Submitted to the ICS-6 proceedings 2002-06-14.

Plasma sheet dynamics during substorm from global ENA measurements onboard IMAGE

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Abstract. We investigate the dynamics of the plasma sheet out to about 15 R_E during a substorm with auroral onset at around 09:19 UT in the main phase of the 4 October 2000 geomagnetic storm. We use hydrogen energetic neutral atom (ENA) images obtained by the high energy neutral atom (HENA) imager onboard the IMAGE spacecraft. The images were obtained in the 27-60 keV range and integrated for 6 min. We use a constrained linear inversion technique to retrieve the corresponding equatorial proton distributions. The results show that the ENA ¤ux coming from beyond 8.5 R_E decreases sharply about 8 min before dipolarization and 10 min before proton injection was observed at geosynchronous midnight. The sharp decrease appears to spread tailward from about 10.7 R_E with a speed of roughly 175 km/s. A possible cause for the decrease of plasma sheet ¤ux is the dipolarization induced electric that locally transports the plasma earthward faster than it can be replenished by the $\mathbf{E} \times \mathbf{B}$ drift from furhter down the tail. It is also possible that the decrease can be partly attributed to the sudden thinning observed a minute before dipolarization as reported by *Ohtani et al.* [1992].

1. Introduction

Since its launch the high energy neutral atom (HENA) imager [*Mitchell et al.*, 2000] onboard the IMAGE spacecraft [*Burch*, 2000] has capture about a two dozen of storms. During a couple of these storms the vantage point and orbital con£guration has allowed HENA to image not only the ring current ring region, but also the near-earth plasma sheet. During these periods HENA has revealed enhanced ENA ¤uxes coming from equatorial distances as far down as 18 R_E. At substorm dipolarizations these enhancements these enhancements have decreased rapidly over 20 min.

Here we present the latest analysis results from one substorm during the 4 October 2000 geomagnetic storm. We investigate the timing of the observed decrease in relation to geosynchronous observations of dipolarization and energetic proton injection.

2. Observations

The 4 October 2000 storm displayed frequent substorms during the main phase [*C:son Brandt et al.*, 2002b, a; *Reeves et al.*, 2002]. At around 09:30 UT IMAGE, GOES-8 and one of the Los Alamos National Laboratory (LANL) satellites were suitably located during a substorm onset. GOES-8 observed a sharp rise in B_z and a sharp decrease in B_x as can be seen in Figure 1, which is consistent with a sudden dipolarization of the magnetic £eld. GOES-8 was located around 00:47 MLT at the time of dipolarization. Figure 2 shows the 75-113 keV proton ¤ux. The injection occurred at 09:38 UT at around 22:38 MLT and was dispersionless.

Figure 3 shows three snapshots of the substorm that had its auroral onset at around 09:21 UT. The £rst row (a-c) shows the hydrogen ENA images in the 27-60 keV range. The images were integrated over 6 min. The £eld lines of L= 4, 8 and 12 are drawn at noon, dusk, midnight and dawn and

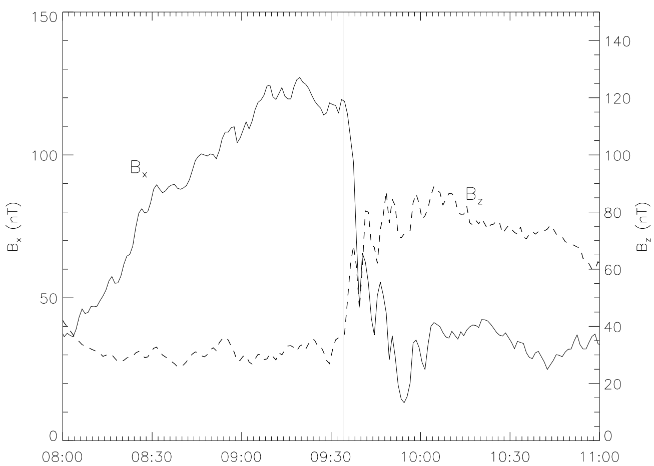

Figure 1. The x and z component of the geomagnetic £eld observed at geosynchronous. The dipolarization takes place at 09:34 UT at 00:47 MLT.

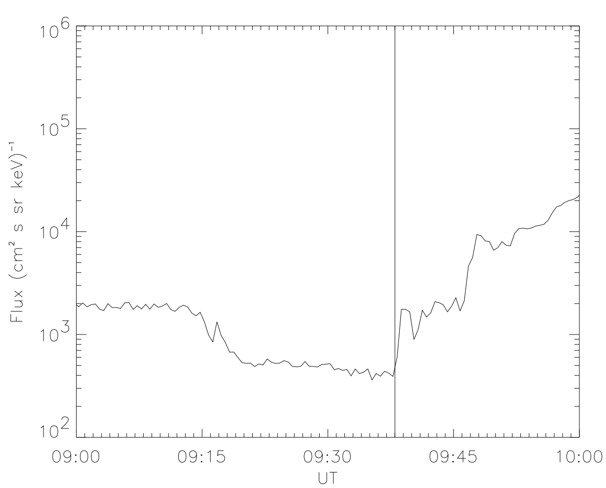

Figure 2. The proton injection in the 75-113 keV channel observed by the 1989-046 satellite. The satellite was at 22:38 MLT during the time of injection. The solid vertical line indicates the injection.

the MLTs are indicated by red number at the end of the £eld lines. The £eld of view (FOV) of the instrument is 360°in the vertical direction (noon to midnight) but only 120°in the horizontal direction (dusk to dawn). Before the substorm onset we see that the ENA ¤ux from the nightside appers to be extended well outside the L=8 £eld line. Around onset (Figure 3b) the ENA ¤ux from the plasma sheet region decreases. About 20 min after dipolarization it has all dissappeared and a clear enhancement can be seen inside the L=4 £eld line as can be seen in Figure 3c.

The bottom row (d-f) shows the corresponding equatorial proton distribution obtained from a linear inversion technique as described by *C:son Brandt et al.* [2002a]. In this inversion we only display the isotropic pitch angle component and the technique utilizes a £xed dipole £eld. During a substorm dipolarization the magnetic £eld is by de£nition far from £xed and probably signi£cantly non-dipolar already at geosynchronous orbit. However, *C:son Brandt et al.* [2002a] showed that this leads to an underestimation of the radial location of the proton distributions and perhaps a slight smearing. Even so we have chosen to show the proton distributions to attempt to study the timing and radial evolution of the plasma sheet proton distributions. As can be seen in the ENA images in the upper row, the equatorial proton distributions in the post-midnight sector are enhanced out to 14 R_E (and probably more since the use of the dipolar £eld underestimates the radial distance). In Figure 3e the plasma sheet ¤ux decreases and in Figure 3f it is down to background levels.

3. Investigating the dynamics

There are two important questions we are investigating: (1) What causes the decrease in plasma sheet ¤ux? (2) Can we see any signatures of an onset region and propagation of this decrease? In order to investigate this we summed the local time wedge between 23:20 and 04:40 MLT in the equatorial proton distributions derived from the ENA images in the 27-60 keV range and with 6 min integration time. The result is shown in Figure 4. The colorcoded lines are the integral intensities of each radial bin. Each color represents a different radial distance as indicated to the left of the plot. It is clear that the proton ¤uxes from 8.5 R_E and beyond decreases quickly at around 09:26 UT while inside there is an increase in proton ¤ux. This is consistent with plasma being transported earthward from $\geq$8.5 R_E and energized as it encounters higher magnetic £elds strengths. Let us £rst investigate what plot may tell us and then discuss what may cause the decrease. The steepest decrease appears to start £rst at 10.7 R_E. The steep decrease then appears to propagate tailward as has been indicated by the triangles and connecting

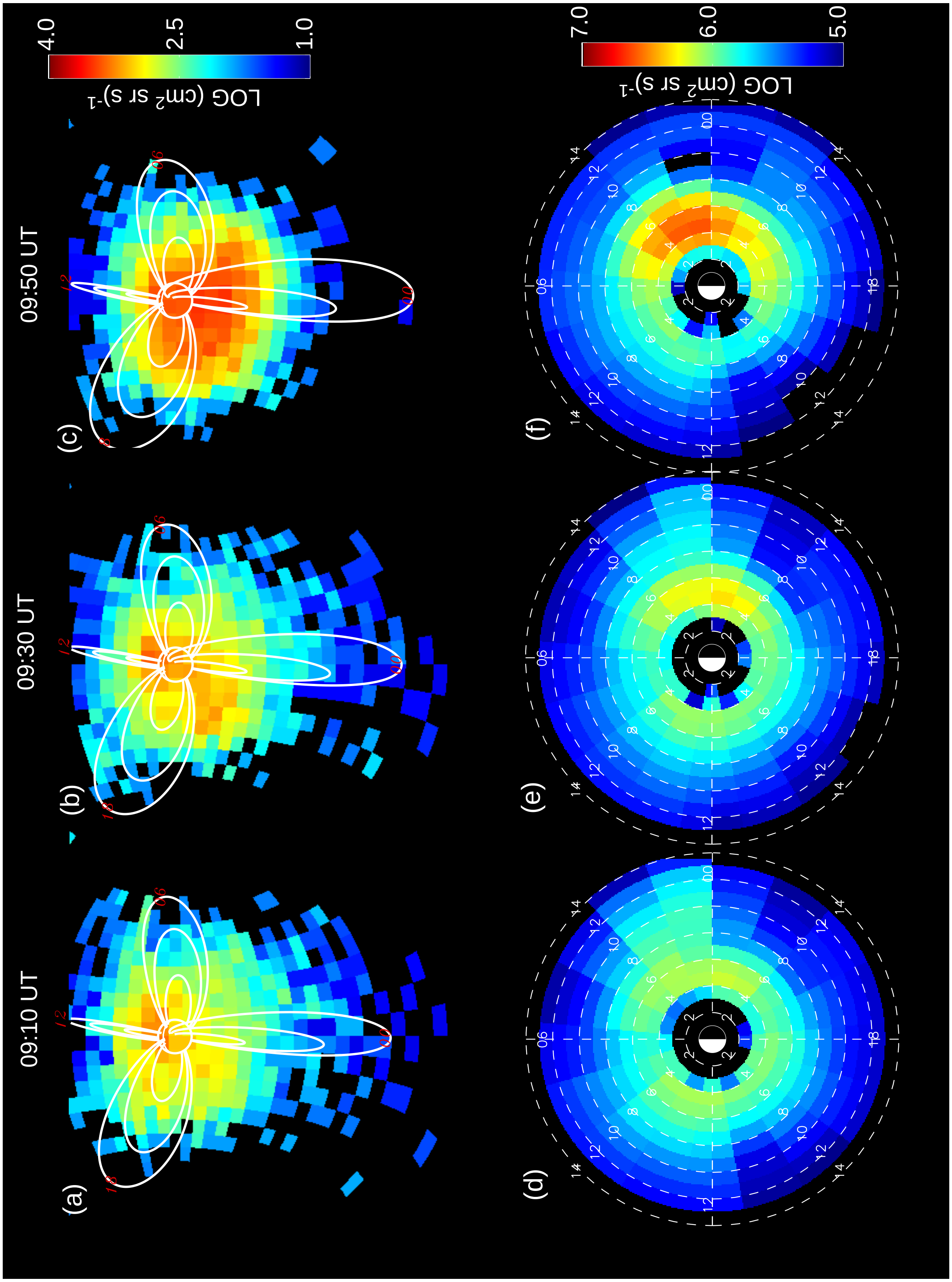

Figure 3. The upper row (a-c) show the ENA ¤ux in the 27-60 keV range. Sun is up and dusk is to the left and the £eld lines of L=4, 8 and 12 are shown for reference. The sequence shows before (a), during (b), and after (c) substorm dipolarization. The bottom row (d-f) shows the corresponding equatorial proton distributions obtained by applying a linear inversion technique to the ENA images.

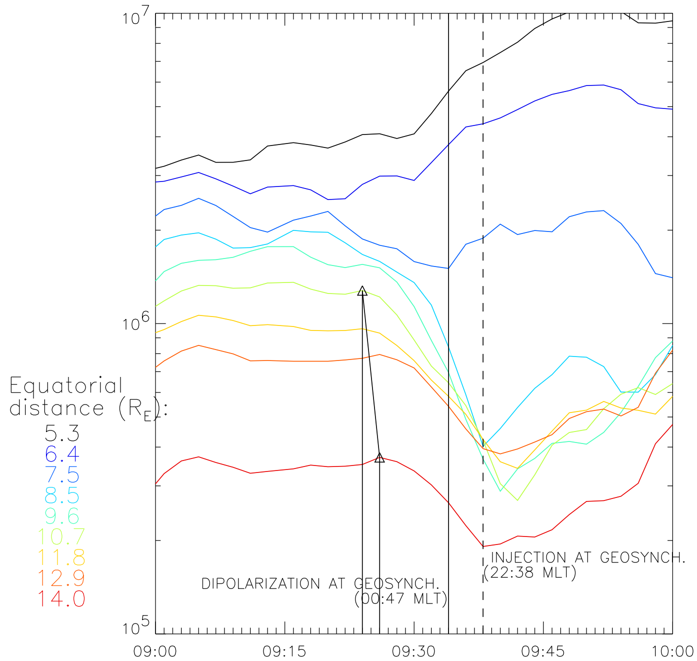

Figure 4. The evolution of the equatorial proton distribution in each radial bin summed over 23:20-04:40 MLT. Each radial bin is 1 R_E wide and the solid and dashed line marks dipolarization and proton injection (75-113 keV) at geosynchronous.

line. The resulting speed of this propagation is about 175 km/s. An earthward propagation is too dif£cult to distuinguish in this data, but the fact that both the geosynchronous dipolarization and proton injection occurs several minutes after the £rst decrease is observed suggests that there is an earthward propagation. If we assume that the decrease is caused by earthward transport of plasma, we can use the £rst occurence of the decrease at 10.7 R_E and 09:24 UT and the occurence of the proton injection observed at geosynchronous and 09:38 UT by the LANL satellite to give us a propagation speed of about 36 km/s.

The £rst cause of the decrease that comes to mind is that as the dipolarization is intitiated in a region, the resulting induced dawn to dusk electric £eld increases the $\mathbf{E} \times \mathbf{B}$ velocities locally so that plasma is accelerated earthward faster than it can be replenished by the $\mathbf{E} \times \mathbf{B}$ drift further down the tail.

Another factor that needs to be considered is the thickness of the plasma sheet that emits the ENAs. *Ohtani et al.* [1992] showed substorms where the z-component of the geomagnetic £eld actually decreased a minute or so before the dipolatization. This means that the plasmasheet thinned just before the dipolarization. Whether it is this thinning that causes the sharp decrease in ENA ¤ux, or it is the electric £elds associated with the dipolarization, is dif£cult to say at this point due to the coarse time resolution of the ENA images.

4. Summary and Conclusions

We have investigated the global plasma sheet dynamics out to about 15 R_E during a substorm that had its auroral onset at 09:19 UT in the main phase of the 4 October 2000 geomagnetic storm. We have used ENA images obtained from the HENA imager onboard the IMAGE spacacraft. The ENA images were obtained in the 27-60 keV range with 6 min integration time. A linear inversion technique was used to retrieve the corresponding equatorial proton distributions. To investigate the dynamics we summed the proton ¤uxes in the local time region on the nightside between 23:20 and 04:40 MLT and plotted each radial bin as a function of time. Although this technique is under re£nement there are some preliminary conlcusions that can be drawn:

1. The proton ¤uxes above about 8.5 R_E decreases sharply about 8 min before dipolarization was observed by GOES at geosynchronous.

2. The £rst sharp decrease occurred £rst at around 10.7 R_E and then propagated tailward.

3. The speed of the tailward propagation of the decrease can be estimated to roughly 175 km/s.

4. It is hard to distuinguish any earthward propagation of the decrease.

5. During this event the decrease of the plasma sheet ¤ux beyond 8.5 R$_E$ is followed by a dipolarization and then a proton injection at geosynchronous.

6. The decrease of the ENA ¤ux coming from the plasma sheet can be caused by the dipolarization induced electric £eld that transports plasma earthward locally faster than it can be replinished by the $\mathbf{E} \times \mathbf{B}$ drift from further down the tail. There is also the possibility that the initial sharp decrease can be an effect by the explosive thinning that has been observed just before dipolarization [*Ohtani et al.*, 1992].

The next steps in this investigation will focus on £nding events with conjunctions with in-situ measurements in the plasma sheet; re£ning the inversion technique to incorporate a dynamic Tsyganenko £eld; and investigate the spectral signatures of the dynamics.

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