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Interactive comment on "Local time extent of magnetopause reconnection X-lines using space–ground coordination" *by* Ying Zou et al.

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This paper is concerned with estimating the extent of reconnection X-lines on the Earth's magnetopause, with an overall aim of measuring, and understanding spatial and temporal variability in magnetic reconnection. For studies of this type, conjugate observations combining spacecraft and ground-based measurements can be very important. There are some aspects of reconnection (such as the localised plasma physics) that can only be measured by in-situ spacecraft. There are also some aspects (such as the macrophysics of the process) that can only be measured by instruments that provide a wider view, such as auroral imagers or ground-based radars. However, the local time extent of reconnection regions can only be determined unambiguously using ionospheric measurements (in the absence of a massive armada of spacecraft). Similarly, the amount of flux transfer occurring during reconnection can only be deter-

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mined unambiguously using ionospheric measurements. And consequently, the patchy (spatial variation) and bursty (temporal variation) of reconnection can only be unambiguously studied using ionospheric measurements.

To measure the extent of reconnection from ionospheric measurements (which can then be mapped back to the magnetopause) first requires the identification of the ionospheric footprint of the open-closed magnetic field line boundary (OCB). The regions where the ionospheric plasma flow crosses this boundary (in the frame of the boundary – which is typically in motion itself) map to the regions on the magnetopause where reconnection is occurring. Although the text shows that the authors appear to appreciate this, they do not analyse their ionospheric data in this way.

Consequently, I have some major issues with the introductory text and the radar data analysis and presentation. The authors need to address these major points before the paper can be reviewed properly.

(1) Some of the background referencing is misdirected and inadequate:

The referencing of spacecraft observations associated with reconnection (extending from lines 95 to 117) starts with the phrase – 'The extent of reconnection X-lines has been observationally determined based on fortuitous satellite conjunctions…'. This is not true. Even if the word 'determined' was changed to 'estimated' it would still be a stretch of the truth. The 'extent of reconnection X-lines' cannot be unambiguously determined (or even estimated) from spacecraft observations. Interpretations of multiple spacecraft observations still have to make the assumption that the X-line is continuous between spacecraft, or that it is not continuous between spacecraft. X-lines may also continue longitudinally outside of the view of the spacecraft. All that multiple spacecraft measurements can do (given that the assumptions made are correct) is provide upper or lower limits on the X-line extent.

The referencing of ionospheric observations associated with reconnection (extending from lines 118 to 141) concentrates on those related mainly to local (often single radar) measurements of fast anti-sunward flows observed by radar (such as pulsed ionospheric flows [PIFs]) and their auroral counterpart (poleward-moving auroral forms [PMAFs]). These typically occur within the polar cap, and not necessarily at the ionospheric footprint of the OCB. Although all these observations are of phenomena that are consequences of reconnection, and which provide important information about the patchy and bursty nature of reconnection (and links to FTEs, etc.), they don't allow the unambiguous estimation of the extent of the X-line. Hence, many of these references are actually superfluous to the paper.

As mentioned above, to measure the extent of the reconnection X-line in the ionosphere requires the identification of the footprint of the OCB and the region for which there is plasma flow across it. (Although, similar caveats to the spacecraft observations also exist if there is not complete longitudinal coverage covering the whole ionospheric projection of the X-line.) There are a large number of papers that have studied and measured reconnection in this way that are not mentioned in the introduction of the present paper. A significant reference that reviews most of the work in this area, as well as outlining the techniques required to make these measurements, is Chisham et al. (2008) – Remote sensing of the spatial and temporal structure of magnetopause and magnetotail reconnection from the ionosphere – Rev. Geophys., 46, RG1004. Other papers that have measured the extent of the reconnection X-line using these methods include; (i) Pinnock et al. (2003) – The location and rate of dayside reconnection during an interval of southward interplanetary magnetic field – Ann. Geophys., 21, 1467-1482, which studied the same event that was observed in Equator-S data by Phan et al. (2000). They estimated the length of the reconnection X-line on the dayside magnetopause at this time to be ∼38 Re based on the 10 hours of local time that flow was observed crossing the OCB in the ionosphere. (ii) Chisham et al. (2004) – Measuring the dayside reconnection rate during an interval of due northward interplanetary magnetic field – Ann. Geophys., 22, 4243-4258, which measured the X-line extent of lobe reconnection during northward IMF to be ∼6-11 Re.

(2) Identification of the extent of the reconnection region from fast ionospheric flows is flawed:

Lines 52-54 state – ‘The extent has also been inferred by radars as fast ionospheric flows moving anti-sunward across the open-closed field line boundary, but whether a particular ionospheric flow results from reconnection needs to be confirmed.’ Firstly, the measured flows do not need to be fast. The fast flows highlighted in the paper are obviously driven by reconnection but these are predominantly polar cap flows (relating to the newly-opened flux tubes moving over the polar regions towards the nightside), not flows at and across the OCB. Any flow across the OCB, whether fast or slow, implies that reconnection has occurred, as closed flux has been converted to open flux. By the same argument, if flow across the OCB is measured, spacecraft measurements are not required to prove that this flow is a result of reconnection (hence I disagree with the statement on lines 132-135).

Lines 198-206 detail the SuperDARN radars used in the study. What I do not understand is why the authors restricted their study to only a few of the northern hemisphere radars when there is a much wider network of northern hemisphere SuperDARN radars that would provide a much greater longitudinal coverage? Larger coverage provides a much better global picture of the ionospheric convection and hence the reconnection-driven flows across the OCB.

Lines 297-298 state – ‘The extent is determined at half of the maximum flow speed, which was ∼400 m/s’. Why? There is still flow across the boundary outside this region that results from reconnection. Consequently, the dashed magenta lines in figures 2, 4, and 6 mean nothing, except to nicely frame the fast poleward flows into the polar cap. In a similar vein, lines 366-367 state ‘We quantify the flow azimuthal extent as the full-width-at-half-maximum (FWHM) of the velocity profile’. Why? Any poleward flow (across the OCB) represents the creation of newly reconnected flux. In all 3 examples there are significant poleward flows east of the dashed magenta lines.

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In figures 2e and 2f the flow extent is ‘quantitatively determined’ using measurements at 80 degrees latitude. Why use the flows at this latitude to determine the longitudinal extent when they are well within the polar cap? These are not the same as the flows at the OCB latitude, and hence they do not show the longitudinal extent of reconnection. Hence, they cannot be reliably used to estimate the length of the X-line.

(3) The open-closed field line boundary (OCB) in the ionosphere is insufficiently determined:

Lines 390-391 state ‘The flow crossed the open-closed field line boundary at 77 degrees MLT. . .’. The determination of the OCB location is not clearly outlined anywhere or displayed clearly on the figures. Indeed, the OCB location in figures 2, 4, and 6 is never sufficiently determined (or visually presented) so it is impossible to know what the longitudinal extent of flows across the boundary is. The boundary is vaguely discussed as being the equatorward edge of the cusp, which is identified in these figures as being co-located with regions of high Doppler spectral width. (In actuality, comparing figures 2c and 2d, the poleward flow at the equatorward edge of the cusp is slower than that within the polar cap, and most likely extends over a wider longitudinal region.) Although the high spectral width regions circled in these figures may very likely be a result of cusp precipitation, they do not necessarily highlight the full extent of the cusp. High spectral width values are observed within the polar cap at all magnetic local times (see the discussions and references in Chisham et al. (2008) [details above], and Chisham et al. (2007) – A decade of the Super Dual Auroral Radar Network (SuperDARN): scientific achievements, new techniques and future directions – Surv. Geophys., 28, 33-109 [specifically sect. 4, pages 60-67]). If Doppler spectral width is being used to estimate the location of the OCB then it is important to determine the spectral width boundary (SWB) location (see references in the same 2 papers). It is also important that spectral width values are only considered from radar beams that are aligned close to the meridional direction (see Chisham et al. (2005) – The accuracy of using the spectral width boundary measured in off-meridional SuperDARN HF radar beams as a proxy for the open-closed field line boundary – Ann. Geophys., 23, 2599-2604).

(4) Quality and clarity of the figures containing the radar data:

The radar data plots in figures 2, 4, and 6 are incredibly messy, cluttered, and difficult to interpret, especially panels a and d, where line-of-sight (LOS) velocity and spectral width are displayed across the radar fields-of-view. These figures need to be simplified. Is all the LOS velocity data required in panel a? Are the merged vectors not information enough? Especially given that the LOS data on their own are open to severe misinterpretation. Can a boundary be determined from the spectral width data (see above) rather than highlighting a vague blob of high spectral width? If such a boundary was determined, then over-plotting this boundary on the velocity vector panels would be highly informative.

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