Convection in the Magnetosphere-Ionosphere System: a Multi-Mission Survey of its Response to IMF B_y Reversals

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1. Summary

The y-component of the interplanetary magnetic field (IMF B_y) exerts significant influence on the variability of the coupled solar wind-magnetosphere-ionosphere system. Through multiple superposed epoch analyses, we have identified some of the timings involved in the SW-M-I system's response to reversals in the orientation of the IMF B_y component. Data from the Cluster Electron Drift Instrument indicates that the lobes respond quickly, with initial changes starting in as a little as 5 min after a reversal and an end state being reached within 30-40 min. However, plasma flows recorded in the plasma sheet show no clear response to IMF B_y reversals suggesting that the dynamics in this region are more complex. Data from the ground-based SuperDARN radar network show that ionospheric flows match their counterparts in the magnetosphere.

2. IMF B_y control

It is well known that the IMF B_y component influences many different aspects of the magnetosphere-ionosphere system. For example, in the magnetosphere, an IMF B_y component shifts the site of dayside reconnection, introduces twisting of the magnetotail, and produces directionally-dependent fast flows in the magnetotail associated with untwisting. In the ionosphere, the IMF B_y component has been shown to drive asymmetries in the aurora, including in transpolar arcs, and form large-scale morphological changes to the ionospheric convection patterns.

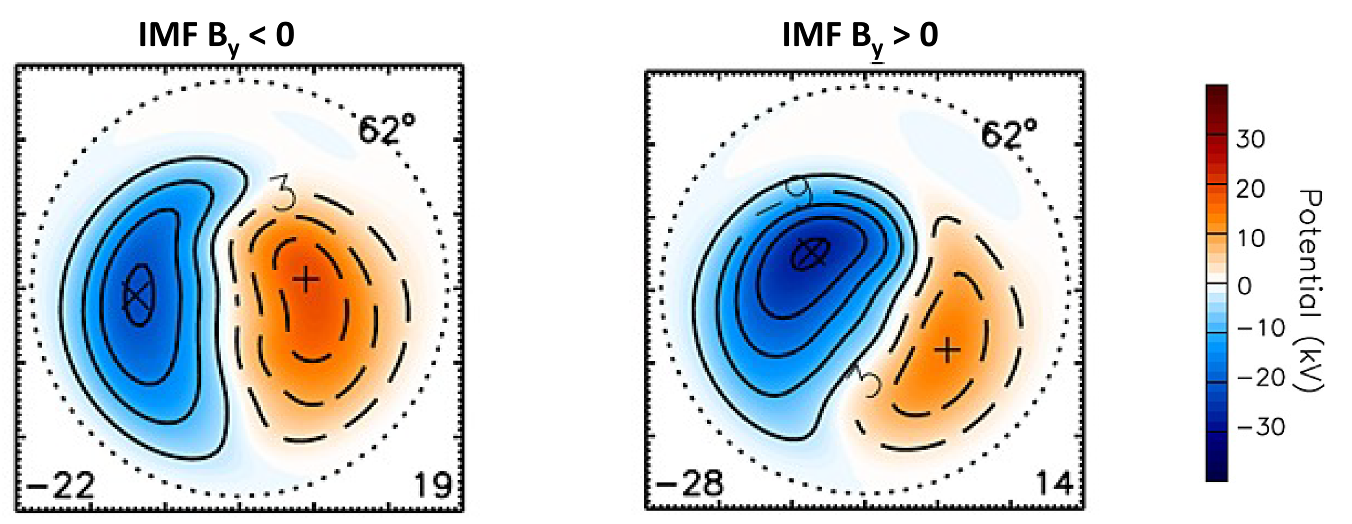

Fig 1. The average convection pattern for IMF B_y < 0 and IMF B_y > 0, over a 20-30min steady period [Adapted from Fig. 3 in Grocott & Milan, 2012]. The figure shows the typical two-cell convection pattern which is highly dependent upon the IMF By orientation.

However, how long it takes the M-I system to respond to changes in upstream driving, particularly to reversals in the IMF B_y component, has remained unclear.

3. IMF B_y reversal identification

Using the method discussed in Case et al. (2018), we identify intervals where the IMF B_y component switches orientation (e.g. $B_y > 0$ to $B_y < 0$), having been steady before the reversal and remaining steady afterward. Doing so allows us to undertake superposed epoch analyses, with the reversal time defined as "zero epoch".

To study the response time of the magnetosphere, we look at two regions – namely the lobes and the plasma sheet. For convection data in the lobes, we utilise the Cluster mission's EDI data and for the plasma sheet, we utilise Cluster's CIS, Geotail's LEP, and Themis' iESA instruments. Additionally, to find the corresponding flow data in the ionosphere, we utilise the SuperDARN ionospheric radar network.

4. Magnetotail lobe flow response

In the following figure are the averaged Y-directed flows for the night-side magnetotail lobes ($X < 0\ R_E$) for both hemispheres and IMF B_y reversal types.

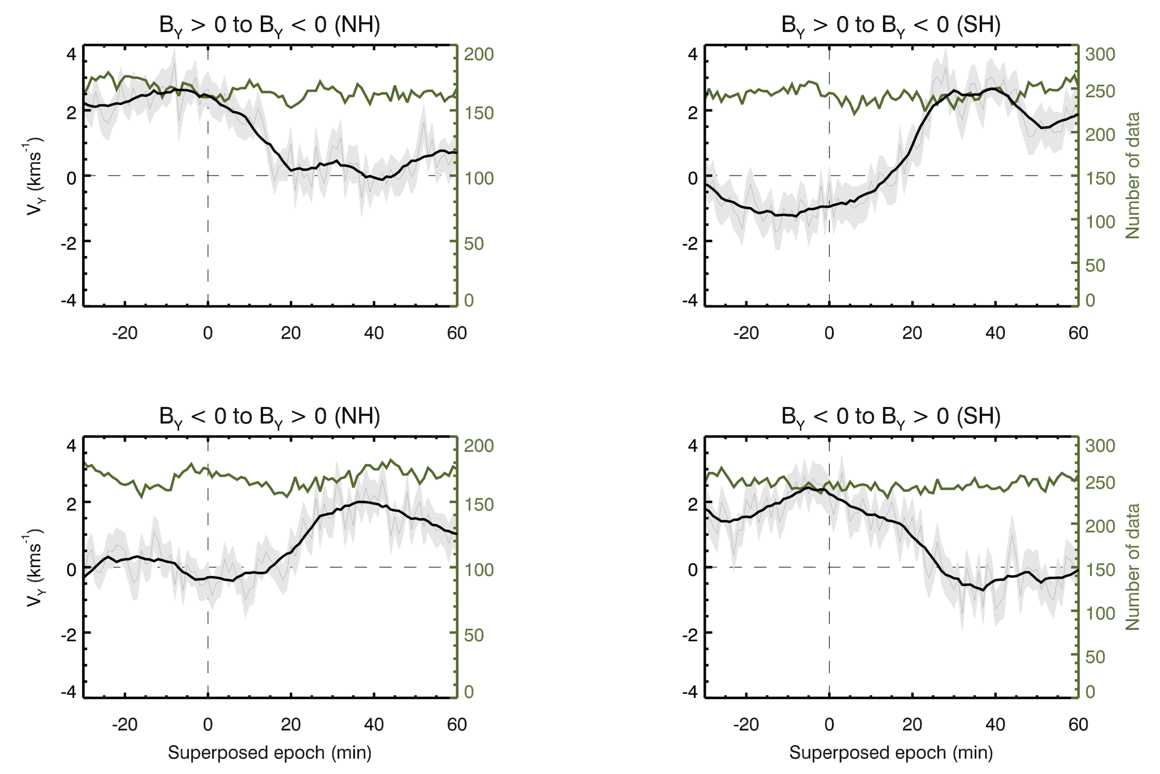

Fig 2. The average lobe flows for 30 min preceding an IMF B_y reversal to 60 min afterward. Data are split into four panels based on hemisphere and reversal direction. The grey line on the secondary y-axis shows the number of data per timestep.

We see a clear response in the direction of the lobe flows to a reversal in the IMF B_y orientation. In the Northern Hemisphere (NH), flows are in the positive Y direction for IMF $B_y > 0$ and negative Y direction for IMF $B_y < 0$. This is reversed in the Southern Hemisphere (SH). This result is consistent with asymmetric flux loading of newly opened magnetic field lines on the dayside magnetopause.

The flows respond quickly to an IMF B_y reversal. The direction of the flows starts to change almost immediately following a reversal and have completely reversed direction within 30-40 min.

5. Plasma sheet flow response

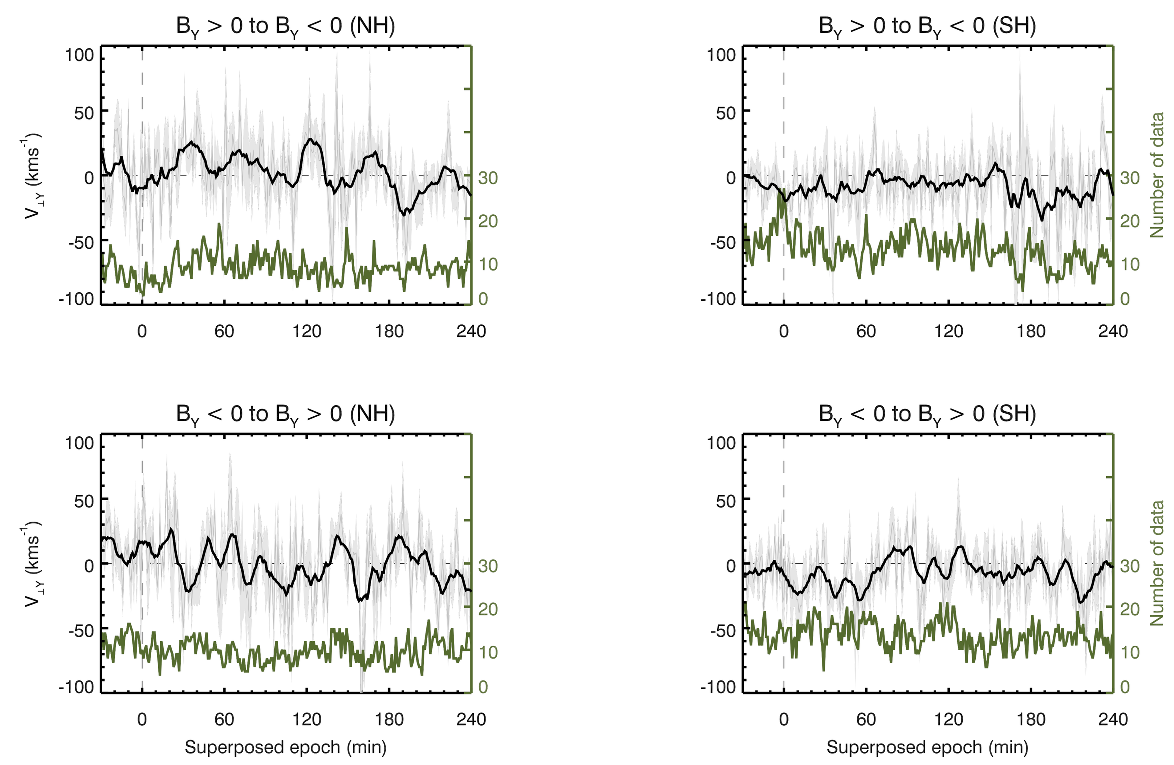

Fig 3. The average plasma sheet flows are presented in the same format as Fig 2.

Unlike the lobe flows, we do not see a clear response in the direction of the plasma sheet flows to a change in the IMF B_y orientation. In fact, there appears to be no relationship between the flow direction and the IMF B_y orientation at all. Small data numbers could be an issue, so we check the SuperDARN data to verify.

6. Ionospheric flow response

Flows in the ionosphere are intrinsically linked to the convection of the magnetic field in the magnetotail, with different latitudes mapping out to different regions of the tail. Therefore looking in the ionosphere provides a useful source of information on the magnetotail dynamics.

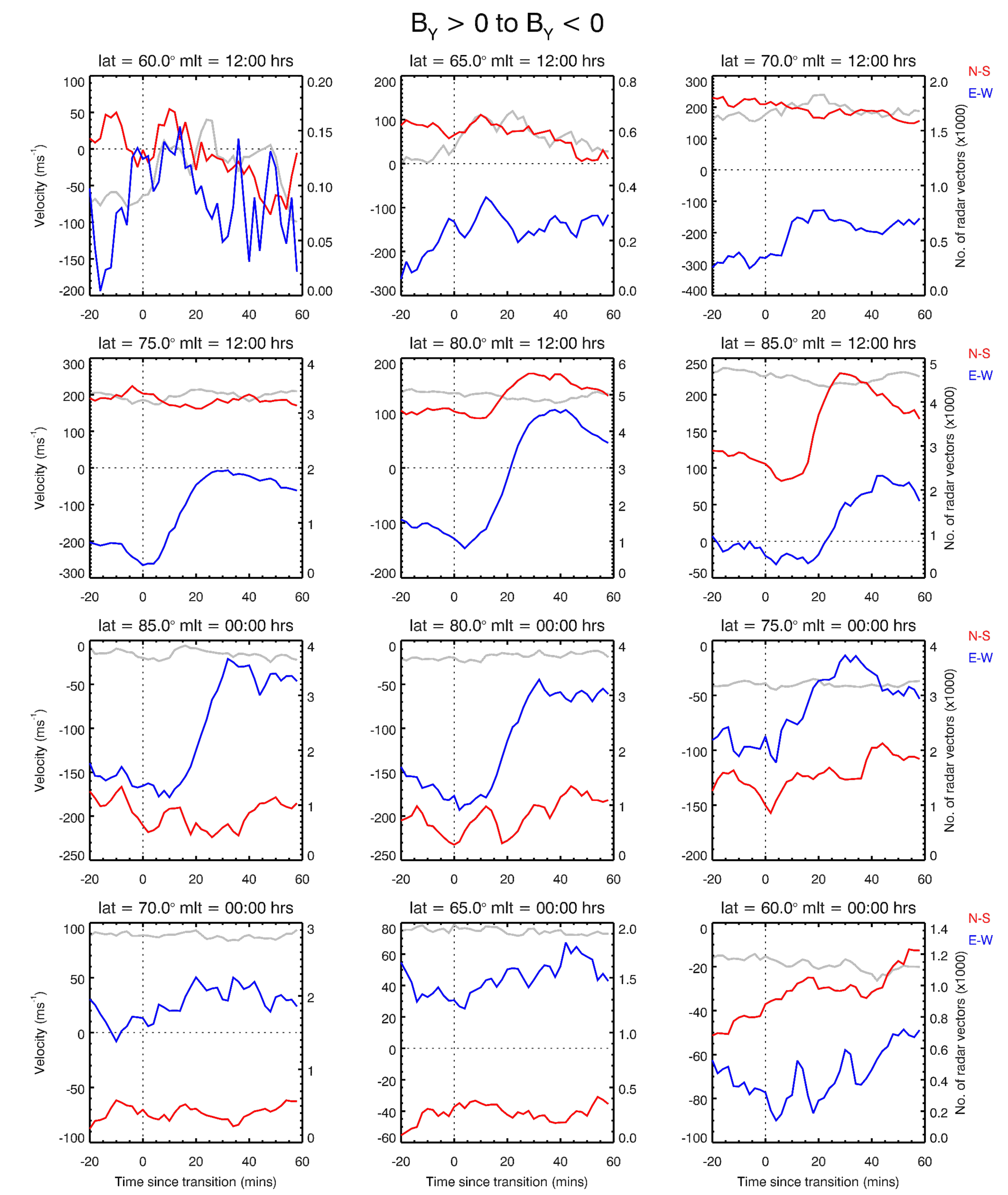

Fig 4. Ionospheric flows recorded in the Northern Hemisphere by the SuperDARN radar, associated with a positive to negative IMF B_y reversal. Plotted in red are the average velocities in the North-South direction and in blue in the East-West direction.

For latitudes ≥75° MLAT (ACCGM coordinates), we see a clear response in the ionospheric flow direction to the orientation of the IMF B_y component. At 80° MLAT, mapping into the lobe region, we see a clear reversal in the E-W ionospheric flow direction. This result is consistent with the lobe flows in Fig 2.

At latitudes ≤70° MLAT, however, the response is much less clear. Indeed, at 60° MLAT there is no response evident at all – which is consistent with a lack of response in the in situ plasma sheet data in Fig 3.

7. Conclusions

- Lobe flow orientation is controlled by the IMF B_y direction and respond promptly to changes. Response starts almost immediately and is complete within 30-40 min.
- Data from the ionosphere at ≥75° MLAT also shows this clear and prompt response.
- Flows in the plasma sheet do not appear to respond to IMF B_y direction, and nor do the corresponding ionospheric flows (≤70° MLAT).
- This seems to contradict previous results (e.g. Juusola et al., 2011), however, we suggest it may be due to timing. Fast plasma sheet flows may require, e.g., reconnection events and this timing may be lost during a superposed epoch analysis.

References

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