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On the origin of reverse polarity TCRs

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Abstract. Reverse polarity, or South-then-North (SN) bipolar, traveling compression regions (SN TCRs) are often observed in the Earth's magnetotail lobes. These events have been interpreted as either slowly earthward propagating "proto-plasmoids" during extremely quiet geomagnetic conditions, or due to pressure pulses in the solar wind or magnetosheath compressing the magnetotail. This study presents a survey of 21 IMP 8 observations of SN TCRs and the corresponding solar wind pressure conditions as measured by WIND. We found that solar wind or magnetosheath pressure pulses nicely explain most (17), though not all, of the SN TCR observations. Therefore, it appears that both explanations previously given are needed to explain SN TCRs. We also found that most of these events occurred during northward Interplanetary Magnetic Field (IMF) conditions. This suggests that the magnetotail may respond differently to solar wind dynamic pressure pulses for different orientations of the IMF.

Introduction

Traveling compression regions (TCRs) are the lobe signature of a passing plasmoid [e.g., *Slavin et al.*, 1984, 1994; *Moldwin and Hughes,* 1994]. They are formed due to the compression of the magnetotail lobe against the magnetosheath pressure by the vertical (north-south) extent of a plasmoid [*Slavin et al.*, 1994]. This gives a north-then-south bipolar signature with a magnetic field compression centered on the inflection point of the bipolar signature. These signatures have been observed from 30 R_E to 220 R_E downtail. It was noticed early on [*Moldwin and Hughes*, 1992] that many TCR-like signatures had south-then-north bipolar signatures opposed to the expected north-then-south signature. There were two ideas proposed to explain these reverse polarity TCRs: (1) that they are formed by earthward propagating plasmoids [*Moldwin and Hughes*, 1994] (Figure 1a.), and/or (2) they are formed by a pressure pulse in the solar wind compressing the magnetotail [*Slavin et al.*, 1994] (Figure 1b).

In a survey of IMP 8 data *Moldwin and Hughes* [1994] found that about a third of all bipolar signatures in the GSM z direction associated with a magnetic field compression were south-then-north. These events were found to be highly localized in the east-west direction compared to TCRs, which were observed all across the tail. They also only occurred during extremely quiet geomagnetic conditions during northward interplanetary magnetic field (IMF), but occurred after small high latitude substorm activity as indicated by high latitude ground magnetogram stations. Therefore Moldwin and Hughes suggested that these signatures might be due to the passage of a slowly earthward propagating plasmoid formed by reconnection in the plasma sheet. However, the reconnection did not extend all the way through the plasma sheet, effectively trapping the "proto-plasmoid" on closed flux tubes (Figure 1a). This model is supported by the direct observation of flux ropes in the plasma sheet that have south-then-north bipolar signatures and strong core fields [*Elphic et al.*, 1986; *Kivelson et al.*, 1993; *Moldwin and Hughes*, 1994]. An alternative interpretation for the events is that they are due to pressure pulses in the solar wind (see Figure 1b). It has been shown that the magnetotail lobes respond to large discontinuities in the solar wind pressure (e.g., [*Collier et al.*, 1998a]) though *Patel* [1972] examining Explorer 33 data did not find a systematic change in the lobe magnetic Bz component following sudden impulses (SI). *Moldwin and Hughes* [1994] found that 9 of 19 SN TCRs had a large SI magnetic signature in low latitude

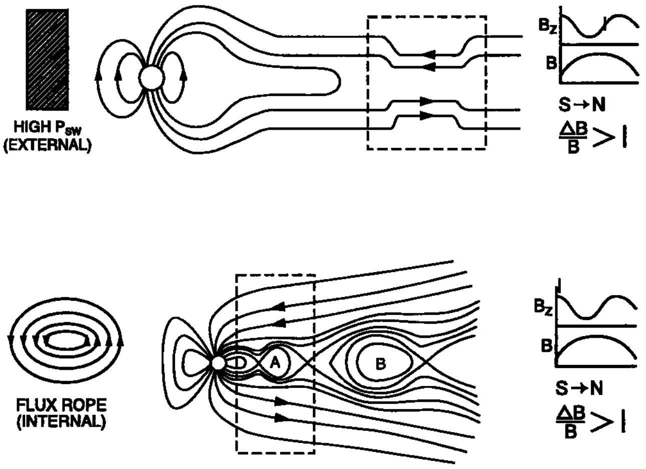

Figure 1. (a) A schematic model of a proto-plasmoid trapped within closed field lines and convected earthward. (b) A solar wind pressure pulse constricting the magnetotail and moving tailward. Both models would produce South-then-North turnings of the lobe magnetic field with the inflection point coincident with a compression.

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Table 1. The properties of the 21 SN TCR intervals. The columns show the date, if the event was a wave (W) or single (S) SN TCR, the peak-to-peak amplitude of the Bz bipolar turning (nT), the magnitude of the compression as a percentage of the background lobe field, if the SN TCR was correlated with a solar wind pressure pulse or foreshock-generated pressure pulse, the IMF Bz direction at the maximum pressure, and Kp.

Date	S/W	B_z	Comp	Pulse	IMF	K_p
28 Nov 94	W	3.1-7.0	25-31	Y	N	3
28 Nov 94	W	1.1-2.6	1-7	Y	N	6+
30 Mar 96	S	1.5-2.5	3-11	Y	S	1-
29 Oct 96	W	0.8-1.3	1-3	Y	S	3
30 Oct 96	S	2.2	7	Y	N	2-
24 Nov 96	S	3.0	5	N/Y	N	2-
25 Nov 96	W	2.2	7	Y	N	5-
7 Dec 96	S	1.5	7	N/N	N	2-
21 Dec 96	S	1.6	4	Y	N	2-
21 Feb 97	W	0.8-2.2	1-7	Y	N	3+
18 Mar 97	S	1.4	10	Y	N	1
18 Mar 97	W	0.8-1.7	3-7	N/N	N	1
14 Aug 97	S	1.9	3	Y	N	3
15 Aug 97	W	1-1.5	3-8	Y	N	2+
3 Oct 97	S	4.6	10	N/N	N	0
16 Oct 97	S	0.8	5	N/N	N	0+
10 Nov 97	W	1.6-3.2	4-11	Y	S	4
18 Dec 97	S	1.4	12	Y	N	0+
7 Feb 98	W	2.0	4	Y	N	1+
19 Feb 98	W	1.9-3.6	12-18	N/Y	S	1+
20 Feb 98	S	6.9	57	SI	S	2+

magnetograms suggesting that nearly half of the events may be due to solar wind pressure pulses.

The launch of the Wind spacecraft in 1994 with the continued operation of the IMP 8 spacecraft has now provided the opportunity to directly examine the origin of SN TCRs. This study surveyed 4 years of IMP 8 data for SN TCRs and examined the corresponding upstream solar wind data for pressure enhancements.

Methodology and Observations

We visually surveyed the IMP 8 magnetic field magnetotail database from September 1994 through April 1998 for SN TCR events. A total of 25 intervals where found that contained SN TCR signatures. Many (13) of these intervals contained multiple events and therefore a total of 50 individual SN TCRs were identified. Of these 25 IMP 8 SN TCR intervals, 21 had corresponding IMF and solar wind data from Wind. We defined a SN TCR as an event that had a bipolar signature of at least 0.75 nT peak-to-peak and that the inflection point was coincident with a local maximum in the lobe magnetic field of at least 0.5 nT. This is similar to definitions of TCRs (e.g., *Slavin et al.* [1984]; *Moldwin and Hughes* [1994]) except that we required the bipolar signature to be first South-then-North. The average characteristics of these SN TCRs are very similar to TCRs. Table 1 summarizes the properties of the 21 SN TCR intervals included in this study.

Figure 2 shows an example of a SN TCR observed by IMP 8 when it was located at (-33.9, 6.4, 18.5) R_E GSM on 30 Oct, 1996. Note that in the bottom panel the magnetic field maximum is coincident with the inflection point of the south-then-north bipolar signature in Bz (third panel). The top two panels show the solar wind and magnetic field pressure data observed by Wind during the same interval. The horizontal line in the top panel shows the estimated time shift required to propagate the solar wind from Wind to the magnetotail at IMP 8 distances (see *Collier et al.,* 1998b for details of the propagation method and the estimate of the timing uncertainties). Note the large amplitude (about 500 pPA) but short duration (less than 5 min) pressure pulse near this time.

Figure 3 shows the solar wind pressure data from Wind and the GSM Bz and B total from IMP 8 during 16 Oct, 1997, when IMP 8 was located at (-29.2, 7.4, 16.5) R_E GSM downtail in the same format as Fig. 2. Note that there is no clear solar wind dynamic or static pressure pulse near the estimated time. At this time Wind was located at (64, 2, 5) R_E GSE upstream of the Earth, very nearly aligned with the Sun-Earth line. Therefore it is unlikely that Wind missed a solar wind pressure pulse due to its perpendicular separation from the Sun-Earth line. However, pressure pulses have been shown to be generated in the foreshock that can have large amplitude signatures in the dayside magnetosphere [*Fairfield et al.*, 1990]. In order to test for this possibility we analyzed the Interball/Tail and Geotail data for this interval. Interball/Tail was located in the magnetotail lobe about 14 R_E downtail while Geotail was near the equatorial plane 14 R_E downtail but in the magnetosheath.

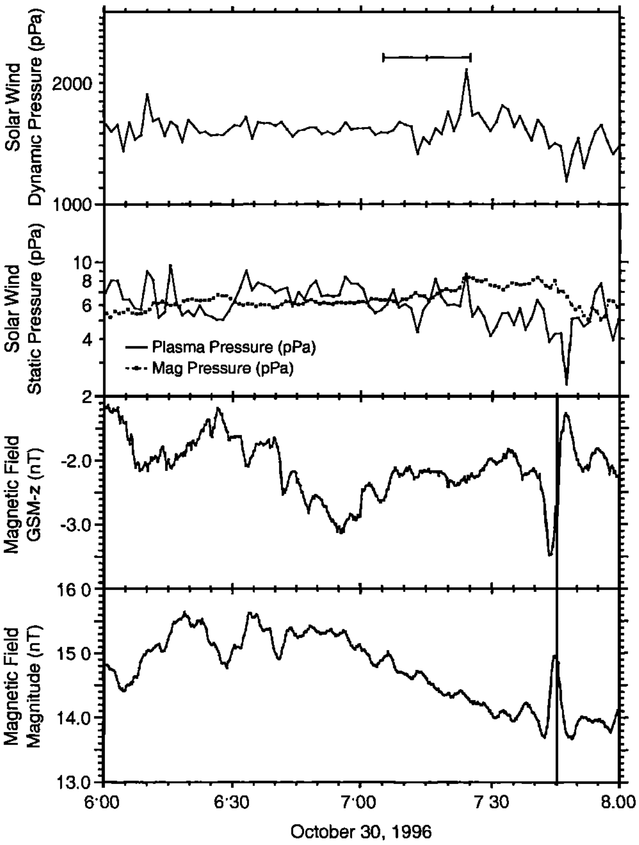

Figure 2. An example of a SN TCR as observed by IMP 8 with the Wind dynamic and static pressure data for the same interval. The horizontal line denotes the expected time delay between solar wind observations at Wind and magnetotail observations at IMP 8. The vertical line identifies the SN TCR.

Interball/Tail observed a south-then-north bipolar turning coincident with a slight compression but after the observation of the SN TCR by IMP 8. This is not consistent with a tailward propagating pressure pulse. Geotail moved from the magnetosheath into the magnetosphere and then back out to the magnetosheath at approximately the same time that Interball observed the bipolar magnetic signature. This is not consistent with an external pressure pulse compressing the magnetosphere but instead with an expansion of the magnetotail.

The 21 SN TCR intervals that had IMF/solar wind data were fairly evenly divided between isolated (11) SN TCRs and wave (10) SN TCRs. Isolated SN TCRs were events that had a single event or events that were separated by more than 15 minutes. Figures 2 and 3 are examples. Figure 4 shows an example of a wave SN TCR with the corresponding solar wind pressure data that occurred on 21 February 1997. IMP 8 was located at (-27.5, 5.6, -18.8) R_E GSM while Wind was at (211, 19, -6) R_E upstream of the Earth. Note that there is a one-to-one correspondence of pressure pulses for each SN TCR observed in the tail (though the relative timing of the later events is not as good as the first three). The IMP 8 data has been shifted approximately 70 minutes to fit the timing of the pressure pulses observed in the tail. This timing is consistent with that predicted by the Collier et al. method used in this study. The wave events typically have periodicities of 8 to 15 minutes and would fall into the low-frequency range of large amplitude compressive pc 5 ULF waves. This event however does not look like a so-called psc event which were identified as damped pc 4-5 waves that followed sudden compressions (SC/SIs) (e.g.[*Baumjohann et al.*, 1984]).

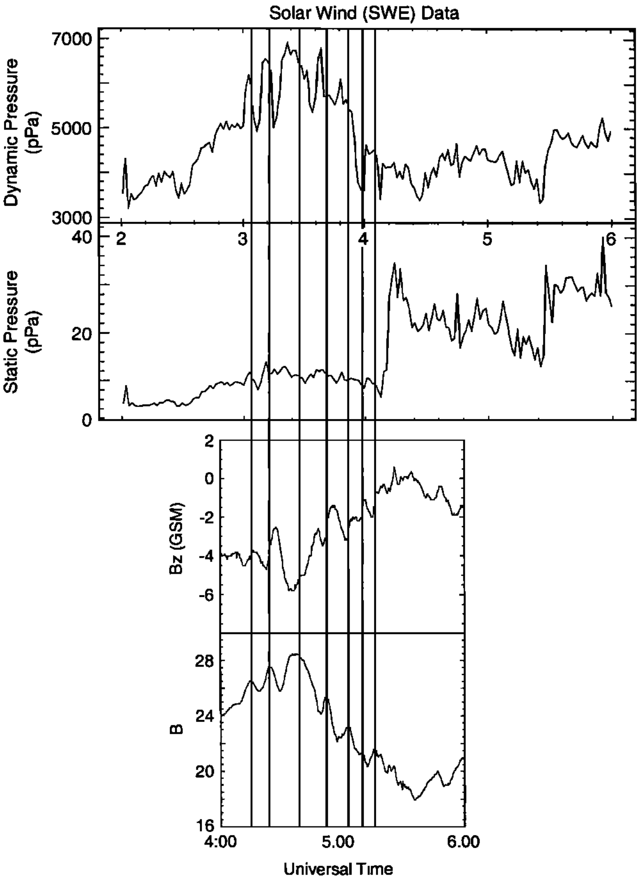

Figure 4. An example of a wave SN TCR observed by IMP 8 with the corresponding Wind solar wind dynamic and static pressure.

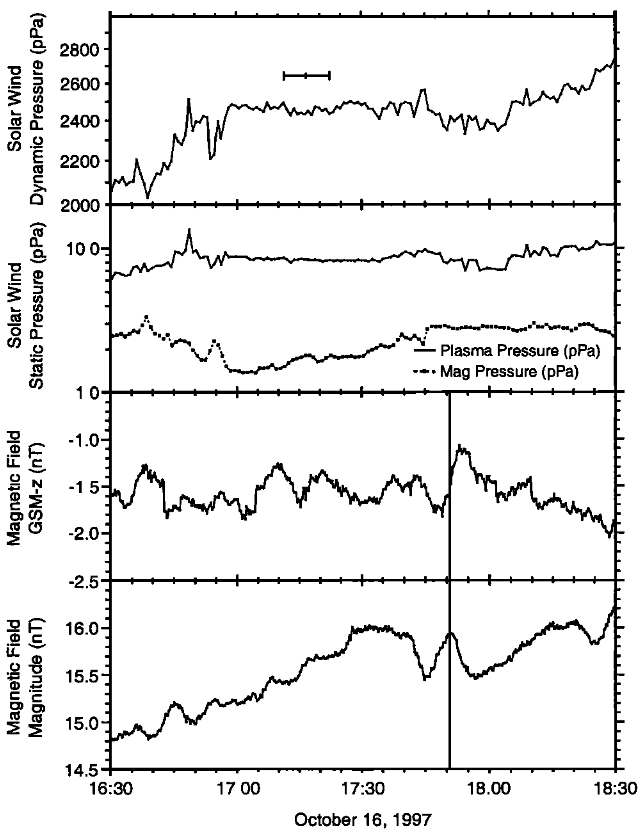

Figure 3. An example of a SN TCR in the same format as Figure 2. Note that there is not a clear solar wind pressure pulse associated with this SN TCR.

Of the 21 intervals, 15 had a clear solar wind pressure pulse(s) within one sigma of the expected time. Of the six non-solar wind pressure pulse associated event, two events were associated with magnetosheath or magnetotail lobe signatures seen at either Interball/Tail or Geotail that suggests that they are associated with foreshock generated pressure pulses. All of the four remaining non-solar wind or foreshock pressure pulse associated events occurred during quiet geomagnetic activity (K_p = 0 to 2) and were localized within 10 R_E of the nominal tail axis consistent with the results of the earlier Moldwin and Hughes study that suggested an internal magnetotail source. Of these events Wind and IMP 8 had a perpendicular separation of less than 16 R_E except for one event. *Collier et al.* [1998b] demonstrated the probability of good correlation between magnetic signatures decreases with perpendicular distance between the spacecraft with a scale length on the order of 40 R_E.

As was found in the earlier Moldwin and Hughes study, these SN TCR intervals predominantly (16 of the 21 intervals) occurred during northward IMF. For the non-pressure pulse associated events this is consistent with the protoplasmoid model of limited reconnection during quiet geomagnetic intervals. However, it is not clear why SN TCR signatures should essentially only be observed when the IMF is northward. There have been several studies showing that dayside ground-based magnetic signatures of SIs at low and mid-latitudes are different for different orientations of the IMF with a clear simple response seen only for IMF Bz north (e.g., [*Russell and Ginsky*, 1995]). The rationale for the difference is the enhancement of the Region 1 current system associated with dayside reconnection partially masks the compression signature during southward IMF on the dayside and enhancement of tail current systems and the magnetospheric extensions of field aligned currents complicate the signature on the nightside. We suggest two other possible explanations. (1) *Kokubun et al.* [1977] found that SIs can "trigger" a simultaneous substorm. Kokubun et al. further showed that for SIs/SSCs that impacted the Earth when the IMF was southward or decreasing during the previous 30 minutes there was nearly a one-to-one correlation between SI/SSCs and substorm onset. Therefore for some of the SI events that occurred with southward IMF the substorm signature masks the SN TCR signature. And (2) *Sarafopoulos* [1995] observed what we have called wave SN TCRs in the magnetotail lobe. The events identified in their studies occurred during northward IMF and quiet geomagnetic conditions. The intervals were correlated with short duration pressure variations in the solar wind. These authors suggest that these magnetotail waves are generated by the external pressure pulses and/or by waves generated by the Kelvin-Helmholtz instability on the magnetopause, which is favored for northward IMF.

Conclusions

The results of this study show that short duration (1-10 minute) enhancements (10-40% $\Delta p/p$) in the solar wind dynamic pressure can create clear compression and GSM Bz magnetic signatures in the magnetotail lobes (Figure 1a). Identical magnetotail signatures can also be produced during quiet geomagnetic activity in the absence of solar wind or fore shock generated pressure pulses presumably due to small-scale magnetic reconnection creating earthward propagating proto-plasmoids though these events are more rare (Figure 1b). Furthermore it is demonstrated that SN TCR signatures are predominately produced during northward IMF. For non-pressure pulse associated events this is consistent with the creation of an earthward propagating proto-plasmoid during quiet geomagnetic conditions. For pressure pulse associated events it is suggested that the magnetotail lobe has two responses depending on the IMF. During southward IMF the pressure pulse signature may be masked and/or weakened by substorm signatures or enhanced tail and field aligned current signatures. During northward IMF the pressure pulse is able to propagate downtail in an undisturbed lobe field creating a SN TCR.

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References

Baumjohann et al., Resonant Alfven waves excited by a sudden impulse, *J. Geophys. Res., 89,* 2765, 1984.

Collier et al., Multispacecraft observations of sudden impulses in the magnetotail caused by solar wind pressure discontinuities: Wind and IMP 8, *J. Geophys. Res., 103,* 17,293, 1998a.

Collier et al., Timing accuracy for the simple planar propagation of magnetic field structures in the solar wind, *Geophys. Res. Lett., 25,* 2509, 1998b.

Elphic et al., ISEE-1 and 2 observations of magnetic flux ropes in the magnetotail: FTEs in the plasma sheet?, *Geophys. Res. Lett., 13,* 648, 1986

Fairfield et al., Upstream pressure variations associated with the bow shock and their effects on the magnetosphere, *J. Geophys. Res., 95,* 3773, 1990.

Kivelson et al., The Galileo Earth encounter: Magnetometer and allied measurements, *J. Geophys. Res., 98,* 11299, 1993.

Kokubun et al., Triggering substorms by solar wind discontinuities, *J. Geophys. Res., 82,* 74, 1977.

Moldwin and Hughes, On the formation and evolution of plasmoids: A survey of ISEE 3 Geotail data, *J. Geophys. Res., 97,* 19259, 1992.

Moldwin and Hughes, Observations of earthward and tailward propagating flux rope plasmoids: Expanding the plasmoid model of geomagnetic substorms, *J. Geophys. Res., 99,* 184, 1994.

Patel, Sudden impulses in the geomagnetotail and the vicinity, *Planet. Space Sci., 20,* 1127, 1972.

Russell and Ginsky, Sudden impulses at subauroral latitudes: Response for northward interplanetary magnetic field, *J. Geophys. Res., 100,* 23695, 1995.

Sarafopoulos, Long duration Pc 5 compressional pulsations inside the Earth's magnetotail lobes, *Ann. Geophysicae, 13,* 926, 1995.

Slavin et al., Substorm associated traveling compression regions in the distant tail: ISEE 3 geotail observations, *Geophys. Res. Lett., 11,* 657, 1984.

Slavin et al., Evolution of the plasmoid-lobe interaction with downtail distance, *Geophys. Res. Lett., 21,* 2765, 1994.

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