Substorm Evolution in the Near-Earth Plasma Sheet

Summary of Research
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The goal of this project is to determine precursors and signatures of local substorm onset and how they evolve in the plasma sheet using the Geotail near-Earth database. This project is part of an ongoing investigation involving this PI, Nelson Maynard (Mission Research Corporation), and William Burke (AFRL) toward an empirical understanding of the onset and evolution of substorms.

The first year began with dissemination of our CRRES findings, which included an invited presentation and major publication. The Geotail investigation began with a partial survey of onset signature types at distances $X < 15$ R_E for the first five months (March—July 1995) of the Geotail near-Earth mission. During the second year, Geotail data from March 1995 to present were plotted. Various signatures at local onset were catalogued for the period through 1997. During this past year we performed a survey of current-disruption-like (CD-like) signatures at distances $X \leq 14$ R_E for the three years 1995—1997.

Substorm Signatures. Table 1 summarizes the main substorm signatures found at distances $9 < X < 30$ R_E. The first row gives the X distance. The second row contains the number of CD-like events observed at that distance. CD-like signatures are characterized by the local onset of significant magnetic fluctuations and dipolarization. The third row contains the number of hybrid events denoted "CD/X". Local onset is characterized by the onset of significant magnetic fluctuations like in CD-like events; however, the magnetic field does not dipolarize monotonically. Rather, the magnetic field may weaken, and may even turn southward (but without an accompanying VX reversal). CD/X events have signatures akin to CD and X-line formation. Dipolarization may delay until local recovery. The fourth row, labeled X/Pl, contains the number of events with clear near-Earth X-line (NEXL) or plasmoid signatures, i.e., simultaneous reversals of the normal magnetic field component from north to south and the plasma velocity from Earthward to tailward. The final row contains the average time from the start of the X/Pl signature to local recovery, i.e., when the X-line moves tailward of the satellite and the plasma sheet recovers in the presence of Earthward plasma flow. The "fraction" column gives the number of each event type found in the $9 < X < 14$ R_E region over the total number of events. The numbers given in Table 1 are normalized to represent two years of data.

The region $9 < X < 14$ R_E is dominated by CD-like signatures at local onset. The region $X > 24$ R_E exclusively displays NEXL signatures at local onset. The intermediate region is dominated by dropout of the plasma sheet and the satellite entering the tail lobe at local onset until local recovery when the plasma sheet re-inflates accompanied by earthward plasma flow. During few events does the satellite remain in the plasma sheet. At such times either a CD-like signature, a NEXL signature, or a hybrid signature is observed.
The behavior is much as originally reported by *Hones et al.* [1973]. The interpretation then was that a NEXL formed at $X < 15$ R_E. Today, we know the NEXL forms near 24 R_E, on average [e.g., *Baumjohann et al.*, 1999]. The present investigation is consistent with this finding. Findings from the CRRES satellite showed that the near-geosynchronous region exhibits ballooning-like signatures in close conjunction with ground onset [e.g., *Erickson et al.,* 2000]. The AMPTE/CCE mission demonstrated that CD signatures characterize local onset in the vicinity of X = 8-9 R_E [e.g., *Lui et al.*, 1990]. The present investigation shows that CD-like behavior dominates out to $X = 14$ R_E, but that reconnection signatures can begin to be found as close as $X = 13$ R_E. Observations of ballooning or current disruption at $X < 10$ R_E while NEXL signatures are found at $X > 20$ R_E has resulted in two competing substorm models. In the so-called "near-Earth current disruption" (NECD) model the substorm evolves inside-out. In the near-Earth neutral line (NENL) model the substorm evolves outside-in.

During our CRRES investigation we usually observed that substorms had a two-stage behavior. The first stage was characterized by ground onset or pseudobreakup in close temporal relation to ballooning, emergence of the substorm current wedge, and electromagnetic energy flowing toward the ionosphere seen at CRRES. The second stage corresponded to auroral re-intensification and poleward expansion in close temporal correspondence to the observation of a second stage of dipolarization due to flux pile-up at CRRES. Consistent with those findings, in the present investigation local onsets observed in the CD region occur close in time to first-stage ground onset, whereas NEXL observations correspond to the second stage.

Local Onsets in the CD Region. We reported on two events in which substorm expansion was observed over the CANOPUS array of ground-based instruments that evidences a clear inside-out evolution at Geotail [*Erickson et al.*, 2002]. In both events a tailward propagating signal was detected at Geotail corresponding to substorm onsets Earthward and westward of the satellite and consistent with ground observation of onset. This was followed after a few minutes by the observation of earthward flow and dipolarization in correspondence to auroral re-intensification and poleward expansion at the local time of Geotail.

In an attempt to find some consistent evidence for an inside-out or outside-in substorm evolution, we examined the plasma velocity signature at local onset in the CD region. Table 2 summarizes our findings. There is no preference for the direction of plasma flow at substorm onset. This would be consistent with the current disruption model for the substorm. However, it does not necessarily contradict the NENL model. Pre-local-onset earthward flow could have occurred on either side of the satellite, and the satellite could first observe the earthward flow, no flow, or a tailward responsive flow. However, on closer inspection pre-dipolarization magnetic field and velocity signatures are consistent with a substorm current wedge approaching the satellite from the earthward side. Dipolarization and earthward plasma flow occurs as the substorm current wedge passes the satellite's position. Given the absence of enhanced Earthward flow prior to this time in all 137 events comprising Table 2, we see this result as supportive of an inside-out substorm expansion and in contradiction to the NENL model, in which the substorm current wedge results from the arrival of Earthward flow and flux pile-up at $X < 10\ R_E$. Given the NEXL forms tailward of the CD region, such earthward plasma flow and flux transport should have been witnessed in many of the 137 events.

The next task would be to concentrate on the plasma-sheet dropout region just tailward of the CD region and the CD/X type signatures to understand the physical, cause-and-effect connection between the CD region and NEXL formation. A renewal proposal was submitted to do this, but was turned down. However, a reduced level of phase-out funding was granted for one year. This is being used at the PI's new institution to prepare our finding for publication in a major journal.

Refereed Papers:

Erickson, G. M., N. C. Maynard, W. J. Burke, G. R. Wilson, and M. A. Heinemann, Electromagnetics of Substorm Onsets in the Near-Geosynchronous Plasma Sheet, *J. Geophys. Res.*, *105*, 25,265, 2000a.

Papers in Conference Proceedings:

Burke, W. J., and G. M. Erickson, Bursty Bulk Flows: Some Electrodynamic Considerations, in *Substorms 5*, pp. 153--156, ESA SP-443, July 2000.

Erickson, G. M., N. C. Maynard, G. R. Wilson, and W. J. Burke, Electromagnetics of Substorm Onsets in the Near-Geosynchronous Plasma Sheet, *Substorms 5*, pp. 385-388, ESA SP-443, July 2000.

Erickson, G. M., N. C. Maynard, and G. R. Wilson, Observations of Two-Stage Substorm Onsets in the Near-Earth Plasma Sheet, in *Substorms 6*, ed. R. M. Winglee, pp. 370-375, University of Washington, Seattle, 2002.

Presentations at Scientific Meetings:

Erickson, G. M., Initiation of the Substorm Current Wedge (Invited), Fifth International Conference on Substorms, St. Petersburgh, Russia, May 16--20, 2000.

Erickson, G. M., N. C. Maynard, G. R. Wilson, and W. J. Burke, Electromagnetics of Substorm Onsets in the Near-Geosynchronous Plasma, Fifth International Conference on Substorms, St. Petersburgh, Russia, May 16--20, 2000.

Burke, W. J., and G. M. Erickson, Bursty Bulk Flows: Some Electrodynamic Considerations, Fifth International Conference on Substorms, St. Petersburgh, Russia, May 16--20, 2000.

Erickson, G. M., CRRES Observations of Substorm Onsets in the Near-Geosynchronous Plasma Sheet, GEM/Tail Substorm, Snowmass, Co., June 21, 2001.

Burke, W. J., G. M. Erickson, and N. C. Maynard, On the Triggering of Substorms, EGS, Nice, France, 2001.

Erickson, G. M., CRESS Observations of Substorm Onsets in the Near-Geosynchronous Plasma Sheet, GEM/Tail Substorm, Snowmass, Co., June 21, 2001.

Erickson, G. M., N. C. Maynard, and G\ R. Wilson, Signatures and Timing of Local Substorm Onsets in the Near-Earth Plasma Sheet, ICS-6, Seattle, 25--29 March 2002.

Erickson, G. M., N. C. Maynard, and G. R. Wilson, Signatures and Timing of Substorms in the Near-Earth Plasma Sheet, AGU Spring Meeting, 28--31 May, 2002. [*EOS Trans. AGU, 83*(19), Spring Meet. Suppl., Abstract SM22A-16, 2002]

Erickson, G. M., Genesis of Substorms in the Near-Earth Plasma Sheet **(Invited)**, 34th COSPAR Scientific Assembly, Houston, TX, 10—19 October, 2002. [COSPAR 2002, D3.8-PSW2, ID-NR: COSPAR02-A-00831]

Erickson, G. M., N\ C. Maynard, and G. R. Wilson, Is the Current Disruption Region the Genesis Region for the Substorm X-Line? AGU Fall Meeting, San Francisco, 6--10 December 2002. [*EOS Trans. AGU, 83*(47), Fall Meet. Suppl., Abstract SM52B-08, 2002]

Seminars:

Substorm Onsets Observed at CRRES, Air Force Research Laboratory, Hanscom AFB, 24 August 2000.

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Erickson, G. M., N. C. Maynard, W. J. Burke, G. R. Wilson, and M. A. Heinemann, Electromagnetic of substorm onsets in the near-geosynchronous plasma sheet, *J. Geophys\ Res., 105*, 25,265, 2000.

Erickson, G. M., N. C. Maynard, and G. R.\Wilson, Observations of Two-Stage Substorm Onsets in the Near-Earth Plasma Sheet, in *Substorms 6*, ed. R. M. Winglee, pp. 370--375, University of Washington, Seattle, 2002.

Hones, E. W., Jr., J. R. Asbridge, S. J. Bame, and S. Singer, Substorm variations of the magnetotail plasma sheet from $X_{SM} \approx -6R_E$ to $X_{SM} \approx -60R_E$, *J. Geophys. Res., 78*, 109, 1973.

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Table 1: X-Distribution of Event Types
(Normalized for 2 Years of Events)

Type	Fraction	X=9	10	11	12	13	14	15	16	17	18	19
CD	79/90	10	33	9	11	9	7	2	2	5	2	0
CD/X	10/17	2	1	0	3	2	2	1	1	1	1	2
X/Pl	3/84	0	0	0	0	1	2	1	1	3	0	2
Δt(min.)		ave=24	–	–	–	10	9	5	4	24	–	32

Type	X=20	21	22	23	24	25	26	27	28	29	30
CD	0	0	0	0	0	0	0	0	0	0	0
CD/X	0	0	0	0	1	0	0	0	0	0	0
X/Pl	2	2	2	3	0	11	9	11	15	7	12
Δt(min.)	32	23	46	37	–	19	37	23	30	13	23

The region $15 < X < 24$ is dominated by plasma-sheet dropout at local onset and plasma-sheet inflation accompanied by Earthward flow at recovery.

Table 2: V_X Distribution at Local Onset
(Geotail, 1995–1997; $9 \leq X \leq 14$)

V_X	Green	Red	All
Earthward	8	23	45
Background	13	24	45
Tailward	10	23	47

Green = Dipolarizations with good ground timing and station conjunction.
Red = Dipolarizations with good ground timing (includes "green" events).