Association Between Geotail Plasma Flows and Auroral Poleward Boundary
Intensifications Observed by CANOPUS Photometers

by

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Abstract

Poleward boundary intensifications are nightside geomagnetic disturbances that have an auroral signature that moves equatorward from the poleward boundary of the auroral zone. They occur repetitively, so that many individual disturbances can occur during time intervals of ~ 1 hr, and they appear to be the most intense auroral disturbance at times other than the expansion phase of substorms. We have used data from three nightside conjunctions of the Geotail spacecraft in the magnetotail with the CANOPUS ground-based array in central Canada to investigate the relation between the poleward boundary intensifications and bursty plasma-sheet flows and to characterize the bursty flows associated with the disturbances. We have found a distinct difference in plasma sheet dynamics between periods with, and periods without, poleward boundary intensifications. During periods with identifiable poleward boundary intensifications, the plasma sheet has considerable structure and bursty flow activity. During periods without such poleward boundary intensifications, the plasma sheet was found to be far more stable with fewer and weaker bursty flows. This is consistent with the intensifications being the result of the mapping to the ionosphere of the electric fields that give rise to bursty flows within the plasma sheet. Two different types of plasma sheet disturbance have been found to be associated with the poleward boundary intensifications. The first consists of plasma sheet flows that appear to be the result of Speiser motion of particles in a localized region of thin current sheet. The second, seen primarily in our nearest-to-the-Earth example, consists of energy dispersed ion structures that culminate in bursts of low energy ions and isotropic low-energy electrons and are associated with minima in magnetic field and temperature and maxima in ion density and pressure. Both types of plasma sheet disturbance are associated with localized regions of enhanced dawn-to-dusk electric fields and appear to be associated with localized enhanced reconnection.

Our analysis has shown that poleward boundary intensifications are an important aspect of geomagnetic activity that is distinct from substorms. In addition to their very distinct auroral signature, we have found them to be associated with a prolonged series of ground magnetic Pi 2 pulsations and ground X-component perturbations, which peak at latitudes near the ionospheric mapping of the magnetic separatrix, and with a series of magnetic B_z oscillations near synchronous orbit. Like substorms, the tail dynamics associated with the poleward boundary intensifications can apparently extend throughout the entire radial extent of the plasma sheet.

Color versions of figures are available at: "http://www.atmos.ucla.edu/~larry/geotail.html"

1. Introduction

Plasma transport in the geomagnetic tail is a fundamental aspect of the dynamics of the magnetosphere and of solar-wind energy transfer to the magnetosphere-ionosphere system. Much of this transport is associated with geomagnetic disturbances that can be identified from auroral observations and ground magnetometers. The two most intense nightside auroral disturbances are the magnetospheric substorm and disturbances (here referred to as "poleward boundary intensifications") that have an auroral signature that moves equatorward from the magnetic separatrix. Substorms happen sporadically and give the largest and most dynamic changes in the magnetotail. Poleward boundary intensifications occur repetitively, so that many individual disturbances can occur during time intervals of ~ 1 hr, and as discussed below, they appear to be the most intense auroral disturbance at times other than the expansion phase of substorms. These disturbances occur during all levels of geomagnetic activity [Lyons et al., 1998], but have received very little attention in the literature. Individual case studies have found them to be associated with localized periods of enhanced tail reconnection [de la Beaujardière et al., 1994] and to be related to the bursty flows in the tail [Kauristie et al., 1996; Yeoman and Lühr, 1997;

Lyons et al., 1998] which are now believed to an important means of plasma transport in the magnetotail [Baumjohann et al., 1990; Angelopoulos et al., 1992]. It has been suggested that the repetitive nature of intensifications at the poleward boundary of the auroral zone could be related to shear Alfvén waves along the outer boundary of the plasma sheet [Liu et al., 1995].

Intensifications in association with auroral surges that form during the expansion phase of substorms have been observed along the poleward boundary of the auroral oval in two-dimensional images of the auroral zone [Rostoker et al., 1987; Nakamura et al., 1993]. These intensifications appear to be the same phenomena as the poleward boundary intensifications. The two-dimensional images show intensification occurring as both east-west structures along the poleward boundary and as north-south features that extend equatorward from the poleward boundary. Henderson et al. [1998] have recently suggested that the north-south structures are related to the bursty flows in the tail. If these intensifications are indeed the same phenomena as the poleward boundary intensifications, they should be also be seen in two-dimensional images during periods other than the expansion phase of substorms; however we unaware of any study of their occurrence during such periods.

The goals of the present paper are to investigate the relation between poleward boundary intensifications and bursty plasma-sheet flows and to characterize the bursty flows associated with the intensifications. To do this, we examine data from three nightside conjunctions of the Geotail spacecraft in the magnetotail with the CANOPUS (Canadian Auroral Network for the OPEN Program Unified Study) ground-based array in central Canada. We use magnetic field data [Kokubun et al., 1994] and plasma data [Mukai et al., 1994] from Geotail and meridian-scanning photometer and magnetometer data from CANOPUS [Rostoker et al., 1995].

2. Poleward Boundary intensifications

Spatially and temporally localized bursts of enhanced plasma sheet flow have been identified both within the near-equatorial plasma sheet [Baumjohann et al., 1990; Angelopoulos et al., 1992], where the flow bursts are primarily earthward, and within the auroral ionosphere [Sergeev et al., 1990], where the flow bursts are primarily equatorward. The flow bursts typically have about 10 min duration (with considerable shorter time-scale structures) both within the plasma sheet and within the ionosphere, and flow speeds are consistent with a mapping of the flows from the equatorial plasma sheet (where v ~ 500-1000 km/s, giving E ~ 1-2 mV/m for B = 2 nT) to the ionosphere (where v ~ 500-1000 m/s and E ~25-50 mV/m). Some bursty flows observed in the plasma sheet are associated with dipolarizations of the tail magnetic field [Angelopoulos et al., 1992]. Dipolarizations are a reconfiguration of portions of field lines well away from ionosphere. Thus the induced electric fields associated with dipolarizations will not map to the auroral ionosphere. However, as the Geotail data discussed below shows, many bursty flows are not associated with dipolarizations, and such flows and associated potential electric fields should map to the auroral ionosphere.

de la Beaujardière et al. [1994] found that bursts of enhanced equatorward flow in the ionosphere are seen first near the magnetic separatrix, where they correspond to a localized increase in plasma flow across the separatrix and thus to a localized increase in nightside reconnection. The flow enhancements extend well equatorward of the separatrix into regions that are normally associated with the central plasma sheet, and in one case that was studied in detail, the enhancement was found to propagate both westward and equatorward at speeds of ~1 km/s. de la Beaujardière et al. also found that the flow enhancements are associated with auroral poleward boundary intensifications. Since

auroral arcs are generally associated with the upward field-aligned current that results from converging ionospheric currents, the poleward boundary intensifications are presumably associated with converging ionospheric currents associated with spatial gradients of the equatorward moving bursts of enhanced flow. de la Beaujardière et al. found the enhancements at the western edge of the equatorward flows, consistent with their association with converging ionospheric Pedersen currents and perhaps accounting for the north-south auroral structures seen with two-dimensional auroral imagers. However, the precise spatial and temporal relation between the arcs and the edges of the flow enhancements has not yet been studied in detail.

To lead to an auroral enhancement, the upward field-aligned currents associated with the flow enhancements must be sufficiently large that a magnetic field aligned potential drop is required [Lyons, 1981]. Since the poleward boundary intensifications we have examined are generally not as bright as substorm aurora that are often associated with field-aligned potential drops of ~10 kV, the poleward boundary intensifications should be associated with field-aligned potential drops of $\lesssim 1$ kV. Such potential drops will not significantly affect the large-scale mapping of the electric fields to the ionosphere.

Since the equatorward drifting auroral disturbances initiate near the boundary between the plasma sheet and polar rain, which is generally believed to be very near the boundary between open and closed magnetic field lines, the auroral disturbances can conveniently be referred to as "poleward boundary intensifications". Since bursty flows are a very common feature of the equatorial plasma sheet, we would expect their mapping to the ionosphere to often lead to auroral poleward boundary intensifications. Data from the CANOPUS meridian-scanning photometers shows that these disturbances are indeed quite common, and that they occur during all levels of magnetic activity [Lyons et al., 1998]. These disturbances have a number of distinct differences from substorms. For example, they initiate near the separatrix and propagate equatorward away from the separatrix. Auroral disturbances associated with substorms, on the other hand, initiate at magnetic latitudes $\lesssim 67°$ that are generally ~5° equatorward of the separatrix, and the disturbances then propagate poleward towards the separatrix. Also, poleward boundary intensifications often repeat many times with a several minute period, whereas substorms generally occur far less frequently and with much longer time delays between onsets.

3. January 18, 1997 Conjunction

CANOPUS ground MSP and magnetometer data, as well GOES 8 and 9 magnetometer data from synchronous orbit are shown in Figure 1 for a good Geotail-CANOPUS conjunction period on January 18, 1997. Magnetic and auroral activity during the period shown (03-08 UT) was quiet except for strong poleward boundary intensifications. The gray-scale panel at the top of the figure shows 5577 Å emissions, which result from the precipitation of $\gtrsim 1$ keV electrons, as a function of invariant latitude and MLT as obtained from a merging of data from MSP's at Gillam (GILL) and Rankin Inlet (RANK) along the same magnetic meridian. Poleward boundary intensifications appear as brightenings along the poleward boundary of detectable 5577 Å emissions. This poleward boundary is clearly seen in the MSP observations of 6300 Å emissions (not shown), which reflect precipitation of plasma-sheet electrons at energies $\lesssim 1$ keV. The poleward boundary of 6300 Å emissions has been shown to be within 1° in latitude of the magnetic separatrix [Blanchard et al, 1997], and the location of this boundary is shown in Figure 1 as a white dashed line. The poleward boundary intensifications can be seen to have occurred repetitively and were particularly bright at 73°-74° latitude from 0515 - 0615 UT, and may have been just as bright from 0345 - 0445 UT. This earlier period, however, was during a period that lasted until ~0500 UT when the optical emissions were partially obscured and significantly scattered by clouds at the higher latitude station (Rankin Inlet).

Some of the intensifications can be faintly seen to propagate equatorward to ~68° latitude, indicating that these disturbances can propagate large distances through the plasma sheet. Figure 1 shows that the poleward boundary intensifications from ~0345 - ~0615 UT were associated with a series of ~50 nT ground magnetic perturbations and a continuous series of Pi-2 pulsations at Rankin Inlet, which is at approximately the same invariant latitude as the brightest auroral activity. Also, the GOES 8 and 9 magnetic field data in Figure 1 show that there was a continuous series of ~5 nT fluctuations in the GSM z-component of nightside magnetic field at synchronous orbit during the time interval of the poleward boundary intensifications.

Simultaneous CANOPUS data and Geotail from x~ -30 R_E are shown Figure 2 for 04-08 UT. The bottom panels in Figure 2 show the x-perturbation and Pi 2 pulsations from CANOPUS magnetometer along the magnetic meridian of the MSP's. The Pi-2's can be seen to occasionally (i.e., at 0435, 0715, and 0730) extent to Gillam (GILL), which is the lowest latitude station shown in the figure. Also note that, except for the occasional Pi 2 activity, there is very little auroral or magnetic activity at lower latitudes. These features are typical of poleward boundary intensifications during quiet periods. (During periods of enhanced convection, such as convection bays, the intensifications observed with the CANOPUS photometers often propagate further equatorward with higher intensities than during quiet times, and can be associated with repetitive ground magnetic perturbations as high as 200-300 nT [Lyons et al., 1998]). Line plots of the x-component of magnetic field B_x and the x- and y-components of the plasma velocity V_x and V_y as measured by Geotail are shown in the panel above the MSP data in Figure 2. The heavier lines in this panel give $V_{perp,x}$ and $V_{perp,y}$, which are the x and y components, respectively, of the velocity component perpendicular to the measured magnetic field. The gray-scale spectrograms in the top of the figure give, from top to bottom, the count rates versus energy of earthward going ions, duskward going ions, and earthward going electrons. MLT estimates for the Geotail spacecraft have been obtained by mapping magnetic field lines to the Earth's surface using the Tsyganenko-96 [Tsyganenko and Stern, 1996] field model.

Geotail was located at longitudes just to the dawn side of 24 MLT during the time period shown in Figure 2. Thus the best conjunction between Geotail and CANOPUS (magnetic midnight at ~0630 UT) occurred from ~0530-0800 UT. During this period, the CANOPUS MSP data shows that poleward boundary intensifications occurred during distinct periods (indicated with gray shading in the figure) and that the intensifications were nearly absent at other times. Throughout the 0530-0800 UT period, Geotail was within the plasma sheet. It can be seen that the plasma sheet during this period had considerable bursty flow activity during the time periods of the poleward boundary intensifications and that the plasma sheet was very stable with little flow during the time periods when poleward boundary intensifications were not seen by the CANOPUS MSP's. This suggests that the plasma sheet has considerably more bursty flow activity during periods with poleward boundary intensifications than during periods without these disturbances, and it is consistent with the poleward boundary intensifications being the result of the mapping to the ionosphere of the electric fields that give rise to the bursty flows. We do not expect to generally see a one-to-one correspondence between individual flow bursts and poleward boundary intensifications because Geotail and CANOPUS are not at precisely the same longitude and the disturbances are both localized in longitude and propagate longitudinally.

Ion distributions within the bursty flows can give considerable information on tail processes associated with the flows. The bursty flows associated with poleward boundary intensifications include periods of time when mostly field-aligned flow was observed (e.g., 0530-0540 UT; 0549-0551 UT; 0605-0609 UT) because Geotail was located within the plasma sheet boundary (PSBL), as indicated by large values of B_x and $V_x > V_{perp,x}$. The

bursty flows also include periods of time when Geotail was near the center of plasma sheet, as indicated by $V_x \approx V_{perp,x}$ and small values of B_x. Further details of the Geotail data during the 0500-0630 UT period are shown in Figure 3. There were three ~10 min intervals of bursty flow (~0530-0540 UT, ~0548-0558 UT, and ~0603-0613 UT) during this 1 1/2 hr period, and the portions of these intervals when PSBL flows were observed are identified in the figure. Geotail remained within the PSBL during the first bursty flow, and moved from the PSBL to near the center of the tail current sheet (as indicated by $B_x \approx 0$ nT and $B_{total} \approx 2$ nT) during the second and third interval. Contrary to what is seen during substorms, there are no persistent magnetic field changes such as dipolarizations of the magnetic field associated with the intervals of bursty flows. There are only the small fluctuations in the magnetic field which are present during periods with and during periods without bursty flows. This lack of persistent dipolarizations in association with the bursty flows holds for all three of the periods we have examined. While this result contrasts with the dipolarization seen in the superposed epoch analysis of Angelopolous et al. [1992], the Angelopolous et al. analysis included earthward flow bursts associated with substorm dipolarizations.

Two dimensional distributions of the bursty flows for the three times indicated by the vertical dashed lines in Figure 3 are shown in Figure 4. The first is during the first bursty flow interval when Geotail remained within the PSBL, and the second and third are for times during the second and third bursty flow intervals after Geotail moved from the PSBL to very near the center of the tail current sheet. For each two-dimensional distribution, spectrograms of ion count rates in the sunward, duskward, tailward, and dawnward directions are also shown as a function of energy for a twenty minute interval that includes the corresponding interval of bursty flows. The time period for which the spacecraft was within the PSBL and the time of the two dimensional distribution are indicated by solid dark and dashed white vertical lines, respectively, for each twenty-minute interval.

The top distribution in Figure 4 is typical of the field-aligned beams of PSBL ions that are ejected from the tail current sheet after undergoing Speiser motion and energization with the current sheet [Lyons and Speiser, 1982]. Consistent with this beam being from within the PSBL, the spectrogram for this period shows that Geotail briefly entered the lobe a few times between 0535 and 0540 UT. The middle and bottom distributions in Figure 4 are very similar to the top distribution even though they are from very near the center of the tail current sheet. The most significant difference between these distributions and the PSBL distribution is that, in addition to earthward flow, the distributions show an asymmetry in the dusk-dawn direction with higher fluxes in the duskward direction. Such an asymmetry is precisely what is expected in the region where particles undergo Speiser motion [Speiser 1965] near the center of the current sheet. Neglecting the effects of B_y, Speiser motion gives a velocity in the x-direction $V_x = E_y/B_z$. Speiser motion also gives an asymmetry in the dusk-dawn direction because particles oscillate about the midplane of the current sheet and are energized while the y-component of their velocity is positive, but are forced away from the current sheet by the magnetic force when their y-component of velocity becomes negative. Notice in the middle spectrogram that the ion distributions only change slightly from the region within the PSBL at 0549-0551 UT to the region of flows near the center of the current sheet from 0551-0557 UT. The only significant change is the enhancement of fluxes in the duskward direction. This implies that Geotail moved from the PSBL to the region of current sheet acceleration without an intervening region of central plasma sheet. The bottom spectrogram is similar to the middle example, other than the satellite stayed nearer the center of the current sheet without fully entering the PSBL.

The combined Geotail-CANOPUS data in Figure 2-4 are consistent with the bursty flows associated with the poleward boundary intensifications on January 18 1997 being the

result of Speiser motion in a thin current sheet that extends earthward to at least ~30 R_E. At these same radial distances, effects of Speiser motion are not seen during periods when the poleward boundary intensifications are absent. The far more isotropic ion distributions during such periods are clearly seen in the spectrograms in Figure 4 during the few minute period prior to and after the ~ 10 min periods of bursty flow. This suggests that the bursty flows associated with the poleward boundary intensifications are within localized regions where the plasma sheet is significantly thinner than elsewhere. The data presented here do not allow us to determine the specific geometry of the thin regions of the plasma sheet. If we assume that the velocities of ~500 km/s that are observed when V_x $V_{perp,x}$ are representative of the actual plasma velocities near the center of the current sheet for the entire ~10 min interval of bursty flows, and that the bursty flow regions moved in the x-direction across the spacecraft, then the length of the thin-current sheet region in the x-direction would be ~ 45-50 R_E. However, longitudinal structure and propagation, as well as temporal evolution of the thin current sheet regions, will affect the duration of an interval of bursty flows. Also, the continuity between the PSBL and the region of Speiser motion within the current sheet implies that the thin current region extended down tail to the intersection of the magnetic separatrix with the magnetic equatorial plane a least at the time when the observed particles were ejected from the current sheet.

The bursty earthward flows are also consistent with the localized regions of thin plasma sheet being localized regions of enhanced electric fields. $V_{perp,x} = 500$ km/s and $B_z = 2$ nT gives $E_y = 1$ mV/m. Since the bursty flows are not associated with identifiable temporal changes in the large-scale magnetic field, the enhanced electric fields must be primarily potential electric fields which, except for small effects of field-aligned potential drops, are expected to map to the ionosphere. A uniform potential electric field $E_y \sim 1$ mV/m would give an unreasonably large potential drop ~250 kV across a 40 R_E tail, which implies that the enhanced electric fields must be localized in longitude and is consistent with the very low plasma flows seen near the center of the current sheet during the time-period without bursty flows. The ground radar observations of ionospheric flows by de la Beaujardière [1994] imply that the longitudinally localized regions of enhanced convection are associated with similarly localized regions of enhanced reconnection.

4. November 13, 1996 Conjunction

Figure 5 shows CANOPUS MSP and magnetic data for a good Geotail-CANOPUS conjunction on November 13, 1996 when Geotail was much closer to the Earth (x ~ -13 R_E) than during the January 18, 1997 conjunction. The magnetic data shown are from GOES 8 and 9, from auroral zone ground stations Poste de la Baleine (PBQ) and Yellowknife (YKC) located ~1 hr in MLT later and earlier, respectively, from the CANOPUS meridian chain, and Pi 2 pulsations from the CANOPUS station Gillam. During this period, there was an onset of a weak substorm expansion phase at 0422 UT as determined from the Poste de la Baleine and GOES 8 magnetometer data (both at ~23 MLT) and the brightening of the aurora ~4° equatorward of the separatrix seen in the MSP data. This brightening can be seen in the MSP data despite the hazy-to-cloudy conditions at Gillam, the lower latitude of the two MSP stations, which caused significant obscuration and scattering of the auroral emissions. Following the period of poleward-propagating aurora during the expansion phase, poleward boundary intensifications were observed most of the time from 0428 to 0619 UT. As with the January 18 example, the poleward boundary intensifications are associated with fluctuations in the z-component of nightside magnetic field at synchronous orbit. In this case the fluctuations are ~ 10 nT and are seen primarily at GOES 9, which was at ~20-21 MLT at the time of the intensifications. That these fluctuations are seen in both examples indicates that effects of the poleward boundary intensifications can extend throughout the nightside plasma sheet earthward to synchronous orbit despite the absence of substorms.

Simultaneous CANOPUS and Geotail data are shown in Figure 6 for 0330 - 0730 UT of the November 13, 1996 conjunction. It can be seen from the bottom panels in Figure 6 that the poleward boundary intensifications were associated with a series of quite large (~200 nT) X-perturbations and Pi 2 pulsations (~100 nT peak-to-peak) at Rankin Inlet, which is within ~1° of latitude of the most intense poleward boundary intensifications. This series of magnetic perturbations and Pi 2 pulsations can be seen to have extended equatorward to Gillam at 67° latitude.

For this case, Geotail was at ~22-23 MLT, so that the best conjunction with CANOPUS occurred from ~0330 to ~0630 UT. Similar to the January 18, 1997 example, the Geotail data in Figure 6 show far more bursty flows associated with a far more structured plasma sheet during periods with, than during periods without, poleward boundary intensifications. In this near-Earth example, the bursty flows are seen only near the center of the tail where $|B_x|$ is below a few nT.   During the interval of poleward boundary intensifications from 0551 to 0618 UT, Geotail was in regions where B_x ~ 5-13 nT and bursty flows were not seen. This example shows a dramatic difference between the B_x ~ 0 quiescent plasma sheet in the absence of poleward boundary intensifications (0330-0415 UT) and the far more structured B_x ~ 0 plasma sheet with considerable bursty flow activity during the period of strong poleward boundary intensifications (0428 -0525 UT).

This difference seen near the center of the plasma sheet between periods with and without poleward boundary intensifications in the November 13, 1996 example is quite similar to that seen further from the Earth on January 18, 1997. However, the structured plasma sheet in the November 13 example includes several well-defined structures that culminate in a burst of low-energy plasma and have plasma and magnetic field characteristics that repeat from burst to burst.   These "low-energy plasma bursts" are identified by vertical, dashed, lines in Figure 6 and can be seen in more detail in Figure 7. Energy-dispersed ions are seen prior to each burst, higher energies being seen first and each event ending with a burst of low-energy ions and electrons. As can be seen in Figure 7, each burst of low energy plasma is associated with a local minimum in B_z and temperature T (and B_{total}, not shown), and a local maximum in electron density n_e, plasma pressure P_{plasma} and total pressure P_{total}. The decrease in P_{total} and increase in B_z that are often seen in association with substorms, and can be seen in Figure 7 in association with the 0422 UT substorm onset (P_{total} decreased from ~0.35 nPa to ~ 0.20 nPa and B_z increased from ~2 nT to ~ 6 nT), are not seen in association with the low-energy plasma bursts.

The low-energy plasma bursts are the dominant dynamic structure seen within the plasma sheet during the period shown in Figure 6 and 7 other than in association with the substorm expansion-phase onset. To the best of our knowledge these have not been previously described or studied. However Nishida et al. [1997] report repeated energy-dispersed patches of ions at a radial distance ~10 R_E on the night side during a quiet period, which may be the same phenomenon as described here. Nishida et al. found that the energy dispersion increased with distance away from midnight in the duskward direction, and he suggested that the energy dispersion could be due to the magnetic drift of ions around the Earth.

Both the low-energy plasma bursts and the bursty flows seen further away from the Earth on January 18, 1997 that appear to have resulted from Speiser motion in a thin current sheet are associated with the poleward boundary intensifications.   Thus it is tempting to say that they are different aspects of the same phenomena, perhaps the low-energy bursts being the near-Earth extension of the bursty flows. Some evidence for a relation to the bursty flows is shown in Figure 8, where the two-dimensional distribution for one of the low-energy plasma bursts is shown. The distribution can be seen to have

slightly enhanced fluxes in the earthward and duskward directions as compared to the tailward and dawnward directions. This is consistent with magnetic drift in the y-direction and an earthward drift of ~200 km/s (See $V_{perp,x}$ in Figure 6) that would result from a 1 mV/m electric field in the y-direction with B_z ~ 5 nT. Thus both the bursty flows associated with Speiser motion and the low energy plasma bursts appear to be associated with localized electric fields of ~1 mV/m.

5. December 25, 1995 Conjunction

Figure 9 shows CANOPUS ground MSP, magnetometer data from GOES 8 and 9, and magnetometer data from auroral zone ground stations Poste de la Baleine (PBQ) and Yellowknife (YKC) for 03 - 08 UT on December 25, 1995. A clear, though weak, substorm onset can be seen at 0500 UT in the MSP observations and in the magnetic X-component at Poste de la Baleine. An additional onset appears to have occurred at 0529 UT, based on a decrease in the Z-component, and subsequent decrease in X, at Yellowknife and a small dipolarization (increase in B_z) at GOES 9. A second decrease in Z occurred at Yellowknife at ~0553 UT, which may have been associated with an onset at 0550 UT (timing based on the Pi 2 onset along the CANOPUS meridian seen in Figure 10). This onset, however is not unambiguous and looks like a poleward boundary intensifications in the CANOPUS MSP data.

To avoid ambiguities associated with the activity between 05 and 0555 UT, we confine attention to the 0600-0800 time interval on this day when there are no signature of substorm activity. During this interval, there were significant poleward boundary intensifications from 0614 to 6653 UT. Unlike the intervals discussed above, fluctuations in the z-component of nightside magnetic field at synchronous orbit are not apparent during this interval of activity. However, like the other two intervals, ground Pi 2 and X-component activity occurred during this interval along the CANOPUS meridian and was particularly prominent at Rankin Inlet (See Figure 10).

Figure 10 shows simultaneous CANOPUS and Geotail data for 0400 - 0800 UT of the December 25, 1995 conjunction. For this case, Geotail was at ~23-23.5 MLT, so that the there is reasonable conjunction with CANOPUS during the 06-08 UT time interval. Similar to the previous two examples, the Geotail data in Figure 10 show far more bursty flows associated with a far more structured plasma sheet during periods with, than during periods without, poleward boundary intensifications. In this example, at x = -28 R_E, the bursty flows are primarily of the type seen at a similar distance down the tail on January 18, 1997. As with the distributions from January 18, 1997, the two-dimensional ion distributions (not shown) from near the mid-plane of the current sheet for the period of significant bursty flows on December 25, 1995 (0640-0647 UT) show enhancements in the earthward and duskward directions, consistent with the distributions being the result of Speiser motion in a thin current sheet.

Figure 10 shows one low-energy plasma burst (at 0622 UT) of the type seen closer to the Earth in the November 13, 1996 example. Thus the December 25, 1995 example shows that both the low-energy plasma bursts and the bursty plasma flows can be seen during the same period of time in the mid-tail. This "low-energy plasma burst" is identified by a vertical, dashed, line in the figure and can be seen in more detail in Figure 11. Figure 11 also shows data in the same format for a pass on December 16, 1996 when Geotail was at nearly same x as on December 25, 1995 and three low-energy plasma bursts were observed. CANOPUS MSP data during the December 16 pass shows poleward boundary intensifications during the time period of the low-energy plasma bursts, but Geotail did not stay well within the plasma sheet long enough to warrant a detailed study of this conjunction. Figure 11 shows that the low-energy plasma bursts can occur as far away

form the Earth as x = -28 R_E. As with the low-energy plasma bursts seen closer to the Earth on November 13, 1996, each burst seen at these larger distances in conjunction with poleward boundary intensifications is associated with a local minimum in B_z, B_{total}, and temperature T, and a local maxima in ion density n_e. However, the consistent maxima in plasma pressure and total pressure seen closer to the Earth are not seen in for the bursts in Figure 11.

6. Conclusions

Using data from three nightside conjunctions between the CANOPUS ground stations and Geotail spacecraft in the tail, we have examined the relation between auroral poleward boundary intensifications, magnetic perturbations, and bursty flows in the tail plasma sheet. We have concentrated on time intervals that were not effected by the expansion phase of substorms in order to clearly distinguish plasma sheet responses to the poleward boundary intensifications from the plasma sheet response to substorms. The data we have examined show a distinct difference in plasma sheet dynamics between periods with, and periods without, poleward boundary intensifications. During periods of poleward boundary intensifications, the plasma sheet has considerable structure and bursty flow activity. On the other hand, the plasma sheet was found to be far more stable with little flows during time periods when significant poleward boundary intensifications were not seen. This is consistent with the poleward boundary intensifications being the result of the mapping to the ionosphere of the localized enhanced potential electric fields that give rise to bursty flows within the plasma sheet. (The induced electric fields associated with large-scale dipolarizations of the magnetic field are not expected to map to the ionosphere.)

We have identified two different types of plasma sheet disturbance that are associated with the poleward boundary intensifications, each having a significant $V_{perp,x}$ near the magnetic equator. During the conjunctions when Geotail was furthest from the Earth (x ~ -25-30 R_E), ~10 min intervals of bursty flows are seen that have ion distributions which suggest that the flows are associated with the Speiser motion of ions in a thin current sheet. Away from the current sheet, where B_x is large, the flows are typical of those seen within the plasma sheet boundary layer. The ion distributions are field-aligned and are of the type that have been attributed to energized particles that have been ejected from the tail current sheet after undergoing Speiser motion in the current sheet. Near the center of current, where V_x $V_{perp,x}$ and B_{total} and B_x are small, the ion distributions are of the type expected within the region of Speiser motion. These distributions look very much like those within the plasma sheet boundary layer, except they are enhanced in the duskward direction. Except for the enhancement in the duskward direction, the particle distribution changed very little during periods when Geotail moved from the plasma sheet boundary layer to near the current sheet, and there were no intermediate regions of stationary central plasma sheet. At these same radial distances, effects of Speiser motion are not seen during periods when the poleward boundary intensifications are absent. This suggests that the bursty flows associated with the poleward boundary intensifications are within temporally and spatially localized regions where the plasma sheet is significantly thinner than elsewhere. These localized regions of thin plasma sheet appear to also be localized regions of enhanced electric fields that are associated with similarly localized regions of enhanced reconnection The two cases we have examined suggest that bursty flows may often be associated with a thin plasma sheet; however the extent to which this association holds should be verified with a larger-scale study of the particle distributions within bursty flows.

The second type of plasma sheet disturbance seen in associated with the poleward boundary intensifications are the low-energy plasma bursts. These bursts are the dominant disturbances in our closer to the Earth (x ~ -13 R_E) conjunction, and they can also be

occasionally seen further from the Earth. They consist of energy dispersed ion structures that culminate in bursts of low energy ions and isotropic low-energy electrons, and they are associated with local minima in B_z, B_{total}, and T and local maxima in n_e, P_{plasma}, and P_{total}. Since both types of plasma sheet disturbance are associated with the poleward boundary intensifications and with localized regions of ~ 1 mV/m dawn-to-dusk electric fields, they may be different aspects of the same phenomenon. However we have not determined a relation between the two types of bursts, nor have we studied enough cases to determine the radial dependence of each type.

We have identified a number of features of the poleward boundary intensifications, in addition to their auroral signatures, which are distinctly different from substorms. Within the plasma sheet, neither dipolarizations of the large-scale magnetic field nor reductions in total plasma sheet pressure are seen in association with the poleward boundary intensifications, whereas these responses are commonly seen in the plasma sheet at r $\lesssim 30$ R_E in association with substorm expansions. Like substorms, the poleward boundary intensifications are associated with clearly identifiable Pi 2 pulsations on the ground, with magnetic x-component perturbations on the ground, and with magnetic perturbations at geosynchronous orbit. Unlike substorms, however, the ground magnetic effects are generally larger at magnetic latitudes near the separatrix (~73°) than at the latitudes ($\lesssim 67°$) of substorm onset. Also, like the auroral effects of the poleward boundary intensifications and unlike substorms, the ground Pi 2 pulsations and magnetic X perturbations are observed to occur repetitively during time intervals as long as ~ 1 hr. The ground X-component perturbations have the appearance of fluctuations with a ~10-15 min period, and perturbations with similar periods are seen in the z-component of the magnetic field at synchronous orbit. These synchronous magnetic perturbations are quite different from the dipolarizations of the field that are commonly seen in association with substorms. However, that the magnetic effects of the poleward boundary intensifications can extend earthward to synchronous orbit and that the auroral effects of the intensifications can extend to latitudes several degrees equatorward of the separatrix suggests that, like substorms, the tail dynamics associated with the poleward boundary intensifications can extend throughout the entire radial extent of the plasma sheet.

These results show that the poleward boundary intensifications are important aspect of geomagnetic activity that warrant further study directed towards understanding their morphology and processes that lead to their formation.

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Figure captions

Figure 1. CANOPUS ground MSP and magnetometer data and GOES 8 and 9 magnetometer data from synchronous orbit for the Geotail-CANOPUS conjunction on January 18, 1997. The gray-scale panel at the top of the figure shows 5577 Å emissions as a function of invariant latitude and MLT as obtained from a merging of data from MSP's at Gillam and Rankin Inlet along the same magnetic meridian. The white dashed line gives the poleward boundary of the plasma sheet as determined form the poleward boundary of 6300 Å emissions. The Pi 2 pulsation and magnetic X-component data are from the CANOPUS station Rankin Inlet (RANK) at 74° invariant latitude. The synchronous orbit data are in GSM coordinates

Figure 2. Geotail and CANOPUS data for the conjunction on January 18, 1997. The middle panel shows the 5577 Å emissions as a function of invariant latitude and MLT as obtained from a merging of data from MSP's at Gillam and Rankin Inlet; the poleward boundary of the 6300 Å emissions is given by the white dashed line. Ground magnetic x-component and Pi 2 pulsations are shown in the middle panels for CANOPUS stations along the magnetic meridian of Rankin Inlet and Gillam and between 67° and 74° invariant latitude. Line plots of Geotail B_x, V_x, $V_{perp,x}$, and $V_{perp,y}$ are shown in the panels above the MSP data. The heavier lines give $V_{perp,x}$, and $V_{perp,y}$. The gray-scale spectrograms at the top of the figure give, from top to bottom, the count rates versus energy of earthward going ions, duskward going ions, and earthward going electrons. MLT's for the Geotail data were estimated by mapping the location of Geotail to the Earth's surface using the Tsyganenko-96 magnetic field model.

Figure 3. Geotail plasma and magnetic field parameters for 0500-0630 on January 18, 1997. Regions identified as plasma sheet boundary layer are identified as PSBL. Vertical dashed lines identify times of two-dimensional distributions shown in Figure 4.

Figure 4. Two-dimensional ion distributions for 0534:04, 0552:14, and 0611:37 UT on January 18, 1997. Also shown are energy-time spectrograms of ion count rates in the sunward, duskward, tailward, and dawnward directions for twenty-minute intervals approximately centered on the times of the two-dimensional distributions.

Figure 5: CANOPUS MSP and magnetic data for the Geotail-CANOPUS conjunction on November 13, 1996 in a format similar to Figure 1. The magnetic data shown are from GOES 8 and 9 at synchronous orbit, from auroral zone ground stations Poste de la Baleine

(PBQ) and Yellowknife (YKC) located ~1 hr in MLT later and earlier, respectively, from the CANOPUS meridian chain, and Pi 2 pulsations from the CANOPUS station Gillam at 67° invariant latitude.

Figure 6: Geotail and CANOPUS data for the conjunction on January 18, 1997 in the same format as Figure 2. Low-energy plasma bursts are identified by vertical, dashed, lines.

Figure 7. Measurements from Geotail on November 13, 1996. From top to bottom are energy-time spectrograms of sunward going ion and electron count rates, and line plots of B_x, B_y, B_z, V_x and $V_{perp,x}$ (heavy line), V_y and $V_{perp,y}$ (heavy line), V_z and $V_{perp,z}$ (heavy line), ion density, temperature, and total (heavy line) and plasma pressures. Low-energy plasma bursts are identified by vertical, dashed, lines.

Figure 8. Two-dimensional ion distributions for 0450:36 UT on November 13, 1996. Also show are energy-time spectrograms of ion count rates in the sunward, duskward, tailward, and dawnward directions for a ten minute interval centered on 0450 UT.

Figure 9. CANOPUS MSP, magnetometer data from GOES 8 and 9, and magnetometer data from Poste de la Baleine (PBQ) and Yellowknife (YKC) for the Geotail-CANOPUS conjunction on December 25, 1995 in a format similar to Figure 1.

Figure 10: Geotail and CANOPUS data for the conjunction on December 25, 1995 in the same format as Figure 2.

Figure 11. Measurements from Geotail on December 16, 1996 and December 25, 1995 in the same format as Figure 7 with the addition of line plots of B_{total} (B_t).