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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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Review of Zou et al for Annales Geophysicae, 28 Aug 2018

This manuscript uses a combination of satellite and ground-based radar data to estimate the spatial extent of magnetopause reconnection for 3 example events. The motivation for the study is very good and the results are potentially interesting and important but, in my view, the crucial radar analysis falls short of the state of the art and needs improving to support the interpretation. Even if this does not radically change the main results, it would put the results on a sounder footing, better evaluate sources and sizes of uncertainties, and allow the results given here to be compared more objectively to past and future studies. For this reason, I would not recommend publication in its present form. My recommendations are as follows:

1. Follow the state of the art

In the current analysis, evidence for the reconnection X-line is essentially based on looking for high-speed flows in the vicinity of a high radar spectral width region (e.g., Figure 2a-d) and the X-line extent is estimated from a longitudinal profile of northward velocity at a relatively arbitrary magnetic latitude. In my view this is a rather crude analysis and it should be possible to do this better by estimating the profile of the reconnection electric field itself along the open-closed field line boundary (OCB) and its time evolution following the methodology set out in detail in:

Chisham, G., et al. (2008), Remote sensing of the spatial and temporal structure of magnetopause and magnetotail reconnection from the ionosphere, Rev. Geophys., 46, RG1004, doi:10.1029/2007RG000223.

Freeman, M. P., G. Chisham, and I. J. Coleman (2007), Remote sensing of reconnection, in Reconnection of Magnetic Fields, edited by J. Birn and E. Priest, chap. 4.6, pp. 217–228, Cambridge Univ. Press, New York.

In essence, this method requires the following steps:

a. Identify the OCB objectively at as many locations as possible using available datasets and interpolate in space and time where necessary using suitable models, e.g., figures 6, 8, 9, 11 in Chisham et al (2008).

b. Estimate the reconnection electric field along the OCB by measuring the electric field component parallel to the boundary (or ExB velocity component perpendicular to it) in the rest frame of the generally moving boundary, e.g., figure 13 in Chisham et al. (2008).

c. Plot profiles of the reconnection electric field versus MLT over the time interval of interest. Use the zero crossing locations of these profiles to estimate the MLT extent of reconnection as a function of time, e.g., figure 7 of Pinnock et al., (2003), The location and rate of dayside reconnection during an interval of southward interplanetary magnetic field, Ann. Geophys., 21, 1467–1482.

d. Project the MLT extent to the magnetopause using a suitable model to estimate the X-line length and its evolution and to compare with in-situ spacecraft observations of presence or absence of reconnection, e.g., figure 8 of Pinnock et al. (2003).

The authors' analysis is only a very crude approximation to this. Particular areas of improvement that I would recommend include:

2. Improved estimates of the OCB (step 1a above)

a. The authors use a 150 m/s spectral width threshold to estimate the OCB but then apply it rather vaguely by drawing a red contour in figures 2d, 4d, 6d which doesn't match the 150 m/s threshold everywhere. The authors then largely ignore this anyway by using examining the ExB velocity on a fixed latitude circle that is generally poleward of where they say the OCB is. For example, for the first event in section 3.1.2, in lines 293-295 it is said that the OCB is at 77 deg latitude based on the spectral width in figure 2d but in lines 360-366 the 80 deg latitude circle is used as the OCB for the velocity cross-section shown in figure 2f. Similarly, in section 3.2.2, it is 77 deg latitude (lines 390-391) from figure 4d and 79 deg latitude (figure 4 caption) used for figure 4f. And in section 3.2.2, it is 80 deg latitude (figure 6 caption) used for figure 6g,h but the spectral width boundary is unstated and appears to be at lower latitude (at about the projected THA position).

b. According to the following references it should be possible to estimate the OCB from spectral widths at a wide range of local times using the method of Chisham and Freeman (2004) and I recommend that this be attempted more carefully and objectively.

Chisham, G., and M. P. Freeman (2003), A technique for accurately determining the cusp-region polar cap boundary using SuperDARN HF radar measurements, Ann. Geophys., 21, 983–996.

Chisham, G., and M. P. Freeman (2004), An investigation of latitudinal transitions in the SuperDARN Doppler spectral width parameter at different magnetic local times, Ann. Geophys., 22, 1187–1202.

Chisham, G., M. P. Freeman, and T. Sotirelis (2004a), A statistical comparison of SuperDARN spectral width boundaries and DMSP particle precipitation boundaries in the nightside ionosphere, Geophys. Res. Lett., 31, L02804, doi:10.1029/2003GL019074.

Chisham, G., M. P. Freeman, T. Sotirelis, R. A. Greenwald, M. Lester, and J.-P. Villain (2005a), A statistical comparison of SuperDARN spectral width boundaries and DMSP particle precipitation boundaries in the morning sector ionosphere, Ann. Geophys., 23, 733–743.

Chisham, G., M. P. Freeman, T. Sotirelis, and R. A. Greenwald (2005b), 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.

Chisham, G., M. P. Freeman, M. M. Lam, G. A. Abel, T. Sotirelis, R. A. Greenwald, and M. Lester (2005c), A statistical comparison of SuperDARN spectral width boundaries and DMSP particle precipitation boundaries in the afternoon sector ionosphere, Ann. Geophys., 23, 3645–3654.

c. The OCB can also be estimated from other data, such as DMSP particle precipitation. It seems that this data might be available for the events studied, see https://heliophysicsdata.sci.gsfc.nasa.gov/websearch/dispatcher Even if not particularly close in MLT or UT it may be useful as a constraint.

d. The T89 model projections of the THA magnetopause crossing to the ionosphere in Figures 4 and 6 appear to agree with the OCB location estimated from the spectral width. It would thus seem reasonable to use the model to estimate the OCB location in the ionosphere at all dayside MLT at this UT.

The projected location of THE may be different in these two cases because from Figure 3 there is evidently a rapid outward expansion of the magnetopause from 9.4 RE to 10.2

RE between 1826 and 1828 UT which would need appropriate re-scaling of the model to capture, and in Figure 5 the spacecraft are separated by over 30 min in time and so again the model conditions are probably different. In these cases, and for the figure 2 event, it seems reasonable to explore simple scalings of the T89 model that would fit the magnetopause crossing location of each spacecraft and see if this improves the projected location of the spacecraft with respect to the spectral width boundary. If so, then the model could be used to extrapolate to all dayside MLT.

e. Alternatively, a simple offset circle model is commonly a good approximation to the OCB, whose free parameters could be constrained by spectral width and possibly DMSP data. This would at least be an improvement on assuming a latitudinal circle that is rather unrelated to the spectral width boundary.

In all of the above cases, limitations and assumptions can be assessed by error and sensitivity analyses. For example, how are the results 1b-d above affected by changing the inferred boundary by 1 degree say?

3. Take account of the generally moving OCB (step 1b above)

As emphasised in the references in 1 above, the reconnection rate is the electric field in the frame of the moving OCB and this can sometimes affect the inference of whether reconnection is occurring or not, e.g., see Figure 13 of Chisham et al. (2008). Some account of this should be taken in the present analysis as it may affect the edges of the inferred reconnection region in particular and hence the FWHM.

4. Project the ExB velocity perpendicular to the boundary (relevant to step 1c above)

Given the strong rotation of the flow seen in figure 2 in particular, consideration should be given of the effect of uncertainties in the assumed orientation of the OCB on the projected flow component across it as this could change the inferred X-line extent.

5. Improved consideration of the temporal evolution

The current analyses are strongly biased towards comparisons of magnetopause and

ionospheric observations of reconnection at a common instant. Given the uncertainties in how reconnection may evolve at the magnetopause, and the ionospheric response times, it would helpful to repeat the analysis shown in figure 2f, 4f, and 6g,h at some sampling frequency throughout the intervals shown in figures 2e, 4e, and 6e,f. The temporal evolution of los data shown in figures 2e, 4e, and 6e,f are a rather poor proxy by which to estimate the evolution of X-line extent and something similar to figure 7 of Pinnock et al (2003) would be very interesting to see, especially for the inferred complex evolution of the Apr 29 event.

6. Discrepancies in magnetopause to ionosphere projection (step 1d above)

The magnetopause crossings of spacecraft THA and THD in figure 2, and THE in figure 4 (and possibly figure 6 too) project several degrees of latitude away from the expected OCB location based on spectral width. This suggests that the estimation of X-line extent at the magnetopause from that inferred in the ionosphere will be in error because it is based on the same T89 model that seemingly incorrectly projects the satellite position to the ionosphere. As mentioned in 2d above, it would be helpful to try to estimate the uncertainty by considering whether there is some simple rescaling of the T89 model that would reduce the discrepancy in the magnetopause-to-ionosphere projection.

I would also add that the description of the mapping method given in lines 372-376 is too vague to allow others to reproduce your method. It also seems that you use the same T89 mapping factor of 55 for all three events, which seems questionable, e.g., solar wind dynamic pressure is 50% larger for Apr 19 event. It also implies that the factor is the same for all MLT which is unlikely I think, especially over the 10 Re magnetopause extent inferred for the Apr 29 event. Please could you improve your method description and assess the associated uncertainties.

7. I would recommend that you reference and discuss the following first 5 papers in lines 136-141 as these have done a similar comparison of simultaneous reconnection

evidence from space and ground to infer X-line length. I would also recommend that you consider the implications of these and the sixth reference to your discussion in section 3.4 as they seem to be relevant to the factors affecting X-line extent (e.g., IMF orientation, component or anti-parallel reconnection, turbulence):

Phan, T.D., Freeman, M.P., Kistler, L.M. et al. Earth Planet Sp (2001) 53: 619. https://doi.org/10.1186/BF03353281

Pinnock, M., G. Chisham, I. J. Coleman, M. P. Freeman, M. Hairston, and J.-P. Villain (2003), The location and rate of dayside reconnection during an interval of southward interplanetary magnetic field, Ann. Geophys., 21, 1467–1482.

Coleman, I. J., G. Chisham, M. Pinnock, and M. P. Freeman (2001), An ionospheric convection signature of antiparallel reconnection, J. Geophys. Res., 106, 28,995–29,007.

Chisham, G., I. J. Coleman, M. P. Freeman, M. Pinnock, and M. Lester (2002), Ionospheric signatures of split reconnection X-lines during conditions of IMF Bz < 0 and |By| $\sim$ |Bz|: Evidence for the antiparallel merging hypothesis, J. Geophys. Res., 107(A10), 1323, doi:10.1029/2001JA009124.

Chisham, G., M. P. Freeman, I. J. Coleman, M. Pinnock, M. R. Hairston, M. Lester, and G. Sofko (2004b), Measuring the dayside reconnection rate during an interval of due northward interplanetary magnetic field, Ann. Geophys., 22, 4243–4258

Coleman, I. J., and M. P. Freeman (2005), Fractal reconnection structures on the magnetopause, Geophys. Res. Lett., 32, L03115, doi:10.1029/2004GL021779.

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