GEOPHYSICAL RESEARCH LETTERS, VOL. 27, NO. 9, PAGES 1379-1382, MAY 1, 2000

Coincident POLAR/UVI and WIND Observations of Pseudobreakups

M. O. Fillingim,[1] G. K. Parks,[1] L. J. Chen,[1] M. Brittnacher,[1] G. A. Germany,[2] J. F. Spann,[3] D. Larson,[4] and R. P. Lin[4]

Abstract. Using POLAR/UVI global images, we have identified a period of successive minor auroral activations during which WIND was making a perigee pass (X $\sim$ -11 R_E). These auroral brightenings are interpreted to be pseudobreakups due to the lack of global expansion. Large magnetic field fluctuations and high earthward ion velocity moments measured by the WIND spacecraft show a nearly one-to-one correspondence with the auroral intensifications. Analysis of the plasma parameters indicates that there is no difference in the behavior of the plasma during pseudobreakups as compared to substorm expansive phase onset. Inspection of the ion distribution functions during high velocity moment events reveals the presence of a two component plasma. The particles contributing to the large mean velocities are energetic ions with energies from $\sim$ 2 to 27 keV. We conclude that pseudobreakups are the ionospheric signature of high velocity moment events.

Introduction

The concept of the "pseudobreakup" was first introduced to describe the disruption of an auroral arc other than the equatorward most arc [*Elvey*, 1957]. Pseudobreakups are associated with Pi2 magnetic pulsations in the auroral zone, and with short lived dissipative events in the plasma sheet [*Sergeev et al.*, 1986]. These events include increases in the plasma velocity moment, increases in the fluxes of ions (50 to 200 keV) and electrons (30 to 90 keV), and magnetic field variations. Multisatellite studies by *Koskinen et al.* [1993], *Ohtani et al.* [1993], and *Nakamura et al.* [1994] have shown that particle injections and dipolarizations associated with pseudobreakups can be as strong as those observed at substorm expansive phase (EP) onset. However, the disturbance is confined both radially and azimuthally; there is no global expansion. The only difference between pseudobreakups and substrom EP onsets are the global consequences.

Aikio et al. [1999] observed plasmoids at $\sim$ 86 R_E in association with pseudobreakups. This, as well as coincident ground based and inner magnetospheric observations, led them to conclude that pseudobreakups and substorm EP onsets are associated with the same magnetospheric processes and that there is a continuum of states from the smallest pseudobreakup to the largest EP onset.

[1]Geophysics Program, University of Washington, Seattle.
[2]CSPAR, University of Alabama in Huntsville.
[3]NASA Marshall Space Flight Center Huntsville, AL.
[4]SSL, University of California, Berkeley.

Paper number 1999GL010773.
0094-8276/00/1999GL010773$05.00

Often pseudobreakups are discussed in terms of substorm growth phase phenomona [*McPherron*, 1991]. However, pseudobreakups are not uncommon during magnetically quiet periods [*Berkey and Kamide*, 1976].

We present a series of quiet time pseudobreakups observed by the Ultraviolet Imager (UVI) onboard the POLAR spacecraft when WIND was making a perigee pass through the magnetotail. The observations suggest that pseudobreakups are related to short-lived, earthward, high velocity ion moments, high frequency magnetic field fluctuations, and increased fluxes of energetic particles. The behavior of the plasma does not appear to be different from that seen at substorm EP onset, in agreement with previous work. To better understand the origin of the large mean velocities, we investigate the kinetic properties of the plasma during pseudobreakups. Examination of the ion distribution functions indicates that the plasma is very dynamic and may not act as a single component convecting fluid; instead distinct plasma populations can have different velocities.

Observations

On July 26, 1997, between 03:30 and 07:30 UT, WIND moved from a local time of 21 to midnight at a radial distance of about 11 R_E close to the magnetic equator ($|Z_{GSM}|$ $< \sim 1$ R_E). During this time, POLAR was passing through apogee at 9 R_E above the northern polar region monitoring the global auroral activity.

The top panel of Figure 1 shows a "keogram" constructed from UVI images. It shows the latitudinal profile of the aurora at a fixed local time position as a function of UT. All of the images were taken with a Lyman-Birge-Hopfield Band filter in the wavelength range from 160 to 180 nm. The auroral luminosity measured by this filter is proportional to the energy flux of precipitating electrons [*Lummerzheim and Lilensten*, 1994; *Germany et al.*, 1997]. Each image was integrated over 37 seconds, and the time between successive images was 3 minutes. The energy deposition rate in each one-half degree latitude bin was summed over local times from 21 to 03 MLT. The black line shows the footprint of WIND obtained using the model of *Tsyganenko* [1989] for a quiet magnetosphere (Kp = 1). Due to the POLAR spacecraft "wobble," the keogram latitudes are uncertain to $\pm$ 1.5°.

The second panel is a plot of the energy deposition rate (power) in gigawatts. The energy flux from each pixel was multiplied by the area covered by that pixel to get the energy deposition rate. This was then summed over magnetic latitudes greater than 60° and over magnetic local times from 21 to 03 MLT.

The third panel contains three-second resolution magnetic field data from WIND [*Lepping et al.*, 1995] in GSM coordinates. Rapid, large amplitude fluctuations occur the

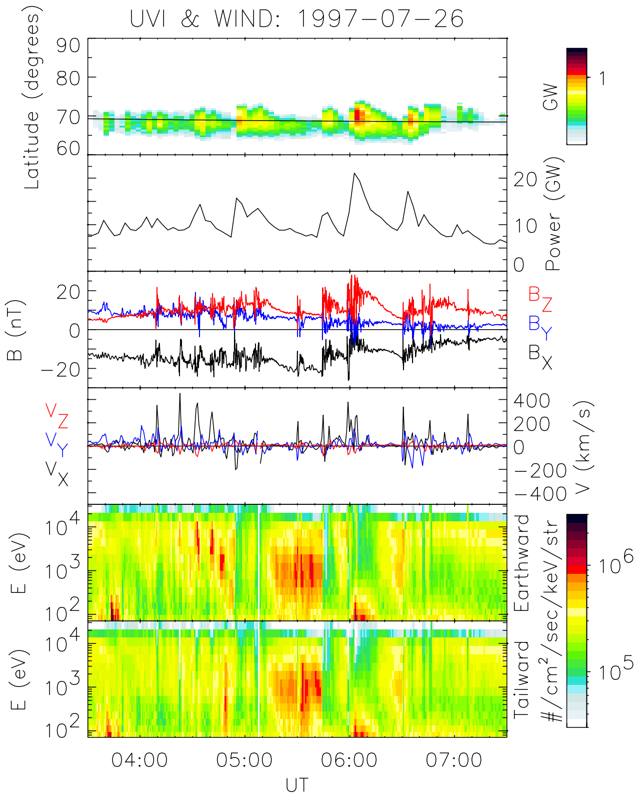

Figure 1. From top to bottom: "keogram;" energy deposition rate (power) from precipitating electrons (both determined from UVI images); GSM components of the magnetic field; GSM components of the ion velocity moments; energy spectrogram for ions traveling earthward; same for ions traveling tailward (last four panels measured by WIND). During this interval WIND moved from a local time of 21 to 00 with a nearly constant radius of 11 R_E within 1 R_E of the GSM equatorial plane.

same time as the auroral brightenings, particularly the most intense brightenings. These magnetic field signatures are not simple dipolarizations, but high frequency waves seemingly superposed on dipolarization trends.

The next panel displays the X, Y, and Z GSM components of the ion velocity moment (<**v**>) observed by WIND. Throughout the period from 03:30 to 07:30 UT, WIND measured the full 3-D ion distribution function from 70 eV to 27 keV every 50 seconds. Large <**v**>, typically in the earthward direction, coincide with magnetic field fluctuations, which in turn coincide with increases in the energy deposition rate into the auroral ionosphere.

The bottom two panels show ion energy spectrograms in the earthward and tailward directions. Close inspection of the energy spectrograms reveals that the high earthward <**v**> are due to increased earthward fluxes up to the highest energy channels and decreased fluxes in the tailward direction. This is most dramatic and most easily seen for example near 04:22 UT and just before 06:00 UT. This is generally the case for all high <**v**> events in Figure 1. The lack of particle fluxes at 05:08 UT is due to missing data.

To better understand how the observed high <**v**> are produced, we examined the ion distribution functions. Figure 2 shows isocontour plots of phase space densities and cuts of the isocontour plots for some representative ion distribution functions. These are 2-D slices of the full 3-D distribution functions in the $\mathbf{B}-\mathbf{V}_\perp$ plane in the spacecraft frame of reference. The horizontal and vertical axes are velocities in km/s parallel and perpendicular to the magnetic field, respectively. The numbers in the upper left, upper right, and lower right are the magnetic field elevation, azimuth (both in GSM), and magnitude. The boxes below show cuts of the contour plots along the parallel (orange stars) and perpendicular (blue diamonds) directions. The horizontal axis is velocity in km/s; the vertical axis is phase

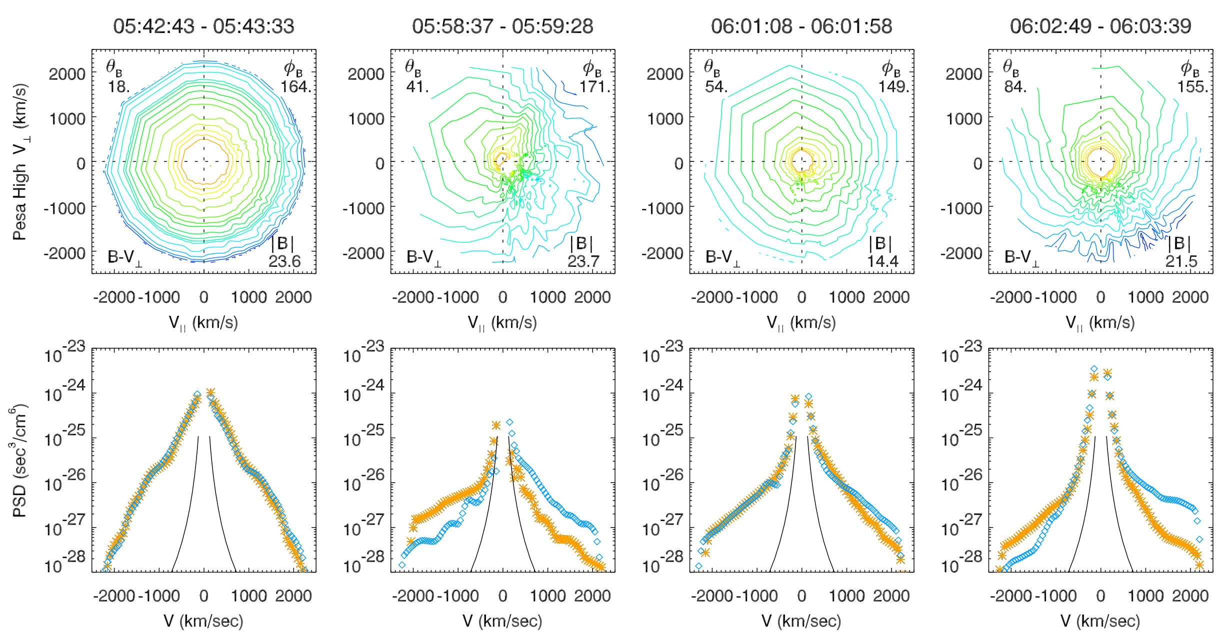

Figure 2. First row: isocontours of ion velocity distribution functions in the $\mathbf{B}-\mathbf{V}_\perp$ plane in the spacecraft frame. Second row: cuts of the distribution functions in the direction parallel (orange stars) and perpendicular (blue diamonds) to the magnetic field. The smooth solid line represents the "confidence level" of the data.

space density in $s^3 cm^{-6}$. The smooth solid lines are the instrument noise level.

The first column shows the ion distribution function at 05:42:43, after the magnetic field direction and magnitude and ion <**v**> at WIND had been relatively stable for ∼ 15 minutes. The contour plot indicates a nearly isotropic distribution.

The next column shows the distribution at 05:58:37, the beginning of a high <**v**> event. There is a very broad "tongue-like" feature in the ion distribution centered approximately 30 degrees from the magnetic field. Due to the moderate elevation angle of the magnetic field (about 40 degrees), the center of this feature is directed approximately earthward. The distribution is depleted in the tailward direction, and there are very few lower energy particles present.

As can be seen in Figure 1, the direction and magnitude of **B** are rapidly fluctuating during the 50 second integration period. For an average magnetic field magnitude of 20 to 25 nT, the local proton gyro-period is ∼ 3 seconds. A proton would complete 17 gyrations during the integration period. The high degree of asymmetry in this distribution indicates that a very dynamical process is taking place.

The next distribution function was taken 100 seconds later, near the end of a high <**v**> event. The phase space distribution is more isotropic than the previous one; however, the <**v**> is over 100 km/s in the + X-direction. This can be seen as the enhancement in the phase space density in the upper left-hand quadrant of the contour plot. Also, cuts through the distribution show that there is an enhancement in the phase space density in the positive perpendicular direction over the parallel direction at energies > 5 keV (∼ 1000 km/s). The contour plot and the cuts through the plot show that the density of lower energy (few hundred eV) ions increased. The magnetic field was still fluctuating rapidly as WIND approached the current sheet. During the integration period, the magnitude of B_X approached 1 nT.

At 06:02:48, there is another high <**v**> event with a maximum velocity near 300 km/s in the X-direction (fourth column). Again there is a broad "tongue-like" feature present, except now the center of the feature is directed in the positive perpendicular direction, about 5 degrees from the + X-direction. Two populations of particles are evident from the cuts through the distribution plot: a lower energy (up to ∼ 2 keV) isotropic component and a higher energy (up to > 30 keV) asymmetric component. The lower energy component is not moving with respect to the spacecraft; the center of the higher energy distribution, in contrast, has a large earthward velocity. During the integration period the sign of B_X changed four times, indicating multiple crossings of the current sheet.

Discussion

None of the auroral brightenings result in "signficant" poleward expansion; hence, these are interpreted as pseudobreakups. Since this is a subjective criterion, some may argue that these activations are small substorms. However, there is a lack of an accepted, quantitative criteria to distinguish between pseudobreakups and small substorms [*Rostoker*, 1998; *Aikio et al.*, 1999].

Angelopoulos et al. [1997] and *Fairfield et al.* [1999] suggest that high <**v**> are associated with high frequency magnetic fluctuations and auroral substorms. We have shown with this example from July 26, 1997, that this association exists not only for substorms, but also for the smallest of auroral activations.

There is a nearly one-to-one correspondence between the auroral activations and high <**v**> in the magnetotail. This suggests a causal relationship between them. However, not every auroral brightening is accompanied by a large increase in ion velocity, and not every large velocity event has an associated auroral brightening. It is easy to explain the former as a matter of spacecraft location; the flux tube of spacecraft may not be connected to the region of the ionosphere where the brightening is occurring. However, a large increase in the ion <**v**> that is not accompanied by an auroral brightening implies that the supposed relationship between auroral brightenings and large velocity moments can be disrupted.

Ion distribution functions and directional energy spectrograms show that large earthward <**v**> are a result of a very dynamic process in which ion fluxes at higher energies (> ∼ few keV) increase in the earthward direction while fluxes at all but the lowest energies in the tailward direction decrease. Data from the solid-state telescope (SST) on WIND (not shown) indicate that increased fluxes of ions up to 1 MeV were observed during these events [*Chen et al.*, 2000].

The distribution function of a simple single component convecting plasma will appear isotropic in the plasma frame of reference. For the contour plots in columns 2 and 4 of Figure 2, there is no frame in which the distributions are symmetric. Particularly in column 4, the center of the high energy distribution is not collocated with the center of the lower energy distribution. This fact argues against the distribution being formed by a single component convecting plasma.

An important caveat is time aliasing due to the relatively long integration time of the instrument. During the integration of the distribution functions, the magnetic field is rapidly fluctuating. The average direction of **B** is used to plot the distribution function. During these fluctuations, the spacecraft may be moving into different regions of the magnetotail. Another possible explanation for the asymmetric distributions is strong particle gradients. Strong particle gradients in the **V** × **B** direction, i.e., -Y-direction, can result in a mean velocity in the earthward direction. Finally, inductive electric fields due to the fluctuating magnetic field could affect the plasma distribution.

We have shown that there is a correlation between high <**v**> and magnetic field fluctuations in the near-Earth tail and pseudobreakups. We conclude that (i) minor auroral activations are the ionospheric manifestation of high <**v**> in the tail, (ii) the high velocity moments observed during pseudobreakups are not due to a single component convecting plasma but rather appear to be caused by highly dynamic processes, and (iii) plasma and magnetic field data from the tail do not show an obvious difference between these events individually and between this group of pseudobreakups and previously analyzed substorms. If pseudobreakups and substorm EP onset are simply the same physical phenomena on different scales, the physical mechanism that controls the size of auroral brightenings remains an open question.

We don't understand what mechanism is responsible for the dynamic processes leading to the large <**v**>. Distribution functions show that large <**v**> are due mainly to the energetic particles with energies from a few keV to 27 keV or greater and that there may be a stagnant lower energy component present at the same time. The presence of a two component plasma distribution calls into question the validity of using moments of the distribution function to describe the dynamics of the plasma sheet. To better understand the plasma sheet dynamics during this interval, we plan to examine the electron behavior and investigate the sources of the observed distributions by calculating the trajectories of the particles back in time using test particle tracking.

Acknowledgments. The WIND magnetometer data is courtesy of Ronald P. Lepping. This work was supported in part by NASA grants NAG5-3170 and NAG5-26580.

References

Aikio, A. T., et al., Characteristics of pseudobreakups and substorms observed in the ionosphere, at geosynchronous orbit, and in the midtail, *J. Geophys. Res., 104,* 12,263, 1999.

Angelopoulos, V., et al., Magnetotail flow bursts: association to global magnetospheric circulation, relationship to ionospheric activity and direct evidence for localization, *Geophys. Res. Lett., 24,* 2271, 1997.

Berkey, F. T., and Y. Kamide, On the distribution of global auroras during intervals of magnetospheric quiet, *J. Geophys. Res., 81,* 4701, 1976.

Chen, L. J., et al., Kinetic properties of bursty bulk flow events, accepted, *Geophys. Res. Lett.,* 2000.

Elvey, C. T., Problems of auroral morphology, *Proc. Nat. Acad. Sci., Wash., 43* , 63, 1957.

Fairfield, D. H., et al., Earthward flow bursts in the inner magnetotail and their relation to auroral brightenings, AKR intensifications, geosynchronous particle injections and magnetic activity, *J. Geophys. Res., 104,* 355, 1999.

Germany, G. A., et al., Remote determination of auroral energy characteristics during substorm activity, *Geophys. Res. Lett., 24,* 995, 1997.

Koskinen, H. E. J., et al., Pseudobreakup and substorm growth phase in the ionosphere and magnetosphere, *J. Geophys. Res., 98,* 5801, 1993.

Lepping, R. P., et al., The WIND magnetic field field investigation, *Space Sci. Rev., 71,* 207, 1995.

Lummerzheim, D. and J. Lilensten, Electron transport and energy degradation in the ionosphere: Evaluation of the numerical solution, comparison with laboratory experiments and auroral observations, *Ann. Geophys., 12,* 1039, 1994.

McPherron, R. L., Physical processes producing magnetospheric substorms and magnetic storms, in *Geomagnetism,* vol. 4, J. A. Jacobs, ed., Academic Press, San Diego, CA, 1991.

Nakamura, R., et al., Particle and field signatures during pseudobreakup and major expansion onset, *J. Geophys. Res., 99,* 207, 1994.

Ohtani, S., et al., A multisatellite study of a pseudo-substorm onset in the near-Earth magnetotail, *J. Geophys. Res., 98,* 19,355, 1993.

Rostoker, G., On the place of the pseudo-breakup in a magnetospheric substorm, *Geophys. Res. Lett., 25,* 217, 1998.

Sergeev, V. A., et al., Permanent flare activity in the magnetosphere during periods of low magnetic activity in the auroral zone, *Planet. Space Sci., 34,* 1169, 1986.

Tsyganenko, N. A., A magnetospheric magnetic field model with a warped tail current sheet, *Plate. Space Sci., 37,* 5, 1989.

M. Brittnacher, L. J. Chen, M. O. Fillingim, and G. K. Parks, Geophysics Program, University of Washington, Seattle, WA 98195. (e-mail: matt@geophys.washington.edu)

G. A. Germany, CSPAR, University of Alabama in Huntsville, Huntsville, AL 35899.

D. Larson and R. P. Lin, Space Sciences Laboratory, University of California, Berkeley, CA 94720.

J. F. Spann, NASA Marshall Space Flight Center, Huntsville, AL 35812.

(Received November 30, 1999; accepted February 1, 2000.)