

## POLAR OBSERVATIONS OF TWO PSEUDOBREAKUP EVENTS

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### ABSTRACT

The state-of-the-art plasma instruments on the POLAR spacecraft provide high resolution observations of short bursts of transverse plasma motion midway between the auroral acceleration region and the plasma sheet. At this location, short duration (< one minute) intervals of strong transverse ion convection are observed on the nightside during all phases of the substorm process. The most intense events are associated with substorm initiation and the passage of the expanding polar boundary over the POLAR satellite. This paper presents and discusses two intervals when the POLAR satellite was in or near the plasma sheet at the time of substorm onset. In both of these cases bursts of transverse plasma motion were observed approximately 10 minutes before substorm onset. We show that these events are pseudobreakup events. We describe the plasma and fields observed at POLAR during these events and show how these data can be used to distinguish among suggested pseudobreakup trigger mechanisms.

### INTRODUCTION

Pseudobreakups are a well known substorm growth phase phenomena (e.g. Koskinen et al., 1993, Ohtani et al., 1993, Nakamura et al., 1994, Pulkkinen et al., 1998). A typical event includes brightening of an auroral arc, a burst of Pi2 micropulsations, and a weak enhancement of the westward electrojet. Pseudobreakups are distinguished from substorms by their relative localization in both time and space. The global nature and general morphology of the magnetospheric substorm process are fairly well established (e.g. Baker et al., 1998). However, there is no consensus on mechanisms responsible for expansion and onset including pseudobreakups (e.g. McPherron and Fairfield, 1998). Most, if not all, of the confusion surrounding substorms is a natural consequence of the rapid temporal and spatial evolution and global extent of substorms. The ISTP era has brought together the tools and infrastructure that allow more precise characterization of the geospace environment. In particular, the plasma and fields instruments on the POLAR satellite, located midway between the ionosphere and equatorial plasma sheet, provide data that can be used to directly and precisely address ques-

tions about substorm expansion and onset. For example, Toivanen et al. (2000a) have used data from ISTP satellites and ground arrays to determine the onset of a substorm on October 17, 1997 to within seconds. In this paper we present and discuss similar data obtained during pseudobreakups on October 17, and August 29, 1997. In particular we discuss how these data can be used to identify some of the postulated trigger conditions involving plasma waves (e.g. Tsurutani, 1998).

Here we present data from the plasma and field instruments on the POLAR satellite: TIMAS (Shelley et al., 1995), HYDRA (Scudder et al., 1995), CEPPAD (Blake et al., 1995), and MFE (Russell et al., 1995). Not shown are data from the Electric Field Instrument (EFI) and the Charge and Mass Magnetospheric Ion Composition Experiment (CAMMICE) on POLAR or the data from Alaskan, Finnish and Canadian ground stations or from geosynchronous satellites which were used in the analysis.

OCTOBER 17, 1997

On this day the POLAR satellite crossed the near Earth plasma sheet at local midnight at about 25 degrees geomagnetic latitude. Toivanen et al. (2000a) have identified a substorm onset at 20:40:42 UT. In this paper we focus on the significant *in situ* plasma feature at 20:30 shown in Figure 1. The E-W deviation of the magnetic field (panel A) starting at ~20:29 UT suggests a local upward field aligned current. The H<sup>+</sup> perpendicular bulk velocity moments in GSM coordinates (panel B) from the TIMAS instrument show the plasma first moving duskward (positive GSM-Y) at ~20:29 UT. The local downward Poynting flux associated with this event (panel C) is 0.2 ergs/cm<sup>2</sup>. Energetic (i.e. >1keV) up-flowing O<sup>+</sup> ions (panel D) were first detected at 20:30, about one minute before the plasma started moving sunward, downward and duskward (panel B). The ion convection event ended about 20:32. The higher time resolution electric field data for the interval near 20:30 UT are consistent with the TIMAS velocity moment data in panel B. The ion convection data before and after substorm onset at 20:40:42 UT are not as well organized because the 12 s resolution of the TIMAS velocity moment data presented here is inadequate to resolve high frequency response clearly visible in the electric field data.

The signature of the ion convection event at 20:30 UT is less clear in ion and electron spectrograms. The omnidirectional H<sup>+</sup> fluxes (panel E) shows a end of a narrow minimum in the flux energy spectrum at about 10 keV at the beginning of the event. Data from the CEPPAD

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ion detector (panel F) do not show this feature because of the broader energy channels. Electron data in panels G and H show a significant decrease in intensity and energy of electrons at about the same time as upflowing O<sup>+</sup> ions (panel D) were detected.

The event at 20:30 occurred more than 10 minutes before an isolated substorm. The preliminary A<sub>E</sub> index shows a moderate level of activity (<100 nT) until ~20:30 when the level increased up to a maximum ~400 nT at 21:15. Magnetometer stations equatorward and eastward of the POLAR footprint detected a localized, relatively weak region of Pi2 pulsations starting at ~20:30. The sky was cloudy near the POLAR footprint, so there is no record of an associated optical signature. No data are available from the LANL spacecraft in this local time sector for this event. Additionally, there is no clear solar wind driver for the 20:30 event. The IMF measured at WIND turned weakly southward at 18:30 and remained so until ~22:00. The IMF By component decreased from +4 to -4 nT crossing zero at 20:18. The expected arrival of this change at the magnetopause is 20 minutes later or 20:38 UT.

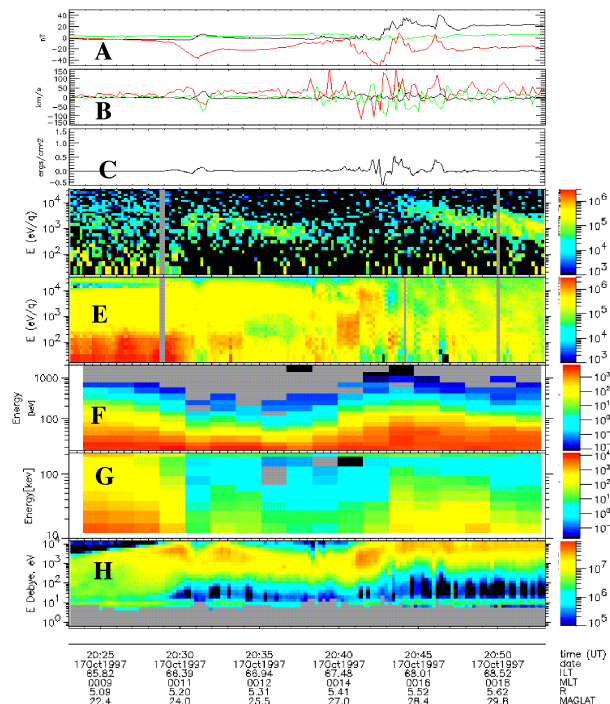


Figure 1: Overview of the plasma environment at POLAR on Oct. 17, 1997. A color version of this figure is available by e-mail from the first author. **A:** Deviation of the observed magnetic field from the TU model field (nT) in field aligned coordinates. (north:black, east:red, field aligned: green). **B:** H<sup>+</sup> ion drifts (km/s) in GSM coordinates. (X: black, Y:red, Z:green). **C:** Downward Poynting flux derived from data in panels A and B. **D:** Upflowing flux of O<sup>+</sup> (cm<sup>2</sup>-s-sr-keV)<sup>-1</sup>. **E:** Omnidirectional H<sup>+</sup> flux (cm<sup>2</sup>-s-sr-keV)<sup>-1</sup>. **F:** Energetic ion count rate (c/s). **G:** Electron flux (cm<sup>2</sup>-s-sr-keV)<sup>-1</sup>. **H:** Electron energy flux (cm<sup>2</sup>-s-sr-keV)<sup>-1</sup>. At 20:30 POLAR was located at 5.2 R<sub>E</sub>, 66° INVL, and 00:11 MLT

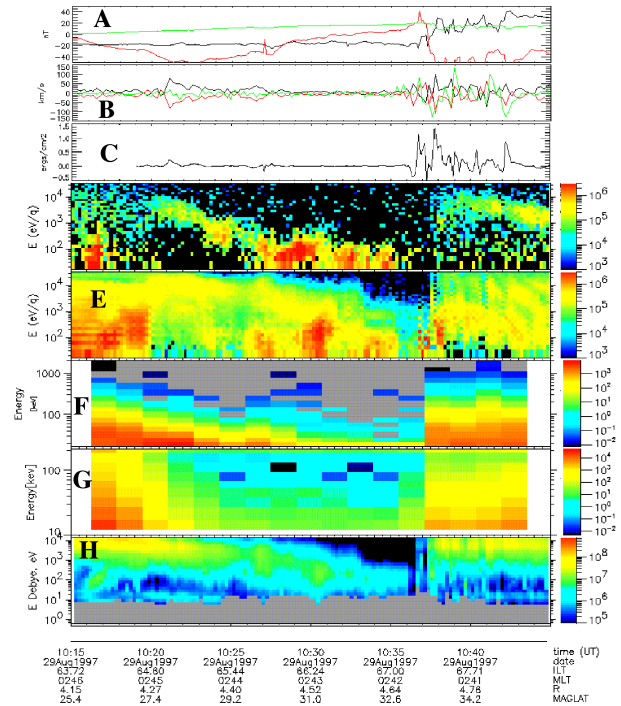


Figure 2: Overview of the plasma environment at POLAR on August 29, 1997 in the same format as Figure 1. At 10:20 POLAR was located at 4.3 R<sub>E</sub>, 65° INVL, and 02:45 MLT. A color version of this figure is available by e-mail from the first author.

AUGUST 29, 1997

The October 17 event is not unique. Figure 2 presents data obtained before and during an isolated substorm on August 29, 1997, in the same format as Figure 1. The substorm onset occurred over the Alaska sector, eastward of the POLAR location at ~10:30 UT (J.V. Olsen, private communication). POLAR was in the plasma sheet at 10:30 but no signatures of the substorm onset is seen until 10:37 when the plasma sheet expanded over the POLAR satellite (Keiling et al., 2000). The pseudobreakup feature of interest here is clearly visible in the H<sup>+</sup> bulk plasma velocity (panel B) near 10:21. The deviation in the Y component of the magnetic field from 10:19:30 to 10:21:30 suggests a local upward FAC. The bulk plasma drift is dawnward and sunward starting at 10:20:40, followed by a slow decay and then an intensification at ~10:27. The local downward Poynting flux (panel C) associated with this fluctuation is 0.2 ergs/cm<sup>2</sup>. The flux of upward flowing O<sup>+</sup> ions (panel D) intensified at ~10:20:30. The low energy H<sup>+</sup> data (panel E) show the end of a narrow minimum in the flux energy spectrum at about 10 keV at 10:20. As in the previous example, the minimum in ion flux does not show up in the higher energy ion data (panel F). The signature in the electron data (panels G and H) at ~10:20 is not as abrupt as that near 20:30 in the October 17 case. Note also that the lower electron energies between ~10:33 and 10:37 (panel H) suggest that POLAR was in or near the plasma sheet lobes before the plasma signature of substorm were seen at POLAR.

The geomagnetic conditions on August 29 were more disturbed ( $K_p=3$ ) than on October 17 ( $K_p=2$ ). Strong pulsations in the Pi2 frequency range were seen at the Canopus magnetometer at Rabbit, near the projection of the magnetic field through the POLAR satellite associated with both the 10:20 event and substorm onset at 10:37 (Eric Donovan, private communication). There are few magnetometer stations south of Rabbit. A station operating at UCLA showed pulsations in the Pi2 frequency range associated with the substorm onset, but not the 10:20 event (Peter Chi, private communication). There was no obvious solar wind driver for the 10:20 event. The IMF turned negative about 08:00. The Z component approached zero briefly at 10:11 and turned positive at 10:22. The expected arrival times of these features at the magnetopause are 08:29, 10:40 and 10:51 respectively. No optical data are available from the Canopus stations near the POLAR footprint. One of the LANL satellites shows a feature associated with the 10:37 substorm, but no intensification in electron intensity 17 minutes before.

## DISCUSSION

Data in Figures 1 and 2 illustrate with unprecedented temporal resolution *in situ* plasma parameters from the near Earth plasmashet at and before substorm onset over an operating ground array of instruments. In particular both of the substorm onsets were preceded by features in the local plasma and ground based arrays by events similar in all respects except their intensity and spatial extent. Field aligned current flow (Panels A in Figures 1 and 2), earthward directed Poynting flux (Panels C), and fluctuations in the Pi2 frequency range in ground magnetometer were observed during both “features” that occurred about 10 to 15 minutes before substorm onset. Neither of these features had an detectable solar wind driver.

Based on their limited spatial extent in the ground data, we identify the features that occurred at  $\sim 20:30$  on 17 October and 10:20 on 29 August, 1997 as pseudobreakup events. The *in situ* plasma sampled by instruments on POLAR and ionospheric conditions monitored by ground arrays were practically indistinguishable at and before the times of substorm onset and pseudobreakup. Global signatures of a substorm were not detected for the pseudobreakup events. In this report we focus on comparisons between the *in situ* plasma measured during the two pseudobreakup events and subsequent substorm onsets.

It is generally believed that one or more plasma instabilities are responsible for the explosive release of energy in magnetospheric substorms (e.g. Baker et al., 1996). There have also been suggestions that plasma instabilities are also responsible for driving pseudobreakup events. The evidence discussed below suggest that this is not the case for the pseudobreakup events presented here.

The net Poynting flux is directed toward the Earth during both pseudobreakup and the October 17 substorm onset times. POLAR was east of the longitude of the substorm onset on August 29 and first detected a burst of tailward directed Poynting flux about 5 minutes after substorm onset. These observations are consistent with the reports of Wygant et al. (2000), and Toivanen et al. (2000a,b) who have investigated the Poynting flux seen at POLAR at substorm onsets in these and similar events. The direction of the Poynting flux at the time of the pseudobreakups and the fact that the differences in the ground ionospheric conditions and *in situ* plasma measurements at POLAR are not measurably different during the pseudobreakup and substorm onset events tell us immediately that, if plasma instabilities are responsible for pseudobreakups or substorm onset, the majority of the free energy driving them is on magnetic field lines tailward of the POLAR location.

Plasma  $\beta$  and velocity moments obtained from TIMAS data can be used to determine if the plasma sampled by POLAR is unstable to ballooning or tearing mode instabilities. Ballooning instabilities generally require a plasma  $\beta > 1$ ; tearing instabilities require ion drifts comparable to the ion thermal speed. The density and temperature of the dominant  $H^+$  ions at the times of pseudobreakup show that the local plasma  $\beta$  values were  $\sim 2 \times 10^{-4}$  for both pseudobreakups and the 10/17/97 substorm onset times. At the time of substorm onset (10:30) on 8/29/97 the local plasma  $\beta$  was  $< 10^{-4}$ , but POLAR was significantly east of the meridian where the substorm began. We can use a magnetic field model to estimate the plasma  $\beta$  at the magnetic equator on the field line passing through POLAR if we assume that the angular distribution of the equatorial ion distribution is such that no significant part of the distribution mirrors above the POLAR location. For the October 17 case the inferred equatorial  $\beta$  on POLAR field lines is  $\sim 0.1$  at the time of pseudobreakup (20:30) and below 1 until about two minutes before substorm onset. For the August 29 case the inferred equatorial  $\beta$  was 0.03 at the time of pseudobreakup (10:20) and remained significantly below 1 until after the plasma sheet expanded over POLAR at  $\sim 10:37$ . These observations directly demonstrate that a region of plasma with  $\beta > 1$  does not exist over an extended region of latitude or local time during pseudobreakup. At substorm onset the data are not as clear. Because of uncertainties associated with both the measurement and magnetic field model the data can not rule out a restricted region of latitude and local time in the near Earth equatorial plasma sheet where the plasma  $\beta$  was on the order of 1 shortly before substorm onset in a limited longitudinal range.

Because of the low plasma  $\beta$  locally and inferred at the equator, we can conclude that ballooning mode instabilities do not play a significant role in processes responsible for pseudobreakups on the magnetic field lines sampled by POLAR. It is not possible from one event

to determine if the relatively large equatorial plasma  $\beta$  inferred just before substorm onset on 10/17/97 is significant or even realistic.

It is generally assumed that the free energy for tearing mode instabilities comes from the current carried by rapid cross tail drifts of energetic ions. The latitudinal extent of this current is presumably small and not expected to be observed at the POLAR location during the intervals shown in Figures 1 and 2 (i.e.  $5 R_E$ ,  $30^\circ$  magnetic latitude). The panels labeled B in these figures do show a small ( $\sim 30$  km/s eastward) drift on October 17 starting at the time of pseudobreakup. Plasma flow was significantly slower and in a different direction (i.e. sunward and westward) between pseudobreakup and substorm onset. The small plasma drift velocities observed during these two events confirm that tearing mode instabilities, if they happen at all, must occur much nearer the equator than the POLAR position as expected (see, for example, Baker et al., 1996).

Finally, we discuss the features in the  $H^+$  energy spectra in the 10-20 keV energy range terminating near the times of the pseudobreakups (panel D in Figures 1 and 2) noted above. We have determined that these features are not directly associated with pseudobreakup or substorm onset based on detailed analysis of data in this region from the POLAR TIMAS region. Li et al. (2000) have shown that such features are commonly seen in the equatorial plasma sampled by the CRRES satellite and by POLAR at relatively low geomagnetic latitudes. The Li et al. simulations show these features are the result of Earthward ion convection from the equatorial plasma sheet population tailward of the POLAR orbit.

### CONCLUSION

We have presented *in situ* plasma and field data from state-of-the-art instruments on the POLAR spacecraft from two substorm events preceded by pseudobreakup events. We determined the Poynting flux was Earthward and there were no solar wind drivers for the two pseudobreakup events presented. We have noted how high resolution plasma data can be used to place limits on the presence of conditions favorable for two of the proposed plasma instability mechanisms believed responsible. Specifically the *in situ* plasma data for both pseudobreakup events appear to be inconsistent with either a ballooning or tearing mode instability on magnetic field lines sampled by POLAR as the driver mechanism. The strength of these conclusions can, and will be, tested by comparing data presented here with predictions made by global and local models of substorm onset such as those developed by Pulkkinen et al (1998) and Li et al. (2000).

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