# Conjunction of Tail Satellites for Substorm Study: ISTP Event of 1997 January 2

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**Abstract.** The interval of 1997 January 1-2 was identified as a favorable conjunction of Geotail and IMP-8 to examine substorm activity in the mid-tail region prior to data acquisition. On January 2, 1997, global auroral observations from Polar indicated a substorm onset at ~0120 UT followed by a substorm intensification at ~0154 UT at a local time spatially separated from the initial substorm activity region. During this event, both Geotail and IMP-8 were in the mid-tail near the midnight meridian (Geotail $(X,Y) \approx (-30,-3)R_E$ and IMP-8 $(X,Y) \approx (-37,2)R_E$). Observations indicated that the substorm onset activity was localized in the postmidnight region. After the onset, Geotail detected a transient dipolarization which was not accompanied by large plasma flows (i.e., $| V_x | \leq 200$ km/s). The subsequent substorm intensification produced enduring dipolarization at Geotail and highly fluctuating magnetic field (mostly northward $B_z$) at IMP-8. Observations for this substorm showed no indication of mid-tail activities occurring prior to auroral brightening for both onset and intensification even though the satellites observed activities subsequently. Close examination of data indicates that the delays were not due to a dawn-dusk expansion of mid-tail activity. These results are consistent with substorm activity beginning in the near-Earth region first, followed by activity in the mid-tail region later.

## 1. Introduction

A number of substorm onset mechanisms exist in the literature. They can be broadly classified into two schools of thought: (1) the onset process located in the near-Earth region ($| X | \leq 15R_E$) with its effect spreading subsequently tailward and (2) magnetic reconnection starting before substorm onset beyond $| X | \approx 15R_E$ causing near-Earth substorm activity later. The former school includes models with various plasma instabilities and direct penetration of solar wind electric field [e.g., *Roux et al.*, 1991; *Lui et al.*, 1991; *Zhu and Winglee*, 1996; *Lyons*, 1996] and has been synthesized into a current disruption model [*Lui*, 1991]. The latter relies on the formation of a near-Earth neutral line in the mid-tail region with plasma flow braking in the near-Earth region to set up the substorm current wedge [e.g., *Shiokawa et al.*, 1998]. The differentiation between these two possibilities remains a central issue in substorm research.

In the ISTP era, there are several periods of close conjunction of satellites in the tail. One such period, 1997 January 1-2, was identified by N. C. Maynard prior to data collection. For this period, both IMP-8 and Geotail were closely spaced in the mid-tail region, complemented by global viewing of auroras by Polar and extensive measurements from ground stations. This set of coordinated measurements provides an excellent opportunity to examine the mid-tail disturbances in relation to auroral substorm onset and to address the issue alluded to in the above. There were two substorms within this period, one on each date. The first substorm will be reported elsewhere. For the second substorm, there was a noticeable spatial difference on the locations of substorm onset and a later intensification. Fortuitously, Geotail was located at the magnetic local time (MLT) of the substorm onset region and IMP-8 was located at the MLT of the substorm intensification region. The results reported in this paper indicate that mid-tail substorm effects seen by Geotail and IMP-8 occurred after the substorm onset identified by Polar and on the ground. There was no indication of mid-tail magnetic reconnection beginning prior to substorm onset or its subsequent intensification. The implication is that the substorm disturbance was initiated in the near-Earth region which spread later to the mid-tail region.

## 2. Observations

A temporal sequence of global auroral images obtained by the UVI instrument on Polar [*Torr et al.*, 1995] around the substorm onset and intensification on this day is shown at the top of Fig. 1. Images from the Polar VIS camera [*Frank et al.*, 1995] also indicate the same substorm development. From this sequence, the auroral breakup marking the substorm expansion onset occurred between ~0118 and 0121 UT. The substorm auroral activity after onset concentrated in the post-midnight region for ~30 min and exhibited definite poleward and local time expansions. At ~0154UT, a substorm intensification occurred in the pre-midnight region, spatially disjoint from the post-midnight auroral activity associated with the onset. Magnetic perturbations associated with the onset and intensification were recorded by the Greenland magnetometer chain as shown in Fig.1. The station SCO (~1.8 MLT) showed a sharp onset of magnetic activity at ~0120 UT, consistent with the Polar images

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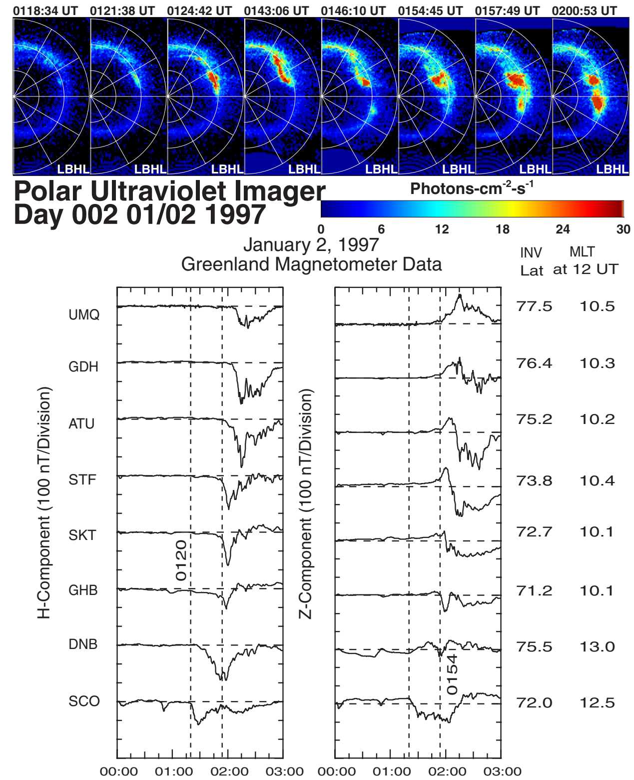


**Figure 1.** A time sequence of auroral emissions from Polar UVI and the H and Z components from the Greenland magnetometer chain on 1997 January 2. Overlays of the latitude ($10^o$ increments) and magnetic local time (2-hr increments; dusk at the bottom and midnight to the right of each frame) are in AACGM coordinates.

indicating the station being situated very close to the onset activity. The station DNB, at a higher latitude than SCO, showed a more gradual onset. The Z-component disturbances indicate that the electrojet was centered at a latitude between these stations at onset. For the substorm intensification, the ground stations which registered the intensification were in the premidnight sector and the Z-component disturbances indicate the electrojet was centered between $72.7^o$ and $73.8^o$

During this period, Geotail was in the plasma sheet at $X \approx -30R_E$ in the post-midnight tail while IMP-8 was also in the plasma sheet at $X \approx -37R_E$ in the pre-midnight tail. The top two panels of Fig. 2 show the magnetic field measurement from IMP-8 and the bottom panels show Geotail measurements of magnetic field, plasma bulk flow, and anisotropy of ~67 keV ions. The $B_y$ component was relatively small during the interval at the two satellites. Based on the Tsyganenko field model [*Tsyganenko*, 1989] and the $K_p = 2$ at that time, Geotail was projected to the MLT of the onset activity but at a lower latitude ($68.9^o$ MLat and 0.43 MLT) than onset. IMP-8 was projected to the same MLT and nearly the same latitude of the intensification region ($70.2^o$ MLat and 23.6 MLT). Even though the above mapping results should be regarded as guidance only, it is reasonable to expect them to provide a good indication of the actual projected satellite locations at least in the pre-onset condition. Therefore, we shall consider these satellites to be well located to monitor the substorm activity in the mid-tail region. Further discussion on this point is given in the next section.

From 0100 UT to the substorm onset (0120 UT), Geotail crossed the neutral sheet several times and remained near that location. Throughout this 20 min interval, Geotail detected only weak northward $B_z$ ($|B_z| \leq 3$ nT) and no significant plasma flow ($|V_x| \leq 100$ km/s). About 3-5 min after onset, Geotail crossed the neutral sheet four times, as shown in Fig. 3. The first three showed weak northward $B_z$ as before. However, for the last crossing, $B_z$ jumped to ~10nT, accompanied by only weak Earthward plasma flow ($V_x \leq 100$ km/s). This change at the neutral sheet is definitely temporal since Geotail was essentially stationary in the magnetospheric frame within the time span of two minutes. The enhanced $B_z$ stayed high and positive for ~4 min, during which time the plasma flow reversed to tailward at ~200 km/s. The 67 keV ion anisotropy observed during the first 10 min after substorm onset was consistent with the plasma flow observation. IMP-8, located at $\Delta X \approx 7.5R_E$ and $\Delta Y \approx 5.6R_E$ from Geotail, did not observe any corresponding enhancement in $B_z$, indicating the localization of the substorm activity seen by Geotail. It is important to note that there was no significant prior activity in plasma flow or $B_z$ change at Geotail before the substorm onset time.

A substorm intensification occurred at ~0154 UT when IMP-8 was right at the neutral sheet and $B_z$ was positive

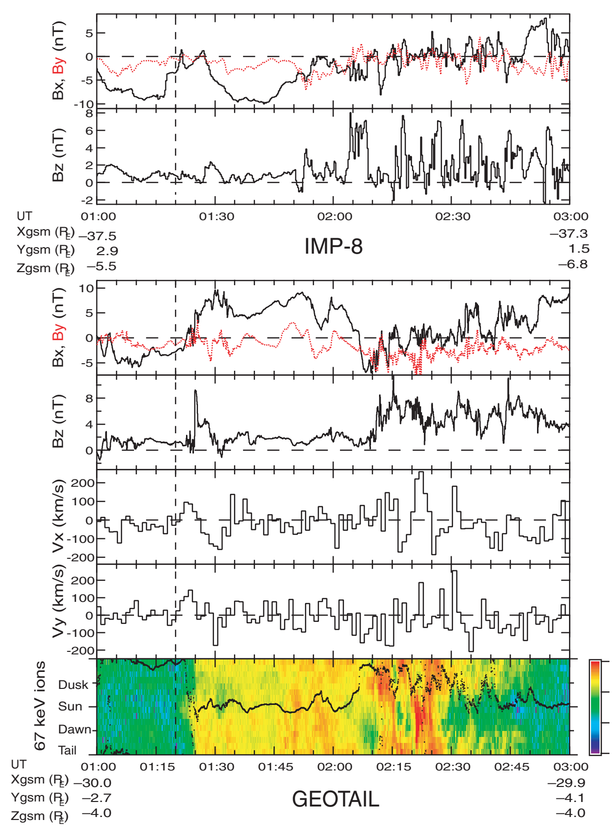


**Figure 2.** IMP-8 and Geotail observations in GSM coordinates on 1997 January 2. The vertical dashed line marks the substorm expansion onset time. The labels for ~67 keV energetic ion anisotropy panel refer to the direction of particle motion. The dots in the anisotropy panel mark the magnetic field direction projected on the equatorial plane.

and small ($| B_z | \leq 2$ nT). From the observed values of the $B_x$ component, IMP-8 remained close to the neutral sheet for the rest of the period shown in Fig. 2. A significant change in $B_z$ started at ∼0203 UT when it jumped to ∼8 nT. Large excursions of $B_z$, remaining mainly positive, were evident thereafter. A significant increase in $B_z$ at Geotail occurred at ∼0210 UT and from then on $B_z$ remained large. During the enhanced $B_z$ interval at Geotail, plasma flow was observed to switch between tailward and Earthward repeatedly. Again, there was no indication of any activity at IMP-8 prior to the substorm intensification, just like the case for the onset.

The equatorial Pi2 activity for this period is illustrated in Fig. 4 which shows the H-component (raw and filtered for Pi2 detection) from the magnetic station Eusebio (GLat: −3.85; GLon: −38.42; Pace MLat: −3.6; Pace MLT: 22.5 at 0120 UT) located in the midnight sector at this time. It can be seen that no large and distinct Pi2 onset was found for both the substorm onset at ∼0120 UT and the substorm intensification at ∼0154 UT. There was a small amplitude (∼0.3 nT peak-to-peak) Pi2 at ∼0122 UT which might correspond to the substorm onset. However, Pi2's of similar magnitudes were seen frequently (e.g., at ∼0108, 0113, 0118, 0128, 0137 UT). Furthermore, that Pi2 was not accompanied by a positive bay onset. Therefore, it is difficult to justify singling out the Pi2 at 0122 UT among them as the one signaling the substorm onset without auxiliary data. There was a prominent Pi2 onset at ∼0050 UT, which was in fact associated with the start of a positive bay. This Pi2 activity corresponds to a small brightening lasting for a few minutes, as shown by the Polar UVI data in the figure, which could be considered as a pseudo-breakup but not as a substorm.

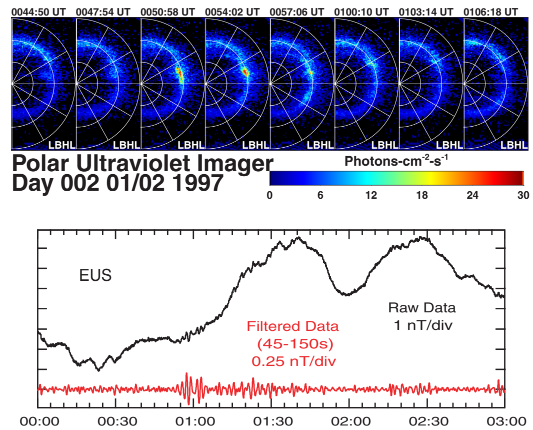


**Figure 4.** A time sequence of the Polar UVI observations around the onsets of Pi2 and positive bay activity at EUS.

## 3. Summary and Conclusion

The ISTP period analyzed here was selected prior to data collection on the basis of the close conjunction of IMP-8 and Geotail in the mid-tail region in order to examine the substorm activity in that region and time the activity onset with respect to those seen at the auroral altitude and on the ground. One particular issue which can be addressed with this conjunction is whether or not signatures of magnetic reconnection can be detected in the mid-tail region prior to substorm expansion onset. For the substorm on 1997 January 2, the onset occurred in the post-midnight sector while a subsequent intensification occurred in the pre-midnight sector. Fortuitously, Geotail and IMP-8 were located in the post-midnight and pre-midnight, respectively. Thus, mid-tail activity relating to substorm onset was monitored well by Geotail and mid-tail activity relating to substorm intensification was monitored well by IMP-8. We have found that the mid-tail substorm disturbance at Geotail was delayed by ∼5 min with respect to the onset time and the intensification disturbance at IMP-8 was delayed by ∼9 min with respect to the intensification onset time. Therefore, for each of the two onsets of substorm activity, there was a substantial delay in the mid-tail region.

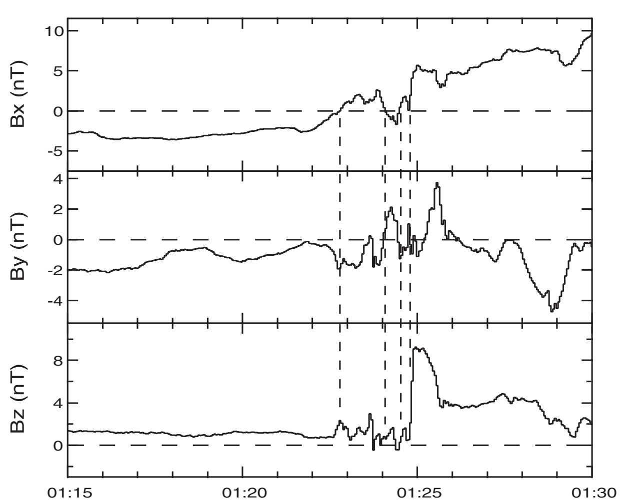


**Figure 3.** An enlarged view of the magnetic field measured around the substorm expansion onset. The vertical dashed lines mark the neutral sheet crossings.

An obvious question is whether the satellite was located in the same dawn-dusk portion of the tail as the substorm activity region since the accuracy of mapping a tail location based on a magnetic field model can always be questioned. If the substorm activity does not extend to the satellite location in the dawn-dusk dimension, then one would not expect substorm disturbances to be seen. The large and sudden $B_z$ increase detected at ∼0125 UT by Geotail indicates the substorm activity extending to Geotail in the dawn-dusk dimension. What about the possibility of the delay in the $B_z$ increase arising from a dawn-dusk expansion of the substorm disturbance? This is also unlikely because the $B_z$ increase occurred when the $V_x$ component was decreasing, contrary to the expectation from a dawn-dusk expansion of substorm disturbance in which the $V_x$ component should increase when the expansion reached the spacecraft location. It is therefore reasonable to interpret the time delay to be consistent with a near-Earth substorm initiation spreading later in a disjoint fashion to the mid-tail region. Similarly, for the intensification, large magnetic field fluctuations at the neutral sheet were observed at IMP-8, implying that the substorm activity extended to the IMP-8 location in the dawn-dusk dimension. The time delay in the onset of substorm activity at IMP-8 with respect to the intensification onset is also consistent with the disturbance for the intensification originating from the near-Earth region and spreading subsequently to the mid-tail region. This result is consistent with the recent findings that at least some dipolarizations are caused by a near-Earth non-MHD process and not by magnetic flux pileup from mid-tail magnetic reconnection [*Lui et al.*, 1999].

A surprising observation from this study is the magnetic signatures at the equatorial station during this period. The onset of Pi2 and positive bay at that station corresponds not to a substorm expansion onset but to a weak auroral brightening expected for a pseudo-breakup. This indicates the unreliability of using onsets of Pi2 and positive bay to determine substorm expansion onset. It is not simply a case of time delay between Pi2 onset and substorm expansion onset. In this case, the observed Pi2 has no relationship with the substorm expansion onset observed later. It is relevant to mention that *Liou et al.* [1999] recently conducted an extensive comparison between various substorm onset signatures. Their result indicates that different substorm onset identifiers generally gives different onset times and a unified definition of substorm onset is necessary to construct a correct sequence of substorm phenomenology.

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