider the sequence of flow patterns given in figure 3 of Knipp et al., showing the response to the northward IMF turning at 10:15 UT. The authors do not present a detailed calculation of the satellite-to-ionosphere propagation delay, but quote a value of 15 min. However, by 10:30 UT the response was already underway with a clear reduction in the dayside flow speeds. The dayside flow pattern characteristic of southward IMF then decays away to almost nothing in the next 10 minutes. At the same time, the pattern characteristic of northward IMF starts to emerge at the highest latitudes almost immediately, but develops over a longer period of about 30 min., as in the observations by Clauer and Friis-Christiensen [1988]. Using the ECPC model, Lockwood et al. (1990) predict that the dayside flows will respond just a few minutes after the magnetosheath field changes at the dayside magnetopause and will subsequently decay over the next 5 - 10 min. The nightside flows will decay with the reconnection rate in the geomagnetic tail on a longer time scale. The model predicts that the centres of the main convection cells will rapidly move antisunward to the ends of the nightside merging gap when the dayside reconnection rate becomes smaller than that in the geomagnetic tail - this is clearly evident in the figure 3. Hence the evolution of the flow pattern is well explained by the ECPC model. Lockwood [1991] has pointed out that for a circular polar cap, the peak dawn-dusk transpolar voltage, ϕ_{pc}, (defined to be across a full diameter of the polar cap) is the arithmetic mean of the voltages placed across the merging gaps by the reconnection at the subsolar magnetopause and in the nightside tail, ϕ_d and ϕ_n respectively. Scaling values from the equipotential contours of figure 3, part b yields ϕ_{pc} of about 95 kV at 10:30, whereas part c shows that it has decayed to about 25kV ten minutes later, when a voltage $\phi_n \approx 55$ kV appears across the nightside merging gap. For several tens of minutes after dayside reconnection has ceased, the nightside X-line can have no information about the change in the orientation of the magnetosheath field. Hence, to a first approximation, we can assume that ϕ_n remained at 55kV and we can calculate from ϕ_{pc} that ϕ_d decayed from 133kV

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to almost zero within the 10-minute period. The nightside voltage does not decay at this stage: we would estimate values for ϕ_n of about 50 kV, 50 kV and 40 kV from parts d, e and f (after another 10, 20 and 50 min., respectively). Lockwood [1991] has explained how this is consistent with the decay of transpolar voltages, as measured by polar-orbiting satellites, following northward IMF turnings [Wygant et al., 1983].

In the light of this discussion, we should consider the explanations for the evolution of the pattern put forward by Knipp et al. At the top of page 723 they consider three possibilities. By citing Greenwald et al. [1990], the authors invoke the idea that the change in the flow moves antisunward with the convection speed. This is what Greenwald et al. observed for B_y (not, as implied, B_z changes) in the cusp region. However, we can easily show that this is not how the effect of a B_z change spreads over the rest of the polar cap. If we consider a circular polar cap (consistent with figure 3 for the ECPC model) of radius r, a transpolar voltage of ϕ_{pc} yields flow speeds in the central polar cap, $v \approx \phi_{pc}/2rB$, where B is the ionospheric magnetic field strength. At this speed, the convection change would take a time $\delta t = r/v = 2r^2B/\phi_{pc}$ to reach the dawn-dusk meridian. For the ϕ_{pc} of 94 kV and r of 2000 km observed at 10:30 UT, δt is over 1 hour. In fact, the decay in dayside flows after 10:30 means that δt would be even greater than this. However, figure 3c shows that the reduction in flow speed has reached the centre of the polar cap within 10 min. This is a mean propagation speed for the flow reduction of over 3.5 km s^{-1}, consistent with the phase motion directly observed by Lockwood et al. [1986]. Lockwood and Cowley [1988] have shown how this is consistent with the observed increase in the response delay towards dawn and dusk, as observed by Etemadi et al. [1988] and Todd et al. [1988] and explained by Lockwood et al. [1990] in terms of the ECPC model.

Secondly, Knipp et al., suggest a possible role of the neutral wind "flywheel" effect. We point out here that this requires a reversal in direction of the normal region 1 and region 2 current systems [Cowley 1991] and to our knowledge this has never been observed. Furthermore, the plasma flows decay rapidly in the afternoon sector where winds are known to be strongest (due to the combined action of coriolis and centrapetal accelerations), but are best maintained in the post-midnight sector where winds are known to be weakest.

The last suggestion by Knipp et al. (that the nightside ionosphere was communicating with a portion of the magnetosphere which was, as yet, unaffected by the northward turning of the IMF) is, in essence, the prediction of the ECPC model, and is the one which is consistent with the previous studies discussed here.

In conclusion, the results presented by Knipp et al. are very interesting and do demonstrate very well the great power and potential of the AMIE technique. The point we wish to make here is that the response to IMF B_z presented is exactly as predicted by the ECPC model.

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S.W.H. Cowley, Blackett Laboratory, Imperial College, London, SW7 2BZ, UK.

M. Lockwood, Rutherford Appleton Laboratory, Chilton, Didcot, OX11 0QX, UK.

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