IMAGE and FAST observations of substorm recovery phase aurora

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1. Introduction

Images from the IMAGE Wide-band Imaging Camera (WIC) and Spectrographic Imager (SI) channel SI12, were compared to in situ data taken by FAST. The IMAGE data segment began during the expansive phase of a substorm and a double oval configuration evolved, consisting of a set of discrete poleward auroral forms and a separate more diffuse oval. The FAST data showed that a narrow (∼1.5° latitude) region of downward currents separated the two ovals. The SI-12 optical observations showed a single oval of precipitating protons located on the equatorward side within the diffuse aura. In agreement with IMAGE, the highest intensity proton flux measured by FAST was concentrated on the equatorward region although low flux protons were present throughout the entire double oval. In the lower latitude diffuse oval occasional structured auroras were embedded. These structured auroras were mostly created by inverted V type electrons but there were narrow regions in which intense beams of accelerated electrons were seen whose energy/pitch angle distribution and accompanying electric field data were consistent with Alfvén wave acceleration. The poleward oval consisted of an intense inverted V precipitation event poleward of which a weak region of Alfvén wave accelerated electrons was located. From the images it appears that the Alfvén wave accelerated electron event in the diffuse auroral regions and the poleward features were part of short lived or rapidly moving auroral forms.

INDEX TERMS:
2788 Magnetospheric Physics: Storms and substorms; 2704 Magnetospheric Physics: Auroral phenomena (2407); 2716 Magnetospheric Physics: Energetic particles, precipitating; 2455 Ionosphere: Particle precipitation

2. Data Presentation

WIND (X = 6 R_e, Y = −33 R_e, Z = −4 R_e solar magneto-spheric coordinates) magnetic field data show that during the period of interest the IMF z component was weakly negative with a strong positive y component. The GOES 10 geo-synchronous satellite magnetometer data (provided courtesy of H. Singer) showed sudden dipolarization occurring at 1445 UT indicating that the data sequence started in the expansive phase of a substorm. IMAGE orbit is highly elliptic with perigee at 1000 km (south) and apogee at 44,000 km (north) providing the most favorable close up view of the northern auroral oval shortly after instrument turn on following perigee pass. Pairs of FUV images are presented from 1516 to 1538 UT in Figure 1. The left Wideband Imaging Camera(WIC) image, is sensitive to auroral and dayglow LBH N_2 and N emissions in the wavelength region from 140 to 170 nm. The right SI12 image, shows proton induced Lyman alpha [Mende et al., 2000]. Dayglow was removed from the raw WIC images by subtracting a 40 pixel Gaussian smoothed version of the image. The subtraction removed the slowly varying large-intensity dayglow and allowed the presentation of fine scale aurora simultaneously in the sunlit and dark regions. Without this correction the dynamic range spanned 14 bits. The SI12 instrument responds only to emissions produced by charge exchanged protons of energy...
greater than 1 keV and it needed no dayglow contamination correction [Mende et al., 2000; Frey et al., 2001]. Geomagnetic latitude (45, 60, 75 and 90) and magnetic local time (midnight, 0300, 0600, 0900, 1500, 1800, 2100) was superimposed with green solid lines. Magnetic noon was indicated with a dashed line.

3. Discussion
[4] The situation in Figure 1 is characteristic of the latter part of a substorm expansive phase followed by the recovery phase and leading to a “double auroral oval” [Elphinstone et al., 1995a, 1995b]. The first image of the sequence (not included in Figure 1) showed a significant part of the nightside auroral oval including a hook like feature, the substorm surge (near 2000 MLT). Later (1458 UT) the remainder of the surge was located at 1930 MLT. After 1504 (not shown) the surge faded and a double oval configuration was seen by WIC consisting of a poleward region of discrete poleward auroras and a second more diffuse equatorward oval. At the start of the sequence (Figure 1) the proton aurora is seen (Right side blue-white images), collocated with the diffuse region. There is a bright patch near midnight which is just equatorward of the substorm surge and presumably located at the substorm onset location [Mende et al., 2001]. The other duskward more intense proton precipitation is longitudinally coincident with the vestiges of the substorm surge but located equatorward of it. The intensity of the protons also faded with the remains of the substorm surge. After 1530 UT the proton auroras were located in the equatorward diffuse aurora. Between 1530 and 1538 the FAST satellite traversed the midnight auroral oval as illustrated by the small green box and a three minute (one minute prior to the image time and two minutes after) satellite track within the box. The WIC images at 15:36:30 and 15:38:31 are almost identical to the recovery phase situation described by Elphinstone et al. [1995a] in their Figure 1 top panel. In the FAST (Figure 2 top panel) magnetic field data negative gradients signify regions of upward current (downward electron flow). The second panel is the spectrogram of downward electrons showing diffuse electron precipitation with embedded structures below latitudes of 67° ILAT, (15:35 UT). The structures are either mono-energetic peaks (15:33:20, 15:34:40 and 15:35:10 UT) with high fluxes in both B parallel and perpendicular detectors consistent with isotropic pitch angle distribution or beams with monotonically decreasing energy spectra.

Figure 1. Collage of simultaneous WIC and SI12 images with superimposed geomagnetic latitude (45, 60, 75 and 90) and magnetic local time (midnight, 0300, 0600, 0900, 1500, 1800, 2100) green solid lines, and magnetic midday with dashed line.
The protons (bottom panel) peak at lower latitude reaching an energy flux of the order of only 1 erg cm\(^{-2}\) s\(^{-1}\) respectively every two minutes. The intensity of pixels which take one exposure (10 and 5 sec duration for WIC and SI respectively) every two minutes. The intensity of pixels which take one exposure (10 and 5 sec duration for WIC and SI respectively) every two minutes. The intensity of pixels which take one exposure (10 and 5 sec duration for WIC and SI respectively) every two minutes. The intensity of pixels which take one exposure (10 and 5 sec duration for WIC and SI respectively) every two minutes. The intensity of pixels which take one exposure (10 and 5 sec duration for WIC and SI respectively) every two minutes.

The electron energy flux (Panel 4) shows a significant peak, of >10 erg cm\(^{-2}\) s\(^{-1}\) estimated the current from the precipitating flux, (~1 \(\mu\)A m\(^{-2}\)) and the current sheet thickness (~400 km) and we found reasonable agreement with dB >200 nT decrease. On the other hand in the downward current region the ion flux is insufficient to account for the measured dB and the current must be carried by cold electrons. Most of the WIC images presented in Figure 1 show double oval configuration with an equatorward diffuse region, a bright poleward edge separated by a darker band. Although the images usually show dynamic behavior, some of these images look very similar to a typical double oval drawn by Elphinstone et al. [1995a, 1995b]. The WIC intensity plot in Figure 2 Panel 6 shows that along the FAST track there is a diffuse equatorward zone and a very bright poleward region separated by a broad dimmer region with one discrete structure in it. The spacing of the two bright regions bordering the central less intense middle region is on the scale of the double oval (~5\(^\circ\)). The downward current region detected by FAST, located on the poleward side of the central dim region, which contains no electron precipitation, was relatively narrow in latitude (~1\(^\circ\)).

4. Conclusions

We conclude from simultaneous FAST and IMAGE FUV data taken during a substorm recovery phase that: 1. During substorm recovery phase the nightside oval had two bright regions separated by a dimmer one. The lower latitude region contained the proton aura and the diffuse electron aurora with embedded structures. The structured auroras were mainly created by inverted V type electrons signifying quasi-static electric fields but in some of the structures intense Alfvén wave accelerated electrons were seen. This region was separated from the higher latitude region by a zone containing downward currents exhibiting minimal electron precipitation. The poleward region consisted of an intense inverted
V precipitation structure poleward of which a weak region of Alfven wave accelerated electrons was located. The Alfven wave accelerated electrons were seen in short lived or rapidly moving features. The low latitude part of diffuse electron aurora was collocated with the more intense proton auroras. Although FAST data showed weak proton precipitation throughout the entire oval the bulk of the proton precipitation (with sufficient intensity to be seen by IMAGE) was located in the equatorward part of the double oval. The proton intensity decreased as the recovery phase progressed while maintaining maximum intensity near midnight.

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