Polar spacecraft observations near 9 RE: rapid multiple dipolarizations and their interpretation

Y. S. Ge, C. T. Russell, T.-S. Hsu, and R. L. McPherron

Abstract: The Polar spacecraft has probed the near-Earth tail region at 9 RE with its orbit in the meridian plane and apogee near the magnetic equator. The onboard magnetometer frequently recorded dipolarizations of the magnetic field during the crossing of the current sheet, including rapid multiple dipolarizations. The interval between two rapid dipolarizations is about 30 minutes, which is close to the time interval of multiple Pi 2 pulsations in a substorm. On several occasions, three or more dipolarizations occur within 2 hours, but most occurrences involve have two rapid dipolarizations. The normal component of the magnetic field to the current sheet rises in a stepwise manner in some events. In others it recovers to the previous level before the next dipolarization. Rapid multiple dipolarizations may occur in a single substorm. We interpret these dipolarizations in terms of the initial onset of reconnection in the near-Earth plasma sheet, followed by more rapid reconnection when lobe plasma reaches the x-point and reconnection on open field lines releases the plasmoid.

Key words: Substroms, Dipolarization, Reconnection.

1. Introduction

Multiple onsets are a common feature of substorms observed on the ground. If these occur before the main breakup, they are called pseudobreakups [2, 5]. After onset they are referred to as intensifications. *Koskinen et al.* [2] and *Nakamura et al.* [5] showed that pseudobreakups have almost all of the features of a substorm onset, but the disturbance seems to ”quench” rather than proceed to full expansion phase development. Pseudobreakup features are found to subside quickly and be tightly localized [5]. However, the physics behind pseudobreakups has not been clearly understood. Dipolarization of the tail magnetic field which is often used to study the onset of magnetospheric substorms is an important feature at onsets. In near-Earth tail region beyond the geosynchronous orbit, the dipolarization is believed caused by the pile-up of magnetic flux transported from tail by reconnection processes [9]. The investigation of multiple dipolarizations in near-Earth region at multiple onsets can help us to understand what leads to the different evolutions of pseudo-onsets and major onsets.

In the Near-Earth Neutral Line (NENL) model of substorms, near-Earth reconnection takes place in two stages, i.e., on closed field lines and then on open lobe field lines. Recently, *Russell* [8] re-emphasized their behavior while presenting a substorm triggering model to understand how northward turnings of the IMF can lead to substorm expansion onsets. In this model, the two stages of reconnection are modulated by the conditions of IMF and a pseudo-onset should take place before the major one. This model is also consistent with the observational conclusiong of *Mishin et al.*, [3, 4] that substorms have two distinct forms of onset. Though many studies of pseudo-onset using ground observations have been made, the investigations on their signatures in space have rarely been performed. The in situ observations can be more revealing because some ground signatures of pseudo-onset are very weak or localized. In this work, we use the Polar spacecraft studying the multiple onsets seen in near-Earth tail region where is believed the earthward transported flux starts to pile up.

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2. Near-Earth Tail Magnetic Field

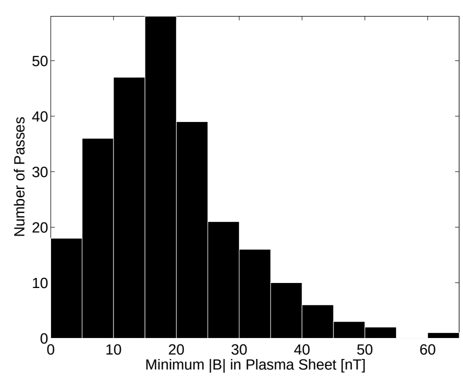

Fig. 1. Minimum magnetic field each orbit (2001-2003) when Polar was at apogee and within 2 hours LT of midnight.

The Polar spacecraft with an orbit of 9 RE apogee spent significant time at near-Earth tail region during the Falls of 2001, 2002, and 2003. Near 9 RE the tail magnetic field is usually quiet and somewhat weakened around the current sheet where Bx reverses. Sometimes the magnetic field is highly disturbed and a strong tail current reduces the magnitude to a low value. The survey using 6-second magnetic field data [7] has been performed on each orbit in the three years when Polar's apogee was within 2 hours local time of midnight. The distribution of minimum field strength during each crossing of the current sheet is shown in Figure 1. The median value is 20 nT, which is much less than the contribution of the dipole field of the Earth at 9 RE on the magnetic equator, about 40 nT.

Weakened by the strengthened cross-tail current, sometimes the field strength can be as low as 5 nT or less. In weak fields in this region, many interesting disturbances are seen by the magnetic field measurements, e.g., the mirror mode instability (see details in the paper 'Mirror Mode Waves Detected by Polar in Near-Midnight Tail', *Ge et al.*, in preparation).

An anti-correlation is observed (Figure 2 (a) and (b)) between the solar wind density and the dynamic pressure with the near-tail magnetic field using one minute resolution propagated ACE data from the advection technique of [10]. It indicates that larger solar pressures (mainly caused by larger densities) compress the tail field more, enhancing the tail current and producing lower fields near 9 RE. Similarly the correlation with the convected southward IMF in Figure 2(c) shows that the more IMF flux (left half side shows southward IMF flux) is moved to the magnetotail, the lower is the near-Earth tail magnetic field. More details can be found in [1].

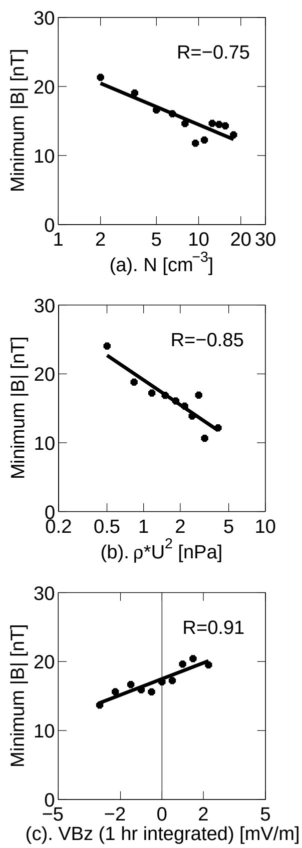

Fig. 2. Relation between median tail magnetic field at the current sheet crossing (reversal in Bx) and solar wind parameters: (a). Solar wind number density; (b). Solar wind dynamic pressure; (c). Convected IMF flux. Values shown are medians in overlapping (by half) bins. R is the correlation coefficient of the medians.

3. Multiple Dipolarizations

The magnetosphere can be reconfigured in shorter time than the duration of a typical substorm. Figure 3 shows a typical multiple dipolarization event recorded by the Polar spacecraft in near tail. The Polar spacecraft crossed the current sheet at 1120 UT on October 16, 2001. Three sudden increases of Bz component are seen from 1140 UT to 1230 UT. All these increases are accompanied by sudden decreases of Bx component, which indicates that the magnetic field changes from tail-like to more dipolar field. The immediate decrease in the Bx component and in the magnetic field strength and the fluctuations of magnetic field also indicate that plasma sheet expanded and Polar reentered hot plasma region. Every dipolarization has a sharp front and a following gradual decrease of Bz component, corresponding to a explosive release of tail field energy and a slow recovery phase respectively. But the Bz component does not return to the level before the dipolarization. This process is repeated for three times within one hour during this interval. The second event also involves a stretching of tail field which is indicated by the rapid increase of Bx component before the dipolarization. A quite weak dipolarization occurs at 12:46 UT.

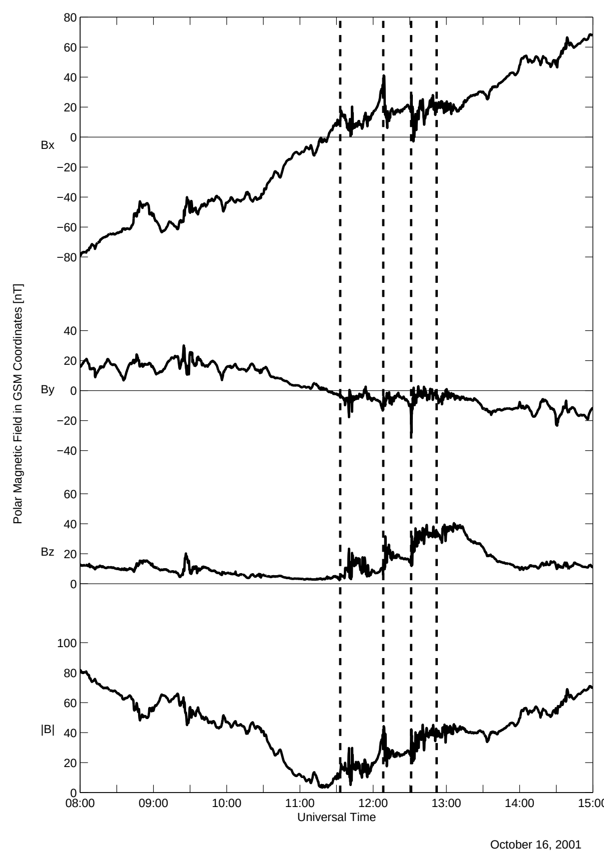

Fig. 3. Time series of magnetic field on a multiple dipolarization event, October 16, 2001 (6s resolution). Dash lines show the dipolarizations seen by Polar.

Figure 4 shows the AL index and the power of ground Pi2 pulsations during this event. The Pi2 power is averaged over all stations that recorded Pi2 onsets in MEASURE ground magnetometer chain. Multiple ground Pi2 onsets appear corresponding to the dipolarizations except for the first one. Considering that the MEASURE chain is located at dawn at this universal time, this suggests that the first onset does not generate a global

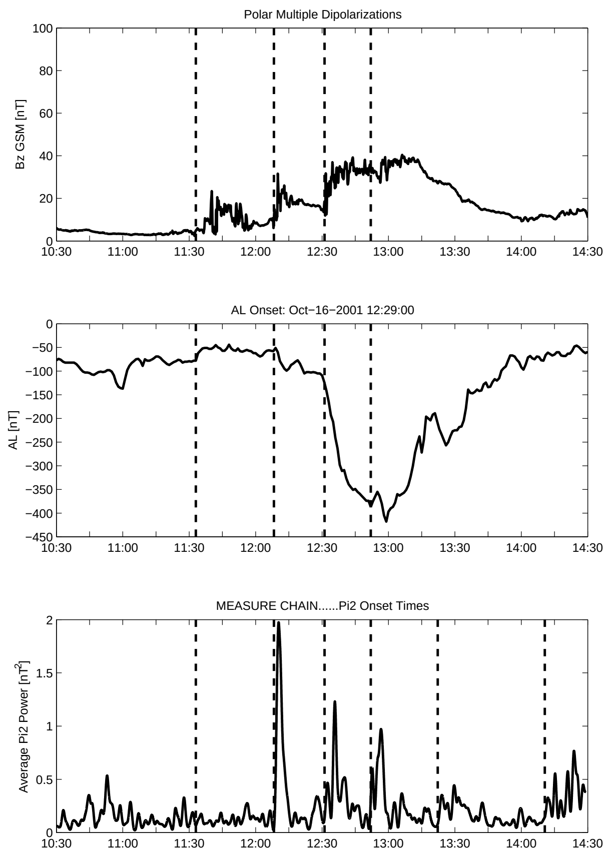

Fig. 4. Top panel: Polar MFE Bz in GSM; Middle panel: Quick-look AL index; Bottom panel: Averaged ground Pi2 power over MEASURE chain

Pi2 pulsation. At the second dipolarization, AL starts to drop and ground stations record the strongest Pi2 onset, which suggests that this onset can be the major onset of the substorm. There are also multiple Pi2 onsets corresponding to the following dipolarizations seen by Polar, even to the minor one at 12:46 UT. However, the determination of a major onset here should be made with care. Solely from the AL index, a major onset would be selected corresponding to the third dipolarization seen on Polar. Since there is limited station coverage for AL near midnight at this Universal Time (12:31), the major onset is uncertain here. Although the ground signatures for multiple onsets are very variable and some are too weak to be detected, in situ observations by Polar record the disturbances more clearly. The change of magnetic field in the dipolarization for the pseudo-onset (11:32 UT) is comparable to that in the major onset. Another multiple onsets event (details can be found in a paper in preparation by *Ge et al.*) shows Pi2 onsets as well as AL index onsets for every dipolarization when the ground station is close to midnight. Futhermore, good optical observations, i.e., all-sky image, in that event are very helpful in the determination of major onsets.

The IMF condition for the event is examined using the propagated ACE data which is shown in Figure 5. We can see from this figure that the dipolarizations occur when IMF is southward. The first and second dipolarizations occur when the southward component of IMF begins to increase, and the third event corresponds to a northward turning of the IMF.

4. Summary and Discussions

In substorms, multiple onsets are quite common features. Using the Polar spacecraft magnetic field observations, we can more readily record every onset of a substorm when the spacecraft is in the near-Earth tail region. The multiple dipolarizations appear typically separated by 30 minutes which is close to the median time separation of two consecutive Pi2 onsets on the ground (*Hsu and McPherron*, submitted recently) and is also consistent with the results of earlier work done by [6]. Pi2 pulsations generated at multiple onsets can be different. The pseudo-onset appears to generate Pi2 pulsations that are quite confined in local time. Determination of the substorm major onset only from ground Pi2 and AL index should be performed very carefully when the aurora image or observations in space are not available.

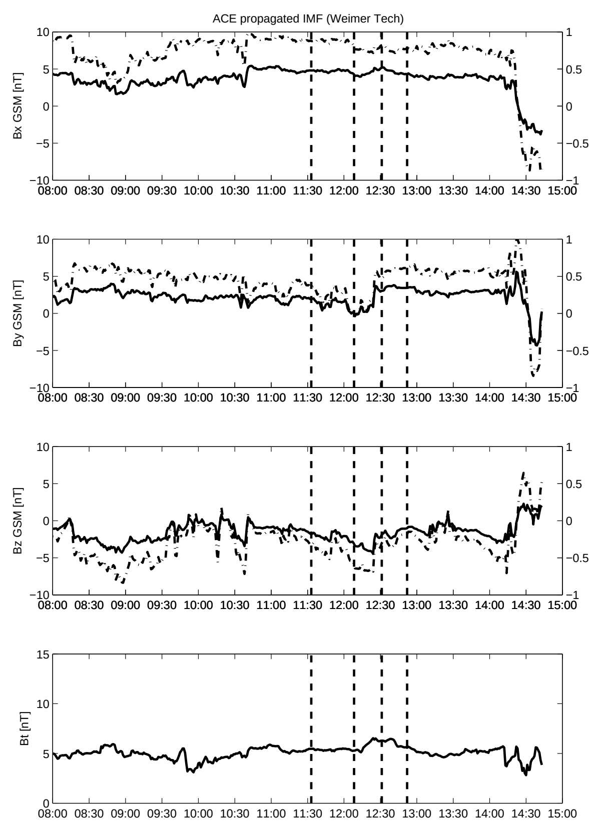

Fig. 5. Propagated ACE IMF data using Weimer Technique: Three components in GSM coordinates and the field magnitude (solid lines); Cosine of angles of three components (solid-dot lines)

The localization of Pi2 at the pseudo-onset is not hard to understand. Since the aurora does not expand significantly in the pseudo-breakup [5], the disturbance on polar cap region cannot be strong enough to generate a global pulsation. In the model suggested by [8] and also in other NENL models (e.g., [3, 4]), the pseudo-onset very possibly corresponds to the reconnection beginning on the closed field lines of the plasma sheet. The reconnection rate is limited until lobe open field lines start to reconnect. Once reconnection reaches the tail lobe, information on the substorm can propagate quickly and globally. The more subtle effects of the pseudo-onsets are more difficult to be detected remotely making in situ observations more important in this situation.

So far, we still do not have an unambiguous answer to why the magnetosphere changes its configuration on this time scale (around 30 minutes) during a substorm. Perhaps it is the time for reconnection to move through the plasma sheet to the lobes. The incoming THEMIS mission should provide the observations needed to shed light on this question.

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