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The solar wind depletion (SWD) event of 26 April 1999: Triggering of an auroral "pseudobreakup" event

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Abstract. The interplanetary solar wind depletion (SWD) event of 26 April 1999 and its magnetospheric consequences are examined. The SWD event is characterized by a solar wind density decrease from ~3.0 to 0.7 cm^{-3} leading to a solar wind ram pressure decrease from ~2.0 to 0.2 nPa. This SWD onset is followed by a dipolarization of nightside magnetospheric fields. At approximately the same time, an auroral pseudobreakup occurred in the near-midnight auroral zone. A model is presented to explain the pseudobreakup as energy release by the tail magnetic field reconfiguration. The release of magnetic tension energy is estimated to have been $\sim 3.3 \times 10^{19}$ ergs, while the auroral energy was approximately 30 % of this value, $\sim 1.0 \times 10^{19}$ ergs. This result may imply that the magnetic field collapse led to direct particle acceleration through parallel electric fields.

Introduction

The Earth's magnetosphere and magnetotail are controlled by the solar wind ram pressure and embedded interplanetary magnetic fields. A decrease in the solar wind plasma density leads to a decrease in the solar wind ram pressure, with a subsequent expansion of the dayside magnetosphere [*Lazarus*, 2000]. This paper focuses on the solar wind plasma depletion event of April 26, 1999. We discuss the solar wind depletion properties, and the magnetosphere/magnetotail/ ionosphere responses. In particular, we develop a simple model that explains the magnetospheric/ionospheric observations.

Observations

Figure 1 illustrates the interplanetary features for the 26 April 1999 SWD event. The WIND spacecraft was $\sim 38R_E$ upstream of Earth (see Table 1). From top to bottom, the panels are: the interplanetary magnetic field (IMF) magnitude and 3 components and the solar wind plasma parameters. The WIND field and plasma instrument descriptions can be found in *Lepping et al.* [1995] and *Ogilvie et al.* [1995], respectively.

The solar wind ion density decreased from ~4.0 to 0.7 cm^{-3} at ~ 1120 UT, and remained at unusually low values until ~1212 UT. This SWD region is shaded in gray in Figure 1. The onset of the event was characterized by a sharp decrease in solar wind velocity (V_x) from ~440 to 360 km/s, and an abrupt change in the tangential velocity component V_y (from ~+70 to -60 km/s). The magnetic field magnitude increased from ~7 to 9 nT at the event onset (and was roughly constant through the event). B_z changed from ~+2 nT to zero and B_y from ~ -6 to -7 nT as the event evolved.

The ram pressure ($P_{\rm ram} = 1.16\rho_{\rm p}V_{\rm SW}^2$, assuming the helium fraction to be ~4 %) decreased dramatically at the start of the SWD event. Prior to the event onset, $P_{\rm ram} \approx 2.0$ nPa, and at ~1120 UT it decreased by an

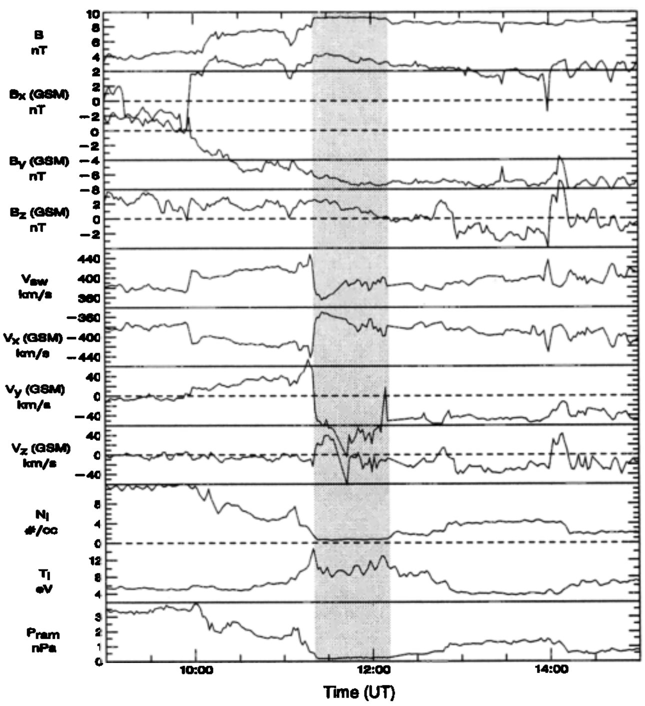

Figure 1. The solar wind parameters recorded by WIND on April 26, 1999. The shaded area, from ~ 1120 to 1212 UT, is the region of low ion densities.

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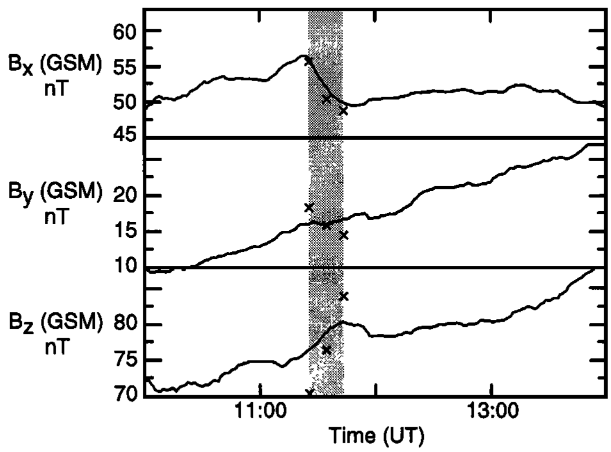

Figure 2. Geomagnetic field dipolarization on April 26, 1999 detected by the geosynchronous satellite GOES-10.

order of magnitude to ~0.2 nPa. Geomagnetic activity was low (AE < 80 nT) throughout the SWD event (not shown).

Instruments onboard the interplanetary ACE spacecraft [*Chiu et al.*, 1998] and GEOTAIL [*Nishida*, 1994] also detected this SWD event (not shown). At ~1015 UT at ACE, the solar wind ion density decreased from ~5 to less than 1 cm^{-3} and the solar wind velocity decreased from ~430 to 390 km/s. The IMF magnitude correspondingly increased from ~6 to 8 nT. This solar wind depletion at ACE lasted until ~1102 UT. At ~1130 UT, GEOTAIL determined that the plasma density decreased from ~2.5 to 0.2 cm^{-3} and this low density lasted until ~1211 UT. The GEOTAIL magnetic field varied between ~8 and 12 nT during this period. The important point is that the SWD was detected by ACE, WIND and GEOTAIL, confirming that the SWD was large in spatial scale compared to the size of the Earth's magnetosphere/magnetotail. A summary of spacecraft locations and SWD onset times at each spacecraft is given in Table 1.

As previously mentioned, the interplanetary event at WIND occurred at ~1120 UT. Using the measured WIND solar wind velocity, the anti-solar edge of the SWD event took ~7 min to reach the nose of the magnetopause (X = 10 R_E). A geomagnetic field "dipolarization" was detected from ~1127 to 1145 UT by the geosynchronous satellite GOES-10 [*Singer et al.*, 1996] located at ~2 MLT (magnetic local time)(Table 1), indicated by the shaded region in Figure 2. The B_x component decreased from ~56 to 50 nT and the B_z increased from ~76 to 80 nT, while the B_y remained unchanged. Three crosses in each panel at 1127 UT, 1136 UT and 1145 UT are the calculated geomagnetic fields using the *Tsyganenko* model (T96) [*Tsyganenko*, 1996]. The results of T96 show stronger dipolarization than the GOES-10's observations.

Table 1. Spacecraft and their locations at SWD onsets.

Spacecraft	Location (R_E,GSM)	Observed onset of the SWD
ACE	(225.1, -23.5, -18.2)	1015 UT
WIND	(37.8, -23.8, 16.4)	1120 UT
GEOTAIL	(-14.0, 26.4, 3.5)	1130 UT
GOES-10	(-5.1, -3.7, 2.0)	1127 UT

A near-midnight ultraviolet auroral spot occurred at ~1135 UT. It was detected by POLAR UVI [*Torr et al.*, 1995] and shown in Figure 3. In this figure, the magnetic south pole (close to the geographic north pole) is at the center, 60° magnetic latitude noon is at the top, and midnight is at the bottom. Time increases from panels (a) to (l) (top left to right and then down). The interval between images is ~1 min 50 sec. The first sign of a significant auroral feature was found at 1135:08 UT. This was ~8 min after the SWD first reached the nose of the magnetopause. This brightening was centered at ~ 72° magnetic latitude, and was elongated in longitude from ~22 to 24 MLT (the POLAR "wobble" is mainly in the east-west direction during this event, which may contribute partially to this longitudinal extent. This will be discussed later in more detail). At 1149:51 UT, the spot had spread to cover a longitude elongation from ~19 to 23 MLT. By this time, the spot had faded considerably. The total duration of the spot was ~15 min.

At ~1137 UT, the center of the auroral spot was located at ~ 72° latitude and ~ 190° longitude (in geographic coordinates). The spot was located just above the Chukchi Sea between Russia and Alaska, so unfortunately there was poor ground station coverage. The ground-based magnetometer at Kaktovik (70°, 216°) detected a H component decrease of ~50 nT from ~1133 to ~1142 UT. No geomagnetic disturbances were detected at Contwoyto Lake (66°, 249°) or at a lower latitude station Gakona (62°, 215°). Thus, the geomagnetic disturbances associated with the auroral spot were weak and localized.

Near-midnight auroral spots with a lifetime of ~10 min have been speculated to be pseudobreakups by *Arballo et al.*, [1998], *Spann et al.*, [1998] and *Tsurutani et al.*, [1998]. Recently, *Zhou and Tsurutani* [2000] have shown there is an excellent agreement between near-midnight auroral spots and small negative bays (ΔH < 150 nT) (for two events). The agreement is excellent for both the onset and decay of the spot (temporal agreement) and also the location of the aurora compared with the ground stations where ionospheric currents are detected (general spatial agreement). The characteristics of the auroral spot for the event presented here (short time duration and small area) and the agreement between the temporal and spatial scales of the aurora and the concurrent ground observations, both indicate that this auroral spot was most likely a pseudobreakup.

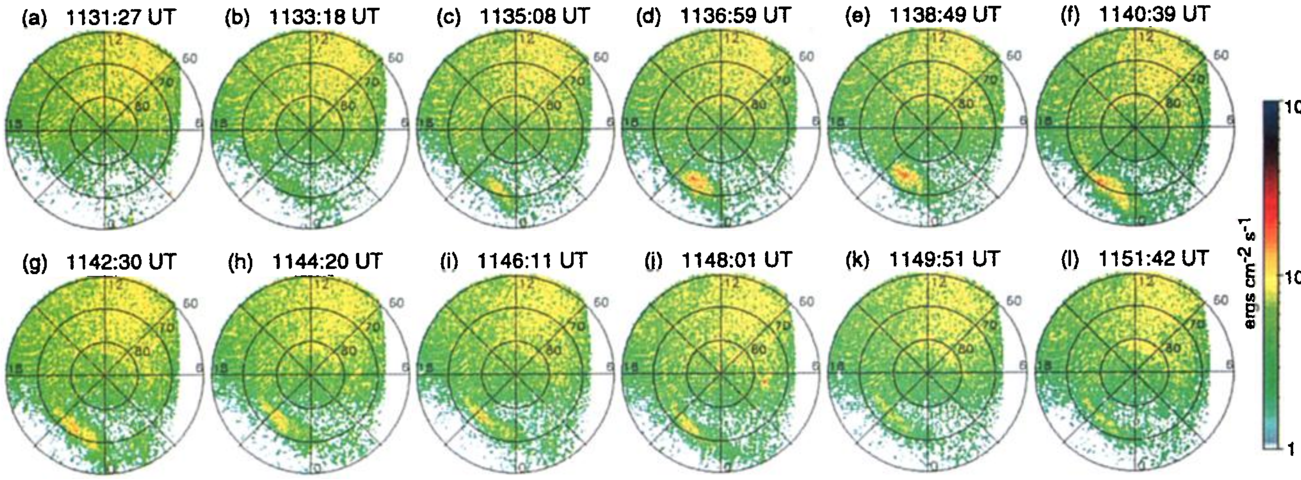

Figure 3. A near-midnight auroral spot event on April 26, 1999. The images come from the POLAR LBHL filter.

Calculations and model

In order to understand how this solar wind depletion event triggered nightside auroral energy deposition, the tail magnetic field reconfiguration and release of magnetic tension are calculated. As shown by Figure 1, before the SWD onset from ~1015 to 1100 UT, the solar wind was relatively steady with the IMF magnitude at ~7.0 nT, IMF $B_z > 0$, and $P_{\text{ram}} \sim 2.0$ nPa. After the SWD onset from ~1120 to 1210 UT, the solar wind magnetic field was a constant ~9.0 nT, IMF B_z was still northward, and P_{ram} was ~ 0.2 nPa. For purposes of calculation, we assume that the magnetosphere was in pressure equilibrium before the SWD and also after the SWD caused the magnetosphere to expand. We will use the T96 model to calculate the tail field configurations in these two "steady states".

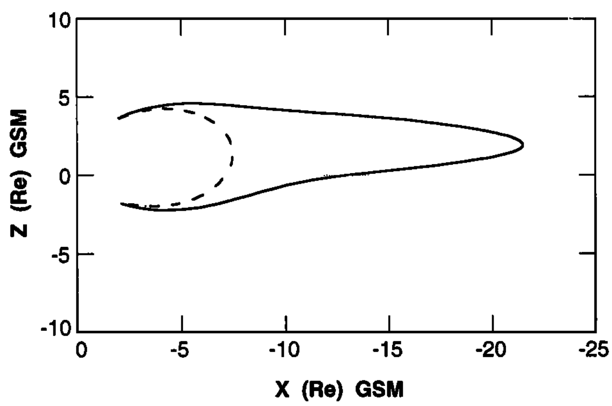

Figure 4. The tail magnetic field (from the T96 model) in the X-Z GSM plane. The "before" (solid line) and "after" (dashed line) steady state configurations are shown.

Using the measured solar wind ram pressure, IMF B_y, B_z, and the D_{ST} indices as the input into the T96 model, the two steady state configurations are obtained and are shown in Figure 4. In this Figure, the magnetic field lines are projected into the GSM X-Z plane. The magnetic field footpoints in the ionosphere are at the center of the auroral spot shown in Figure 3, panel (e). Prior to the SWD event, the tail fields were elongated (solid line). According to the T96 model just after the SWD event, the field became more dipolar, decreasing from $\sim 21.5R_E$ to $\sim 7.5R_E$. The magnetic field dipolarization detected by GOES-10 (Figure 2) is consistent with this calculated/modeled result.

Such "dipolarization" of the tail magnetic fields can lead to energy conversion from magnetic tension energy

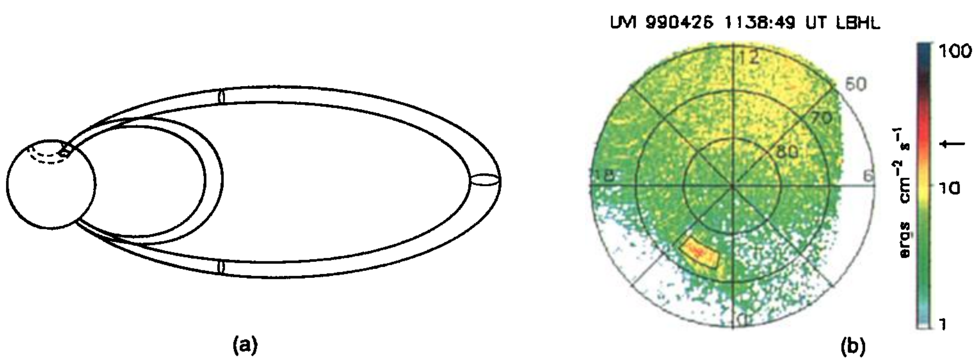

Figure 5. A flux tube prior to and after impingement of the SWD event (left hand panel (a)). The small auroral pseudobreakup region used for energy calculation is shown in the box area in panel (b).

to other forms of energy (eventually auroral energy). Figure 5a shows a schematic of the flux tube "before" and "after" configurations. The magnetic tension is given by:

$$T_B = B^2/8\pi \quad (1)$$

The magnetic energy within a flux tube (and associated with the auroral spot at the northern auroral zone) is

$$\varepsilon = T_B \Delta V/2 \quad (2)$$

where ΔV is the volume change of the magnetic flux tube as it moves from X $\approx$ -21.5 to -7.5 R_E (Figure 5a). The footpoint of this tube is the auroral spot (the boxed area in Figure 5b). The maximum error in the spot area due to the spacecraft wobbling is ~50%. Therefore, the minimum ΔV is $\sim 2.0 \times 10^{28}$ cm^3. For a first order approximation, we assume an average lobe magnetic field strength B of ~20 nT. Thus ε is $\sim 3.3 \times 10^{19}$ ergs.

In comparison, we examine the amount of energy associated with the pseudobreakup aurora. In Figure 5b, we show the auroral imaging at 1138:49 UT (when the auroral brightening was most intense). The average intensity of precipitating auroral electrons over the spot is ~20 ergs cm$^{-2}s^{-1}$. The aurora remained at a maximum intensity for ~10 min. The "measured" area (the boxed area in Figure 5b) is $\sim 1.7 \times 10^{15}$ cm^2. Thus the minimum spot size is $\sim 8.5 \times 10^{14}$ cm^2 due to possible wobbling effects. Thus, the total energy released into the ionosphere by precipitating electrons in the pseudobreakup auroral area is $\sim 1.0 \times 10^{19}$ ergs.

Conclusions and speculations

In this paper we have shown that on 26 April 1999 a SWD event arrived at the dayside magnetopause at approximately 1127 UT. Subsequently, a nightside magnetic field dipolarization occurred from approximately 1127 to 1145 UT. A small magnetic negative bay appeared near local midnight from ~1133 to 1150 UT, simultaneously with a small auroral brightening (pseudobreakup) at 21-24 MLT from ~1135 to 1150 UT.

The solar wind depletion event clearly leads to magnetotail dipolarization/collapse. This is borne out by both observations and modeling. We have interpreted the pseudobreakup event as being caused by this tail collapse. If this scenario is correct, the tail magnetic tension energy was converted to plasma energy with a ~30% efficiency. The physical process for this mechanism is not well understood. Assuming that the trapped plasma is betatron and Fermi accelerated by the collapsing tail fields (which certainly must have occurred), perpendicular plasma heating would result. However, the size of the loss cone at 72° latitude is only ~ 1°, indicating a ~1% efficiency in energy deposition to the ionosphere, much lower than what has been noted above. Another possibility is that the tail collapse generated field-aligned currents with concomitant parallel electric fields. Assuming this scenario, the energy conversion for this process must be extremely efficient.

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