IMAGE/HENA: GLOBAL PRESSURE AND CURRENT DISTRIBUTIONS IN THE MAGNETOSPHERE DURING THE 1 OCTOBER 2002 STORM MAIN PHASE

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Abstract

Global energetic neutral atom images (ENA) of the Earth's ring current can be used to derive the global ion and pressure distribution by using a constrained linear inversion technique. The ENA images are obtained in the 10-198 keV range by the high energy neutral atom (HENA) onboard the IMAGE spacecraft. We present ion and pressure distributions from the 1 October 2002 storm main phases. The typical storm main phase display a pressure peak around midnight at L=3-4. We discuss implications for strong electric fields in the inner magnetosphere due to the closure of the partial ring current (PRC) system through the ionosphere.

Key words: Ring current, ENA imaging, geomagnetic storms

1 INTRODUCTION

The plasma pressure of the magnetosphere is carried predominantly by ions in the 10-200 keV range. This region is what is commonly referred to as the "ring current". The distribution of plasma pressure determines the morphology of the region 2 current system and the distortion of the geomagnetic field via the pressure driven currents. It has also recently been realized that the pressure plays a major role in the morphology, dynamics and strength of the electric field of the inner magnetosphere, through the ionospheric closure of the region 2 system (Wolf, 1983; Fok et al., 2001; C:son Brandt et al., 2002b). Understanding the morphology and dynamics of the global pressure in the magnetosphere is therefore an essential part of understanding the inner magnetosphere and its coupling to the ionosphere.

Roelof et al. (1985); Roelof (1987) showed from ISEE-1 data that it is possible to obtain a global and instantaneous measurement of the hot ion distribution in the ring current by detecting energetic neutral atom (ENA). When singly charged ions trapped in the geomagnetic field interact with the hydrogen atoms of the geocorona, the ions will be converted to ENAs by means of charge exchange and travel in straight lines from their point of interaction. Therefore, the ENAs are similar to photons and one may think of it as the cloud of ions "glowing" in ENAs. In contrast to most optical emissions, the ion distribution emits the ENAs anisotropically due to the pitch-angle distribution (PAD) of the ion distribution. By recording the direction of each detected ENA one can form an image of the ion distribution. Today several investigations of the ring current utilizing the ENA imaging technique have been performed with the most recent effort is the high energy neutral atom (HENA) imager (Mitchell et al., 2000) onboard the IMAGE spacecraft (Burch, 2000).

The classical picture of a geomagnetic storm consisted of a mainphase where the dominating pressure was located on the duskside (see e.g. Ejiri (1978) for a good description of the ion transport during southward IMF). At the northward turning of the IMF, most ions where believed to be trapped on closed orbits in a symmetric ring current, which decayed away due to charge exchange. Today, that picture has changed due to modeling efforts by e.g. Wolf (1983); Fok et al. (2001), but not the least due to the recent results obtained by IMAGE/HENA. This new picture includes a main phase PRC that has its pressure maximum around midnight (C:son Brandt et al., 2002b), and is believed to be direct effect of the magnetosphere-ionosphere (MI) coupling.

2 ENA IMAGES AND ION DISTRIBUTIONS

Figure 1a shows the ENA image from a typical storm main phase. The ENA image was obtained in the 10-60 keV hydrogen ENA channel with a 10-min integration time. There are four pair of dipole field lines at each MLT as marked. Each dipole field line represents L=4 and 8 for reference. This image was obtained from a vantage point almost straight above the north pole. The image is displayed in an azimuthal euqidistant map projection with a 180° ×180° field-of view (FOV). This type of projection closely resmebles what a human eye would see. The dashed grid represents the instrument coordinates of HENA (Mitchell et al., 2000). HENA has an instant 90° ×120° FOV and spins with a 2-min spin period so that the entire sky is imaged onto a 360° ×360° backplane. ENAs in the energy range of about 10-200 keV for hydrogen ENAs, and about 50-180 keV oxygen ENAs, can be detected by HENA. Above these energy ranges, the ENA fluxes are too low and cannot be detected. Since June 2001 HENA is capable of separating hydrogen and oxygen ENAs. In this paper we

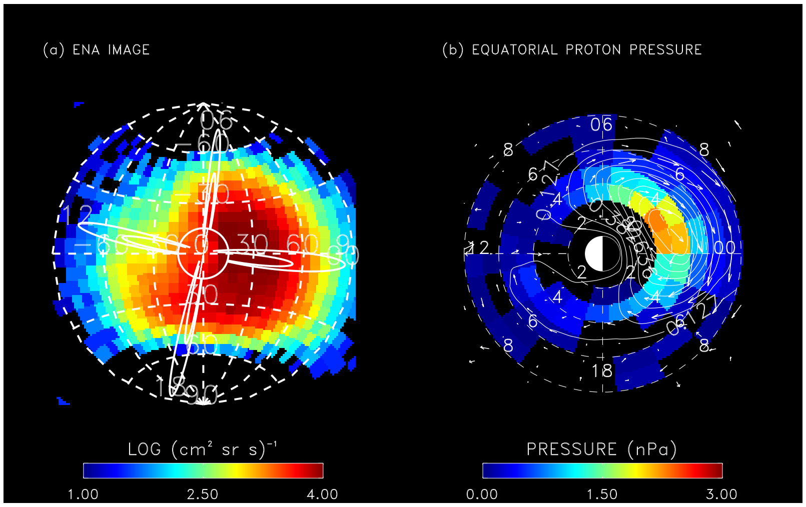

Fig. 1. Pressure (proton) distribution from the 1 October 2002 storm main phase at 13:50 UT. The distribution is obtained from ENA images in the 10-60 keV range. The white arrows indicate the corresponding pressure driven currents.

will only focus on hydrogen ENAs and the analysis of oxygen is reported by Mitchell et al. (2002).

In order to interpret the ENA data appropriately it is necessary to somehow retrieve the parent ion distribution. One way of doing this is through a parameter-free method called "constrained linear inversion" which closely follows Twomey (1977). It is this method we use to invert the HENA images to equatorial ion distributions and it was developed by Dr. E. C. Roelof, R. DeMajistre, Dr. P. C:son Brandt and Dr. D. G. Mitchell at The Johns Hopkins University Applied Physics Laboratory, MD, and briefly described by C:son Brandt et al. (2002a). It is based on the idea that the detected ENA counts C_i in pixel i can be written as a linear equation system for all pixels in the ENA image and solved using the constrained linear inversion technique as outlined by Twomey (1977). The current version of our algorithm uses a dipole field, but it can be shown that for the inner magnetosphere and with the resolution of our grid, this is not a too bad of an approximation. Furthermore, from a single vantage point image it is not possible to retrieve pitch angle distributions (PAD) of the parent ion distribution. We can only therefore assume that the PADs are isotropic for the periods we are studying. For storm main phases the PADs are close to isotropic and for cases where it is not we have to rely on in-situ measurements. It is important to remember that global measurements have their restrictions in detail, but their strength in being able to obtain an instantaneous picture. The full strength of the global datasets are not achieved until they are consistently combined with in-situ measurements.

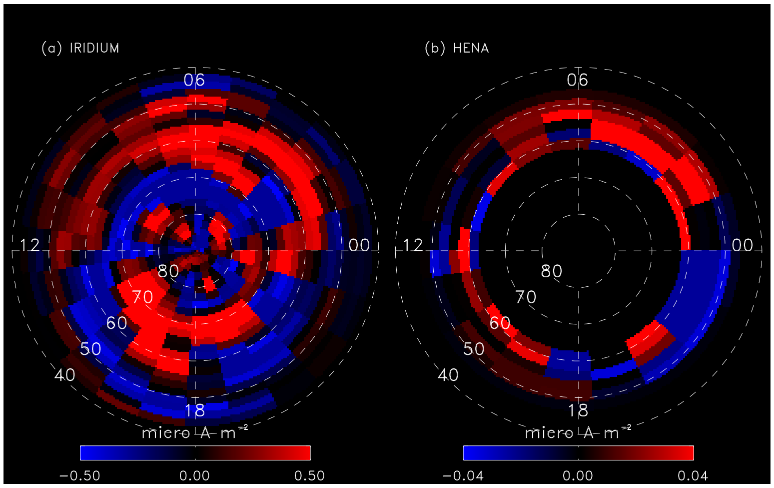

Fig. 2. The FACs reaching the ionosphere computed from the pressure distribution in Figure 1.

3 PRESSURE AND CURRENTS

Once the ion distributions are retrieved it is straightforward to derive the pressure $p_k(L, \phi)$ for each species k in magnetic L-shell and local time ϕ.

$$p_k(L, \phi) = \frac{4\pi}{3}\sqrt{2m_k}\sum_i j_{i,ION}(E_i, L, \phi)\sqrt{E_i}\Delta E_i \qquad (1)$$

Figure 1b shows the pressure distribution of 10-60 keV protons for the 1 October 2002 storm main phase at 13:50 UT. The pressures shown are about a factor of two less than the ones obtained by De Michelis et al. (1999) (for AE >100 nT periods). This is expected since we have only sampled a partial pressure.

Once the pressure distribution is computed, we use the methods described by *Roelof et al.* (this issue) to compute the current system. This current system is the (partial) region 2 current system that has to flow when the pressure is present. The equatorial currents are plotted in Figure 1 as white arrows. The field-aligned currents (FAC) reaching the ionosphere are shown in Figure 2 together with the FACs derived from the magnetometer measurements on board the Iridium satellites. We have assumed that the inertial ("braking") term in the equation $\mathbf{J} \times \mathbf{B} = \nabla p$ is negligible, and therefore cut off the FAC for magnetic latitudes higher than 68° (corresponding to L=7 for a dipole). The red represents up going currents and blue down going.

First, we see that our absolute values are about one order of magnitude less than the ones obtained by Iridium. The reason for this is still under investigation can be that the inversion algorithm tend is too heavily constrained so that the results are over smoothed. Or, it can be due to the simple fact that we have not yet included the >60 keV protons and the O^+ in the calculations, which may contain stronger pressure gradients.

Second, we can see from Figure 2 that while the up going current in the post-midnight sector agrees reasonably well with the Iridium results, our down going current does not extend to over to dusk as the Iridium result does. This can be explained the following way. The ions drift in from the plasmasheet towards the dawn side as has been shown by several models (Fok et al., 2001; Wolf, 1983). The point at which the ions turn around (close to the stagnation point) and start magnetically drift westward, is located at about the same place over belk energy of the ring current (10-200 keV). Now, since the FAC depend only on the azimuthal pressure gradients, the region of up going FAC is rather insensitive to what energy range one samples. However, as ions drift magnetically westward towards dusk they lose energy because they are moving away from the electric potential minimum. Since, the magnetic drift velocity is higher for higher energy ions, low energy ions will be transported outward by the electric field already around dusk. The high energy ions will continue drifting close to Earth towards noon. Therefore, the partial pressure distribution for high energy ions will be more extend through dusk. So, sampling only the low-energy pressure will place the azimuthal pressure gradients close to midnight than the total pressure gradients.

4 SUMMARY

We have shown examples of the global pressure distributions obtained from the HENA imager on board IMAGE. The pressure distributions were derived from ENA images obtained with a 10-min integration time in the 10-60 keV hydrogen channel during the 1 October 2002 storm main phase at 13:50 UT and show that the peak of the partial pressure is located around midnight.

The pressure was then used to calculate the current system according to the methods described by *Roelof et al.* (this issue). The FAC reaching the ionosphere was compared to the FAC patterns derived from the magnetometer data from the Iridium satellites. It was concluded that the up going FAC in the post-midnight sector agreed well with the Iridium data. The down going currents was located around dusk in the Iridium data, whereas our result showed the down going currents more towards the evening sector. The explanation for this lies in the fact that we have not yet dervied the higher energy proton and O^+ pressure from the HENA data.

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