

Reply to comment by G. A. Abel, M. P. Freeman, and G. Chisham on “Location of the reconnection line for northward interplanetary magnetic field”

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1. Introduction

[1] In their comment, *Abel et al.* [2005] express concern about the conclusions presented in the study on the location of the reconnection line for northward interplanetary magnetic field (IMF) by *Trattner et al.* [2004]. This study concluded that both reconnection scenarios, antiparallel and component reconnection, occur simultaneously [see also *Nishida et al.*, 1998; *Onsager et al.*, 2001]. During northward IMF conditions, the location of the high-latitude antiparallel reconnection region depends on the IMF B_y component, and its local time extent is limited. A reconnection line formed in the antiparallel region at high latitudes will not be limited to this region but will extend into regions with smaller magnetic shear angles, forming long reconnection lines extending over several hours in MLT. Therefore, being magnetically connected to an antiparallel or component reconnection site depends mainly on the location of the observing satellite.

[2] The method used by *Trattner et al.* [2004] is based on calculating the distance to the reconnection site from low-velocity cutoffs of the downward precipitating and the mirrored magnetosheath distributions in the cusp [see *Onsager et al.*, 1991; *Fuselier et al.*, 2000]. The calculated distance was traced back along the geomagnetic field, starting at the position of the Polar satellites, by using the semiempirical Tsyganenko 1996 (T96) magnetic field model [*Tsyganenko*, 1995]. The IMF direction and geomagnetic field direction at the location of the reconnection site was used to calculate the magnetic shear angle for the reconnection site. For this purpose, the IMF observed upstream of the bow shock by the Wind spacecraft, had to be draped around the magnetopause using the model by *Cooling et al.* [2001], while again the T96 magnetic field model at the reconnection location was used for the geomagnetic field direction.

[3] In their comment, *Abel et al.* [2005] rebinned the events of *Trattner et al.* [2004] and showed that events for component reconnection seems to mainly occurring during positive IMF B_x conditions while antiparallel reconnection events are occurring during negative IMF B_x conditions.

Abel et al. [2005] suggest that a possible explanation lies in how IMF field lines drape around the magnetopause. In particular, they suggest an increased likelihood of departure from the model orientation for an increased distance from the point of first contact. For negative IMF B_x conditions, the IMF will contact the magnetopause first in the northern hemisphere at high latitudes and close to the observations of the Polar satellite discussed by *Trattner et al.* [2004]. For positive IMF B_x conditions the IMF will contact the magnetopause first in the southern hemisphere and draping these field lines around the magnetopause to the northern hemisphere might cause large deviations from the upstream clock angle, causing some of the component events to be consistent with antiparallel reconnection. While *Abel et al.* [2005] put forth an interesting scenario, we do not think the data support the conclusions.

2. Observations

[4] The magnetic local time (MLT) range for events with positive IMF B_x and negative IMF B_y were accidentally reported as 1700–1730 MLT in Table 1 of *Trattner et al.* [2004]. This is the result of a typo where the same MLT range from the neighboring column (negative IMF B_x and negative IMF B_y) was copied into this column. The correct MLT range for the 16 component reconnection events is 1230–1700 MLT.

[5] Figure 1 shows the magnetopause as seen from the Sun for the four possible IMF B_x , B_y directions during northward IMF conditions. Green lines represent magnetopause field lines from the T96 magnetic field model, while red lines depict the IMF field lines from the model by *Cooling et al.* [2001] fully draped around the magnetopause.

[6] Figures 1a and 1b show the conditions for positive IMF B_x , where 5 antiparallel reconnection cases and 18 component reconnection cases have been reported by *Trattner et al.* [2004]. Figures 1c and 1d show the magnetic field configurations for the negative IMF B_x cases, where 24 antiparallel cases and 5 component reconnection cases have been observed.

[7] Figures 1a and 1c depict the 33 Parker spiral cases ($-B_x$, $+B_y$ and $+B_x$, $-B_y$) of the *Trattner et al.* [2004] study

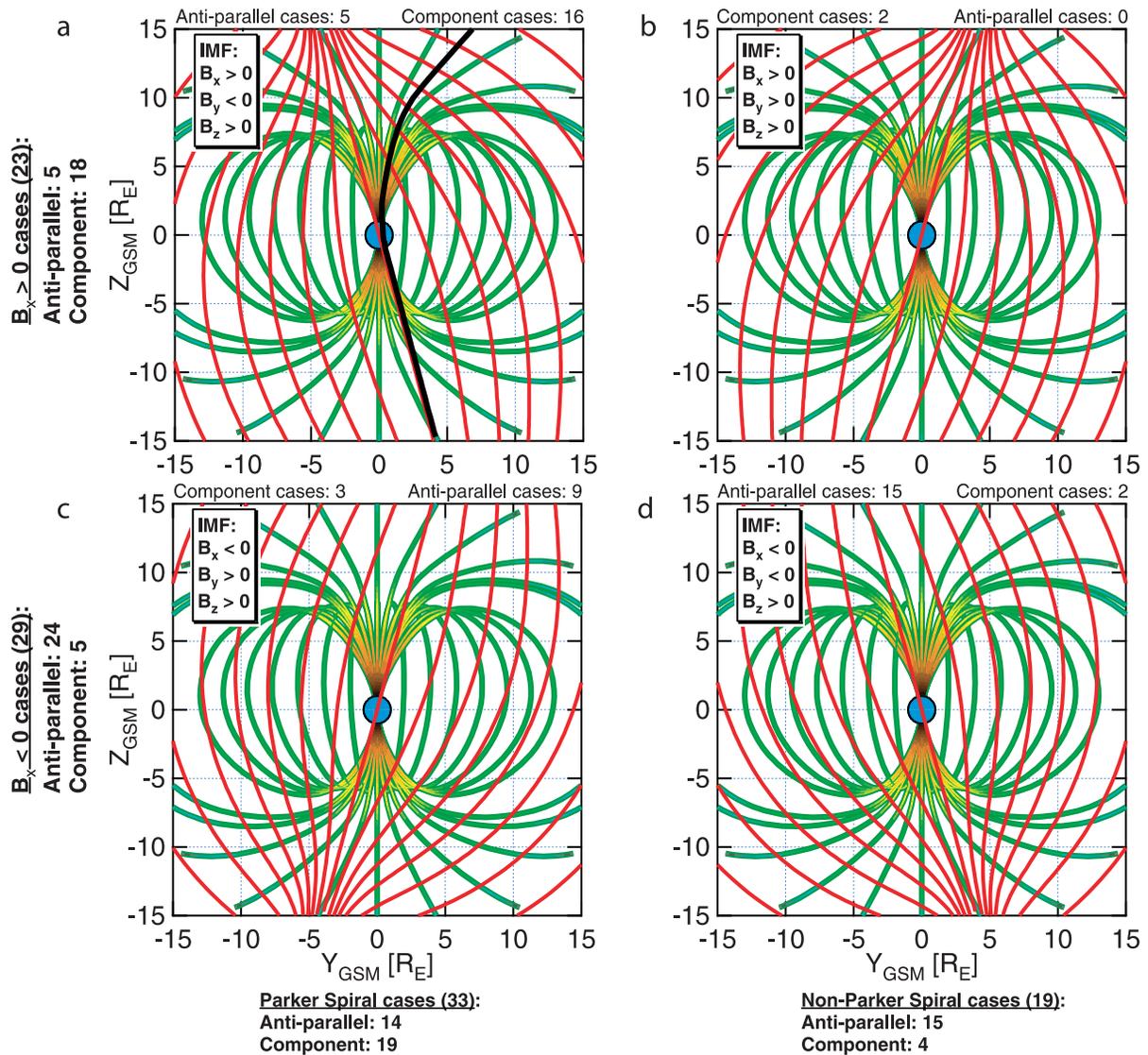


Figure 1. Magnetopause field lines (green) from the T96 magnetic field model and IMF field lines (red) from the model by *Cooling et al.* [2001] fully draped around the magnetopause. (a and b) Conditions for positive IMF B_x conditions and (c and d) conditions for negative IMF B_x conditions. Also displayed are the occurrences of antiparallel and component reconnection events from the *Trattner et al.* [2004] study for these IMF conditions.

in which 14 cases were observed for the antiparallel magnetic field configuration and 19 cases for the component reconnection scenario. Figures 1b and 1d show the 19 non-Parker spiral cases ($-B_x$, $-B_y$ and $+B_x$, $+B_y$) of the study with 15 antiparallel cases and 4 component cases.

[8] For Parker spiral IMF conditions with positive B_x and negative B_y (Figure 1a) the antiparallel reconnection site in the northern hemisphere will be in the dawn sector. The Polar spacecraft in the dawn sector of the cusp would be on a field line mapping to the antiparallel reconnection site (five events) while the Polar spacecraft in the dusk sector would be connected to the component reconnection site (16 cases).

[9] *Abel et al.* [2005] suggests that large deviations from the upstream clock angle might affect the calculation of the magnetic shear angle at the magnetopause, causing cases

which are derived as component reconnection cases to be designated as antiparallel reconnection cases (not considered in the calculation of the magnetopause shear angle are uncertainties in the T96 magnetic field model). A comparison of clock angle observations at the magnetopause with the perfect draping approximation by *Coleman* [2005] showed that the average clock angle in the magnetosheath does reflect the orientation of the upstream IMF to within 30° or less. However, the general assumption that the magnetic field direction at any particular region of the magnetopause is approximately similar to the IMF direction could not be justified.

[10] The *Trattner et al.* [2004] study did not assume perfect draping. Rather, it uses the *Cooling et al.* [2001] model to drape the upstream IMF around the magnetopause. This model is based on the *Kobel and Flückiger* [1994]

magnetic field model which is a straightforward analytic solution for the magnetic potential within the magnetosheath, bounded by a parabolic bow shock and parabolic magnetopause. While this is a valid solution given the specified boundary conditions (i.e., tangential magnetic field at the magnetopause, and a constant magnetic normal component across the bow shock), it is not quite correct. Explicitly, the tangential magnetosheath magnetic field just downstream of the bow shock does not agree well with the Rankine-Hugoniot relations. However, it is anticipated that this problem is only of significant concern in regions where the magnetic field is very small (i.e., where the Alfvén Mach number is very high), or where the IMF is predominantly x -directed. For this reason, *Trattner et al.* [2004] eliminated cases for which the IMF is strongly dominated by the x component (15 events out of a total of 67).

[11] The red lines in Figure 1 represent magnetic field lines derived from the model by *Cooling et al.* [2001]. The bowing of field lines at high latitudes or the flanks indicates that they deviate considerably from the magnetic field direction across the subsolar point (which should already provide a significantly better estimate of the actual clock angle at the magnetopause compared to the perfect draping approximation). Furthermore, in the shear angle plots in the *Trattner et al.* [2004] study the anti-parallel reconnection regions are shown in red and cover a shear angle range from about 150° to 180° which is well within the error for the clock angle as reported by *Coleman* [2005].

[12] The location of the antiparallel reconnection site during northward IMF conditions has been very well documented by observations from the Far Ultraviolet Instrument (FUV) on the Imager for Magnetopause-to-Aurora Global Exploration (IMAGE) satellite [e.g., *Frey et al.*, 2002; *Fuselier et al.*, 2002; *Bobra et al.*, 2004]. During such conditions, localized dayside ionospheric emissions poleward of the auroral oval are observed by the FUV SI12 sensor. These emissions are caused by precipitating magnetosheath ions which have entered the magnetosphere at the anti-parallel reconnection region of the magnetopause [*Frey et al.*, 2002; *Fuselier et al.*, 2002]. A statistical study by *Bobra et al.* [2004] revealed no statistically significant trend for the appearance of cusp aurora emissions and the B_x component. This negative result lead to the conclusion that reconnection in the northern hemisphere does not depend on where the IMF first makes contact with the magnetopause. We have revisited our survey, checking the anti-parallel and component reconnection events for any preference in the magnitude of the IMF B_x component. In agreement with earlier studies, no preference was found.

[13] The behavior of the MLT position of the cusp aurora during northward IMF conditions for a changing IMF B_y component provides further evidence for the location of the antiparallel reconnection region. *Frey et al.* [2002] showed a linear relationship for the MLT location of the cusp aurora spot with a dawn location for negative B_y and a dusk location for positive IMF B_y . That result was interpreted as evidence for antiparallel merging and is in agreement with the model predictions of the location of the antiparallel reconnection site used in the *Trattner et al.* [2004] study. Therefore a satellite observing precipitating magnetosheath ions and located in the opposing sector must be connected to a component reconnection site.

[14] *Bobra et al.* [2004] confirmed the dawn location of the cusp aurora for negative IMF B_y but reported a much wider spread of the cusp location for positive IMF B_y , extending from the dusk sector into the dawn sector. A similar result was reported by *Newell et al.* [1989], who used direct measurements of precipitating ions on the DMSP satellites at low altitudes. While this effect is still under investigation, the dawn location of the cusp aurora could be the consequence of low- and medium-energy ion drift paths within the magnetosphere which would intersect the magnetopause in this sector where a fraction of these ions is scattered into the high-latitude ionosphere [*Bobra et al.*, 2004].

3. Conclusion

[15] While the separation of antiparallel cases and component reconnection cases in the *Trattner et al.* [2004] study with the sign of B_x is interesting, it is mainly an effect of the satellite position in either the dawn or dusk sector for the specific IMF conditions. If the study is restricted to IMF Parker spiral cases, the separation is no longer so dominant. Only one third of the available events in the database have been analyzed, and while there are 25 dawn events and 27 dusk events, they do not uniformly cover all sectors for all possible IMF combinations. For positive IMF B_x and negative IMF B_y conditions (Figure 1a) the Polar satellite was located in the dusk sector 16 times and in the dawn sector 5 times. Accounting for relatively small uncertainties in the draping of IMF field lines across the magnetopause, the antiparallel reconnection region for this condition will remain in the dawn sector. To create an antiparallel reconnection site on the dusk side, the IMF would need to drape across the magnetopause in a very complicated way, depicted in Figure 1a by a solid black line. Since the ends of the field line are anchored in the solar wind, it is difficult to see how this complicated draping would occur.

[16] Thus we conclude that models like the *Cooling et al.* [2001] model provide an excellent approximation for the location of the various regions across the magnetopause. This is particularly true when events with a dominant IMF B_x component are omitted from a study.

[17] To summarize, several hundred Polar cusp crossings during northward IMF conditions showed precipitating magnetosheath ions with no restriction in the dayside MLT sectors. These observations indicate the existence of an extended reconnection line [e.g., *Onsager et al.*, 2001]. Since the antiparallel reconnection site for northward IMF conditions is a relatively narrow region poleward of the cusp which was confirmed by IMAGE/FUV observations [*Frey et al.*, 2002; *Fuselier et al.*, 2002], an extended reconnection line must cross into regions where field lines are no longer anti-parallel. Observing either reconnection at an antiparallel reconnection site or from a component reconnection site depends only on the location of the satellite and to which region it is magnetically connected.

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