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ENA observations of a global substorm growthphase dropout in the nightside magnetosphere

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Abstract. We report a global decrease of the energetic neutral atom (ENA) ¤ux coming from the entire nightside magnetosphere detectable out to dipole L=14 during the growth phase of a substorm at 08:00-09:09 UT on 4 October 2000. The ENA images were obtained in the 27-60 keV range by the high energy neutral atom (HENA) imager onboard the IMAGE spacecraft. The underlying proton distribution is derived by inverting the ENA images using a constrained linear inversion technique. The magnetosphere experienced enhanced convection and the geomagnetic £eld at geosynchronous was stretched. The global ENA ¤ux decrease is found to be related to the rapid stretching of the tail inducing a dusk to dawn electric £eld. The phenomenon can be explained either as a resulting "choking" of the $\mathbf{E}\times\mathbf{B}$ drift from the tail, or, as an adiabatic de-energization of the azimuthally drifting ring current protons.

1. Introduction

During the growthphases of geomagnetic substorms, a decrease in the proton ¤ux in the inner magnetosphere (<10 R_E) has been observed on several occasions (e.g. *Lopez et al.* [1989]). This phenomenon has later been named "growth phase dropout". It occurs during enhanced convection [*Sauvaud et al.*, 1996], such as during the mainphases of geomagnetic storms. *Sauvaud et al.* [1996] explained it in terms of de-energization of the ions gradient-curvature drifting against the electric £eld induced by a stretching of the magnetic £eld lines. Here we present global energetic neutral atom (ENA) images and the corresponding proton distributions showing that the ¤ux in the entire nightside magnetosphere out to dipole L=14 and down to L=4 decreases in relation to the stretching of the geomagnetic tail £eld. The ENA images were obtained by the high energy neutral atom (HENA) imager [*Mitchell et al.*, 2000] onboard the IMAGE spacecraft [*Burch*, 2000]. ENAs are produced when a singly charged ion charge exchanges with the neutral exosphere. The resulting ENA will propagate in a straight line from the production point. Thus ENAs can be used to remote sense space plasma. The proton distributions were retrieved from the ENA images through a constrained linear inversion technique reported by *C:son Brandt et al.* [2002]. The observations imply that there are open drift paths down to L=4, which suggests that it may not be the azimuthally magnetically drifting particles that are being de-energized as suggested by *Sauvaud et al.* [1996]. We propose the possibility that it is the supply of plasma through the $\mathbf{E}\times\mathbf{B}$ drift that becomes choked by the dusk-to-dawn electric £eld induced by the rapid stretching of the tail magnetic £eld.

2. Observations

Around 06:00 UT on 4 October 2000 the IMF B_z dropped below zero and kept decreasing, with some ¤uctuations, until 18:00 UT the same day. Enhanced convection with frequent substorms was observed throughout the main phase of this storm as reported by *C:son Brandt et al.* [2002]. The HENA imager onboard IMAGE detects ENAs in the 10-200 keV range. For a more detailed description of the instrument see *Mitchell et al.* [2000]. HENA observed enhanced proton ¤uxes coming from L$\geq$4 nightside region as can be seen in Figure 1. We have presented the proton distributions in the 27-60 keV range in Figure 1a-1c, that were obtained by inverting the ENA images in Figure 1d-1f, using a constrained linear inversion technique described by *C:son Brandt et al.* [2002]. Here we only present the isotropic pitch-angle component of the equatorial proton ¤uxes. The ion distributions in the plasmasheet and ring current are assumed to be isotropic, as they are expected to be during

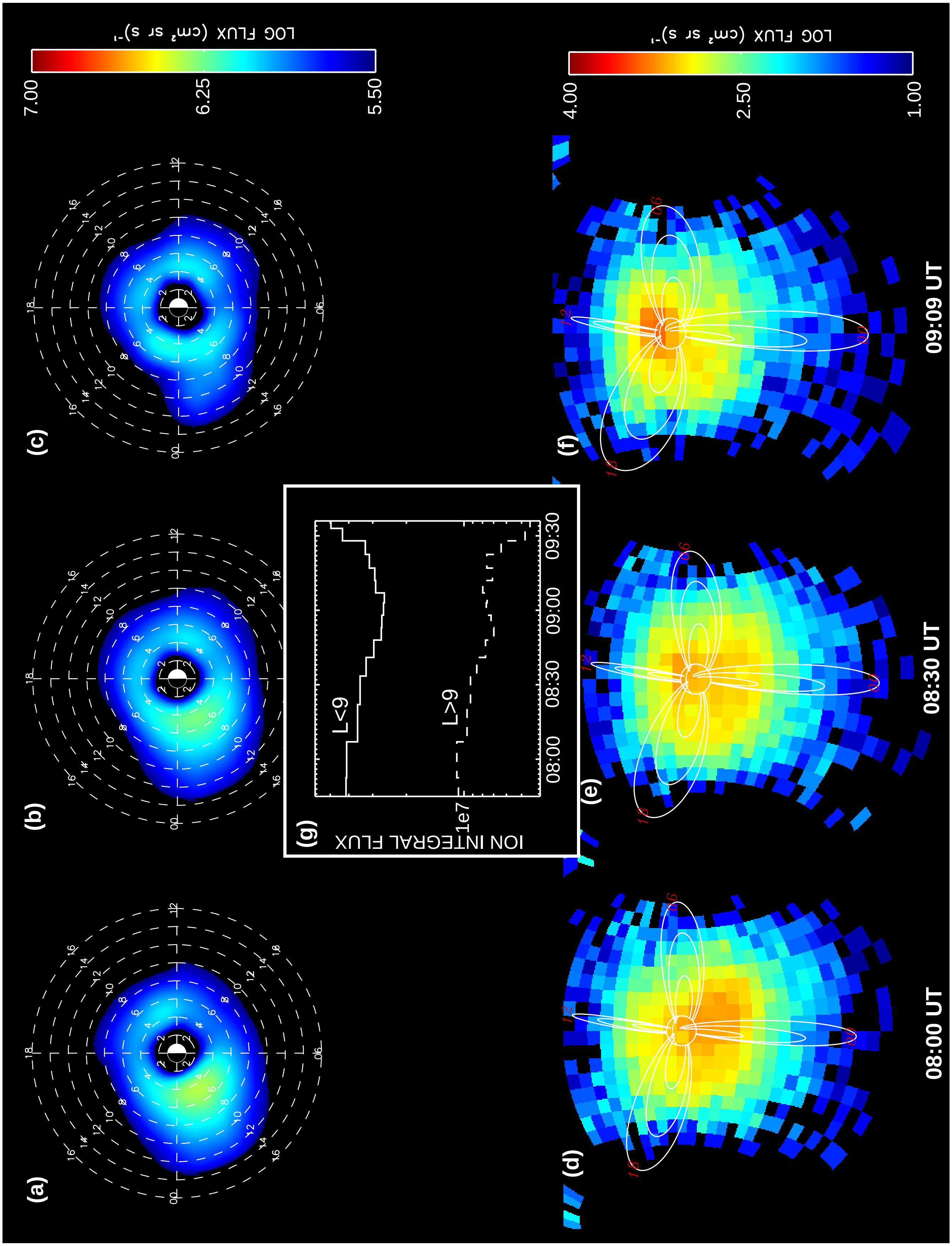

Figure 1. (a)-(c) A sequence of the proton distributions in the 27-60 keV range derived from the ENA images in (d)-(f). (g) The proton ¤uxes integrated over the nightside for the L>9 region (dashed line) and L<9 region (solid line). The sudden increase (decrease) in L<9 (L>9) proton ¤uxes after 09:09 UT is the actual substorm dipolarization and injection as reported

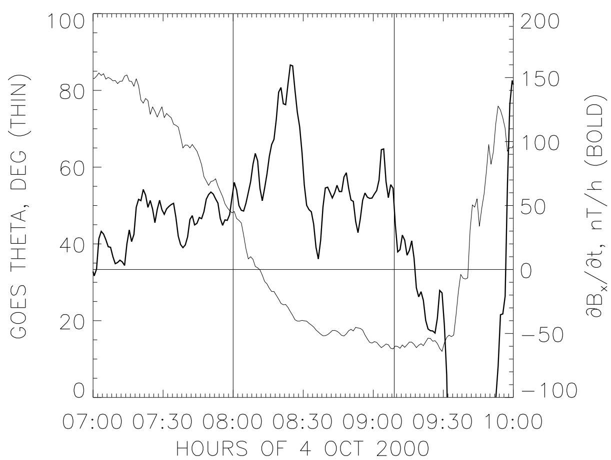

Figure 2. The inclination and the rate of change ($\partial B_x/\partial t$) of the geomagnetic £eld at geosynchronous measured by the GOES satellite. The coordinate system is GSM.

these conditions [*Sergeev et al.*, 1983]. The inversion also assumes a dipole £eld, which has the effect of underestimating the equatorial L-value. For a more detailed discussion of this effect see *C:son Brandt et al.* [2002]. As the IMF B_z dropped below zero the proton ¤uxes was already enhanced on the nightside at 06:30 UT [*C:son Brandt et al.*, 2002]. The morphology and intensity of the proton distribution remained unchanged until 08:00 UT. This would be consistent with the con£guration of the convectional electric £eld being steady and the plasma $\mathbf{E}\times\mathbf{B}$ drifting on open drift paths into L=4 and out somewhere through the dayside magnetopause. At 08:00 UT the proton ¤uxes started decreasing gradually and stopped decreasing at around 09:09 UT. In Figure 2 we show the inclination (θ) and time rate of change, ($\partial B_x/\partial t$), of the total geomagnetic £eld at geosynchronous orbit observed by the GOES satellite around local midnight. The inclination is de£ned as the angle between the magnetic £eld vector and the geomagnetic equator. The components are expressed in geocentric solar magnetic (GSM) coordinates. The $\partial B_x/\partial t$ was calculated from ten minute running averages. The times for the beginning and end of the observed ¤ux decrease are marked by the vertical lines. This is the period when $\partial B_x/\partial t$ reached a maximum. If one associates this with an electric £eld in the central plasma sheet, it would point in the dusk to dawn direction. This means that it opposed the convective electric £eld that transports plasma earthward via $\mathbf{E}\times\mathbf{B}$. We have chosen to show only $\partial B_x/\partial t$ since the contribution from $\partial B_z/\partial t$ was close to zero. A detailed calculation of the induced electric £eld is beyond the scope of this paper. Instead we refer to the modeling done by *Delcourt et al.* [1990], *Sauvaud et al.* [1996] and *Lui et al.* [1991] to justify that the observed values of $\partial B_x/\partial t$ are suf£cient to induce electric £elds of magnitude of $\sim$ mV/m. Figure 3 shows the solar wind proton density during the event observed by the ACE spacecraft. The data is lagged by the solar wind velocity for the arrival at Earth. We see that the density ¤uctuates around 10 cm^{-3} at 08:00-09:00 UT and that the IMF B_z drops from 0 to -2 nT. As can be seen no jump or signi£cant change occured in the solar wind proton density. This suggests that the slight decrease in IMF B_z was associated with an increase in the convection electric £eld, which in turn would stretch the tail of the geomagnetic £eld.

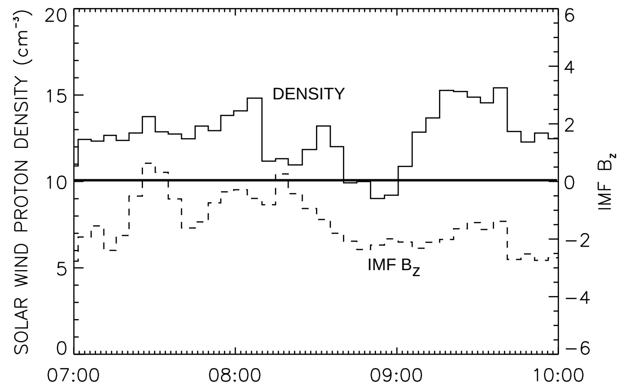

Figure 3. The solar wind proton density (solid line) and IMF B_z (dashed line) obtained by ACE during the time of the event.

3. Discussion

It is not yet clear whether the observed decrease in ENA ¤ux can be interpreted as a decrease in plasma sheet ¤ux, or whether it is due to the thinning of the plasma sheet. Since the ENA ¤ux is the line integral over the ion ¤ux along the line of sight (LOS), it is dependent on both the local ion ¤ux in the source region and the path length of the LOS through the source region. In the current version of the inversion technique a dipole £eld is used although the true magnetic £eld beyond geosynchronous is non-dipolar. While the decrease in plasma sheet ¤ux can be due to a thinning, it does not seem likely that the region inside L=5 should experience any signi£cant thinning, which would effect the ENA ¤uxes. To £rst approximation the ENA ¤ux is proportional to the thickness of the source region. Examining the ENA images in Figure 1d-1f the thickness of the source region inside L=5 would have had to decrease by at least a factor of two, which does not seem realistic. Therefore we propose the scenario

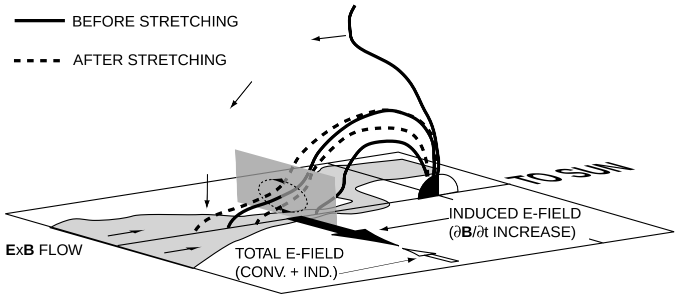

Figure 4. A sketch of the proposed mechanism behind the growth phase dropout. As the magnetic £eld lines stretches an electric £eld is induced (black arrow) which opposes the convective electric £eld. The total electric £eld (white arrow) will therefore be reduced and the $\mathbf{E} \times \mathbf{B}$ drift from the tail will be 'choked'.

illustrated in Figure 4. The idea is that the stretching of the geomagnetic £eld induces a dusk to dawn electric £eld (lying in the plane of the gray semi-transparent area in the y-z plane) that opposes the convection electric £eld, so that the overall electric £eld is reduced and the $\mathbf{E} \times \mathbf{B}$ transport of plasma from the tail to the plasma sheet and the inner magnetosphere decreases. The net result will be a decrease of the ¤ux of the plasma sheet, and the proton population in the inner magnetosphere will continue curvature-gradient drift duskward and be depleted at local midnight.

The scenario proposed by *Sauvaud et al.* [1996] may explain the observed decrease if the decrease in ENA ¤ux from the plasma sheet is due to the plasma sheet thinning, and, if the induced dusk to dawn electric £eld penetrates down below L=4 (as the simulations by *Sauvaud et al.* [1996] suggest). A more detailed study is needed to identify how the two scenarios are related.

4. Summary

We have presented global proton distributions in the 27-60 keV range during a substorm growth phase of 4 October 2000 at 08:00-09:00 UT. The nightside proton ¤ux from L=4 to 14 decreases gradually during this time. The proton distributions were obtained by inverting the ENA images observed by the HENA imager onboard IMAGE through the same constrained linear inversion technique utilized by [*C:son Brandt et al.*, 2002]. The decrease of the proton ¤ux is simultaneous with a rapid stretching of the tail geomagnetic £eld observed by the GOES satellite at geosynchronous orbit. We propose a scenario where the supply of plasma through the $\mathbf{E} \times \mathbf{B}$ drift to the inner magnetosphere is "choked" by the dusk to dawn electric £eld induced by the rapid stretching of the tail geomagnetic £eld. It is also possible that this electric £eld de-energized the gradient-curvature drifting protons inside geosynchronous as proposed by *Sauvaud et al.* [1996]. The proton distributions suggest that the drift paths were open down to L=4 for this energy range.

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