Distant magnetotail reconnection and the coupling to the near-Earth plasma sheet: Wind and Geotail case study

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[1] We have studied the coupling between the distant and near-Earth plasma sheet during an 8 hour interval on April 1, 1999 when the interplanetary magnetic field was northward and dominated by the B_y component. During these 8 hours the Geotail spacecraft sampled the near-Earth magnetotail at $X_{GSM} \sim -25$ R_E while the Wind spacecraft was located in the distant magnetotail at $X_{GSM} \sim -60$ R_E. Wind detected long duration (>8 hours) and likely spatially extended convective high speed flows indicative of continuous magnetic reconnection, whereas only plasma sheet boundary layer beams and some locally generated bursty bulk flows were observed at the Geotail location. Hence the high speed distant tail reconnection flows did not reach the near-Earth plasma sheet at high speed. No apparent signatures of the long duration distant tail reconnection flows in terms of global and auroral geomagnetic activity were observed. *INDEX TERMS:* 2744 Magnetospheric Physics: Magnetotail; 2764 Magnetospheric Physics: Plasma sheet; 7835 Space Plasma Physics: Magnetic reconnection. **Citation:** Øieroset, M., T. D. Phan, M. Fujimoto, and R. P. Lin (2004), Distant magnetotail reconnection and the coupling to the near-Earth plasma sheet: Wind and Geotail case study, *Geophys. Res. Lett.*, *31*, L18805, doi:10.1029/2004GL020321.

1. Introduction

[2] In the *Dungey* [1961] reconnection model, steady reconnection at the dayside magnetopause and subsequent steady reconnection in the distant magnetotail lead to the entry of solar wind plasma into the magnetosphere. Implicit in any such quasi-two-dimensional steady reconnection models is the transport of magnetic flux via high-speed plasma flows from the distant to the inner magnetosphere to complete the circulation loop. Past observations have indeed reported quasi-steady reconnection at the dayside magnetopause [*Sonnerup et al.*, 1981; *Gosling et al.*, 1982] and in the deep tail [*Feldman et al.*, 1985; *Slavin et al.*, 1986; *Nishida et al.*, 1995; *Øieroset et al.*, 2000]. However, how the plasma is transported from the distant to the near-Earth tail remains an open question [e.g., *Hultqvist et al.*, 1999]. High speed flows in the near-Earth plasma sheet are generally short-lived and believed to be locally generated [*Baumjohann et al.*, 1989, 1990; *Angelopoulos et al.*, 1992]. Thus the question remains what becomes of the quasi-steady deep tail reconnection flows.

[3] Here we present a rare opportunity to study the effect of distant tail reconnection on the near-Earth plasma sheet using simultaneous two-spacecraft measurements from the Wind and Geotail spacecraft, respectively. We find that (1) the long-duration distant tail high speed flows did not reach the near-Earth plasma sheet at high speed, and (2) the presence of long duration high speed flows in the distant tail did not affect the geomagnetic activity levels in terms of the AE and Kp indices in any significant way.

2. Observations

[4] Wind plasma and magnetic field parameters are obtained from the 3-D plasma instrument [*Lin et al.*, 1995] and from the magnetic field instrument [*Lepping et al.*, 1995]. The 3-D plasma instrument detects protons with energies from 80 eV to 27 keV. Full 3-D particle distributions are transmitted at variable rates, ranging from 3 seconds to 96 seconds. Geotail plasma parameters are obtained from the LEP instruments [*Mukai et al.*, 1994], which measures ions with energies from 30 eV to 40 keV. LEP particle distributions are transmitted at a rate of one sample every 12 second. The magnetic field is measured by the MGF experiment on Geotail [*Kokubun et al.*, 1994]. Interplanetary magnetic field observations are provided by the ACE spacecraft.

[5] Figure 1 shows the Wind and Geotail orbits in the x-y (GSM) plane from 04:30 UT to 15:00 UT on April 01, 1999. During this interval Wind stayed in the dawn sector (Y_{GSM} between -11 and -12 R_E) between $X_{GSM} = -56$ R_E and -60 R_E with $Z_{GSM} = 3.6$ R_E, while Geotail traversed the dusk side toward midnight (Y_{GSM} from 8 to 2 R_E) at $X_{GSM} = -25$ R_E with Z_{GSM} between 2 and 5 R_E.

[6] The observations from both spacecraft during this 10.5 hour interval are displayed in Figure 2. The time-shifted IMF θ angle ($\theta = \arctan(B_z/|B_y|)$) observed by ACE is shown in Figure 2a. After ~07:20 UT the IMF remained northward and strongly dawnward throughout the following ~8 hours. The AU, AL, and AE indices (Figure 2b) show declining ionospheric activity levels from the beginning of the interval. The AE index stayed below ~100 after ~07:20 UT with only a minor increase to ~160 at ~09:35 UT. The Kp index (Figure 2a) was at 1+ or below for the 06:00–15:00 UT interval.

[7] Figures 2c–2g show the Wind deep tail plasma and magnetic field observations. These observations have been described in detail by *Øieroset et al.* [2000]. Wind was located in the plasma sheet near $X_{GSM} = -60$ R_E (Figure 1) and encountered alternately the low-density (<0.03 cm^{-3}) lobe and the higher-density (0.05–0.3 cm^{-3}) plasma sheet (Figure 2d). High-speed flows with magnitude up to 800 km s^{-1} were observed whenever Wind was in the

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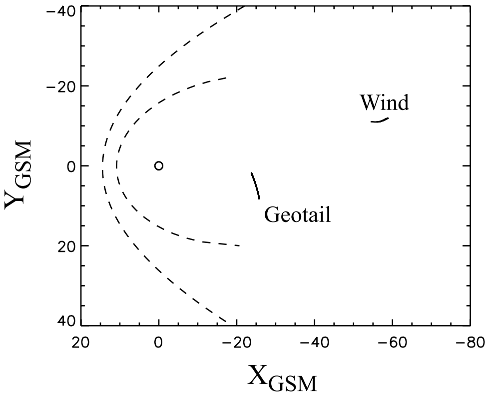

Figure 1. Wind and Geotail orbits in the 04:30–15:00 UT interval on April 1, 1999. Wind was located in the distant tail while Geotail traversed the near-Earth region.

plasma sheet (Figures 2f and 2g). The main component of the flows was in the x-direction, both earthward and tailward flows were observed (Figure 2f), and the flows had a strong component perpendicular to the magnetic field (Figure 2g). *Øieroset et al.* [2000] showed that the flow direction and magnitude of these flows are in quantitative agreement with predictions from symmetric reconnection. The ten hour interval contains two high-speed convective flow reversals (at ~07:56 and ~10:15 UT) indicating earthward and tailward passages of an X-line. It is likely that the high-speed reconnection flows were continuously present for at least 10 hours, since they were always detected whenever Wind reentered the plasma sheet from the lobe (Figure 2g). Hence we may conclude that an active X-line was present for more than 10 hours in the distant tail on this day.

[8] The simultaneous Geotail observations are shown in the Figures 2h–2l. The Geotail spacecraft started out in the northern lobe, as evident from the low density of ~0.02 cm^{-3} (Figure 2k), low temperature (Figure 2j), and the high positive value of the B_x component (Figure 2l), and encountered the plasma sheet between 06:09 UT and 06:33 UT, and again between 07:30 UT and 08:26 UT before finally settling in the plasma sheet after 10:04 UT. For the first two plasma sheet intervals counter-streaming field-aligned beams were observed near the lobe boundary (Figures 2h and 2i). These beams are plasma sheet boundary layer (PSBL) beams. For the last plasma sheet interval (starting at 10:02 UT) Geotail was located closer to the neutral sheet (B_x went down to 4 nT) and single population convective flows (bursty bulk flows (BBFs)) were detected for approximately one hour. These flows were then followed by lower amplitude velocity fluctuations after 11:05 UT.

3. Discussion

3.1. Wind-Geotail Comparison

[9] We focus our discussion on the ~10:00–15:00 UT interval when both Geotail and Wind remained inside the plasma sheet near the neutral sheet.

[10] Before comparing the distant tail Wind observations and the near-Earth Geotail observations we note that Wind was located on the dawn side while Geotail traversed the dusk-to-midnight sector of the plasma sheet. However, since Wind observed quasi-steady reconnection for more than 10 hours while moving a significant distance in space it is likely that the X-line was spatially extended in Y_{GSM}. Furthermore, Geotail observed PSBL beams when the spacecraft crossed the plasma sheet/lobe boundary at 06:09–06:33 UT and at 07:30–08:26 UT. The detection of PSBL beams has been interpreted as evidence for reconnection at a distant tail location [*Schindler and Birn*, 1987; *Onsager et al.*, 1991]. Hence the presence of PSBL beams at the Geotail dusk location is consistent with the

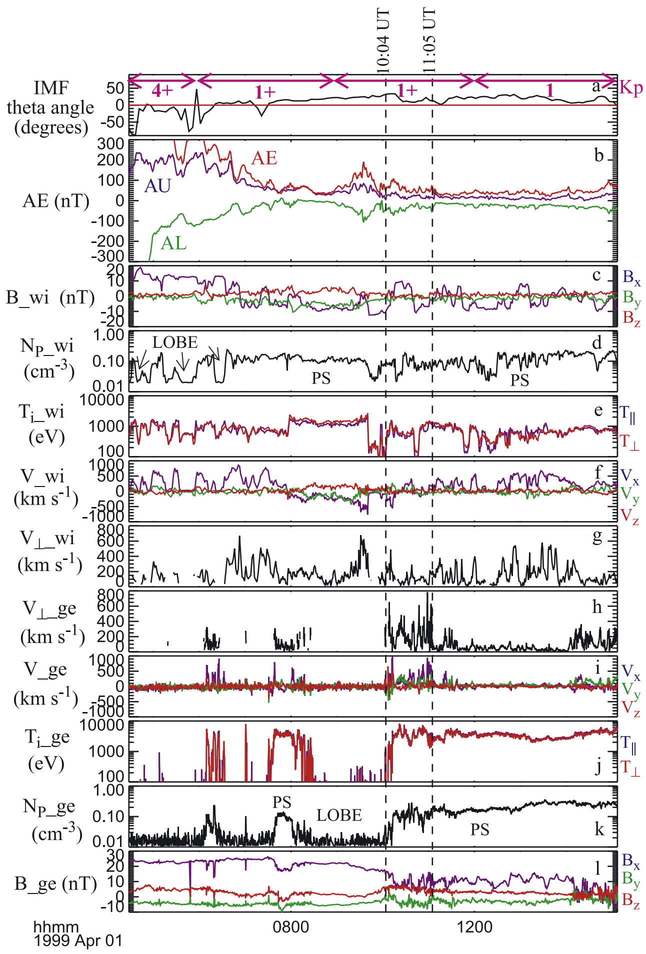

Figure 2. Wind and Geotail observations from ~04:30 UT to 15:00 UT on April 1, 1999. (a) IMF theta angle ($\theta = \arctan(B_z/|B_y|)$); (b) AU, AL, and AE indices; (c) Wind magnetic field (GSM); (d) Wind plasma density; (e) Wind ion temperature; (f) Wind velocity (GSM); (g) Wind component of velocity perpendicular to the magnetic field (plotted in plasma sheet only); (h) Geotail component of velocity perpendicular to the magnetic field (plotted in plasma sheet only); (i) Geotail velocity (GSM); (j) Geotail ion temperature; (k) Geotail plasma density; (l) Geotail magnetic field (GSM); The value of the Kp index is marked for each 3 hour interval at the top of panel (a). The 10:04–11:05 UT interval of BBFs observed by Geotail is marked with the vertical dashed bars. Times of lobe and plasma sheet (PS) encounters are also marked in the plot for both the Wind and the Geotail spacecraft.

distant tail X-line occurring also on the dusk side. Therefore a comparison between Wind and Geotail is feasible.

[11] High speed convective flows of several hundred km s^{-1} were observed by Wind at $X_{GSM} = -60$ R_E whenever the spacecraft was inside the plasma sheet. Therefore it is likely that reconnection was occurring continuously. Convective high speed flows (BBFs) were seen in the near-Earth tail only in the 10:04–11:05 UT interval (Figure 2h). The near-Earth high speed convective flows were more bursty (durations of 5–20 min) and had higher velocities (V_x up to ~900 km s^{-1}) than the high speed flows observed by Wind in the distant tail (V_x up to ~400 km s^{-1}) during the same interval. The large flow speed in the near-Earth plasma sheet indicate that the near-Earth high speed flows were locally generated and not related to the distant tail high-speed flows. Thus the high speed distant tail flows did not reach the near-Earth plasma sheet at high speed.

[12] The disappearance of the high speed flows before they reached $X_{GSM} = -25$ R_E cannot be due to simple conservation of magnetic flux. The increase in the tail magnetic field strength from $X_{GSM} = -60$ R_E to $X_{GSM} = -25$ R_E is less than a factor of 2 [*Slavin et al.*, 1983; *Yamamoto et al.*, 1994], and cannot explain the dramatic drop in flow velocity from several hundred km s^{-1} to ~zero. Indeed, the cross-tail electric field ($V_x \times B_z$) measured at the Geotail location is a factor of three less than what was observed at the Wind location, although such a calculation depends sensitively on the accuracy of the determination of the magnetic field normal to the current sheet. With a continuous supply of high-speed flows from the distant tail for more than 10 hours, i.e., a steady-state situation, the flows could not have been diverted along the magnetic field lines.

[13] Another possibility is that the flows have been diverted toward the flanks. However, there are no signs of a significant flow deflection at the Wind location where more than 95% of the high speed flows were directed within ±20° of the Sun-Earth line (not shown). Therefore the flows would have to be diverted toward the flanks at a later stage, before they reach Geotail. Whether such deflection indeed occurs remains to be investigated.

[14] We note that the ion temperature measured by Geotail is approximately 3 times higher than at the Wind location. The kinetic energy contained in the distant tail flows would be sufficient to account for this heating.

3.2. Geomagnetic Activity

[15] The Kp index was 1+ or less during the 06:00–15:00 UT interval (Figure 2a). Hence the continuous presence of distant tail reconnection in this period did not have any strong effect on the global geomagnetic activity level.

[16] It has been suggested that distant tail high speed flows could originate from a tailward-retreating near-Earth neutral line in the later stages of a substorm [*Angelopoulos et al.*, 1996]. However, for the event presented here the AU, AL, and AE indices (Figure 2b) displayed very low auroral geomagnetic activity. The AE index was declining throughout the 04:30–15:00 UT interval, remaining below 100 after 07:15 UT, with the exception of the 09:20–09:50 UT interval where a minor enhancement to 160 was seen. There is also a small peak where AE reached 100 at 10:13 UT. This minor enhancement is possibly related to the BBFs observed in the near-Earth plasma sheet after Geotail entered the plasma sheet at 10:04 UT (Figures 2h and 2i). The long duration distant tail reconnection flows (Figures 2f and 2g) on the other hand, have no apparent response in the AE index (Figure 2b). While steady reconnection flows were produced continuously for many hours in the distant tail, the AE index was generally below 100 (after 07:15 UT) and declining. Thus the distant tail X-line was not associated with near-Earth reconnection or substorms in this case (Figure 2b).

4. Summary

[17] We have had a rare opportunity to study the effect of quasi-steady distant tail reconnection flows on the near-Earth plasma sheet using simultaneous Wind and Geotail observations from the distant and near-Earth plasma sheet, respectively. We have shown that the long duration high speed flows emanating from a distant tail reconnection site do not reach the near-Earth plasma sheet at high speed. Such a result is consistent with previous (single spacecraft) observations showing only bursty high speed flows in the near-Earth tail [*Baumjohann et al.*, 1989, 1990; *Angelopoulos et al.*, 1992] while distant tail high speed flows generally have longer duration [*Slavin et al.*, 1986; *Nishida et al.*, 1995].

[18] Furthermore, we have shown that although high speed flows continued to be present in the distant tail for more than 10 hours, no significant global or auroral geomagnetic activity was recorded during this time. The question remains what becomes of the long-duration distant tail high speed flows as they approach the Earth. Further plasma observations from the mid-tail plasma sheet, including measurements from the Japanese SELENE mission to the Moon (to be launched in 2006) will shed more light on this issue.

[19] **Acknowledgments.** We gratefully acknowledge helpful discussions with Tsugunobu Nagai and Simon Wing. The Geotail magnetic field data were obtained from the DART system at ISAS. Solar wind magnetic field data were obtained from the ACE science center website. AU, AL, and AE 1-min data were obtained from the World Data Center C2 for Geomagnetism, Kyoto, Japan. This research was supported by NASA grant NAG5-12941 at UC Berkeley.

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