Polar cap boundary auroral ion outflows during substorms and active aurora

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Abstract. Ion conics that frequently occur on the polar cap boundary (PCB) on the nightside auroral oval consist of high fluxes of ions that can account for the majority of the auroral ion outflow. The PCB ion conics are associated with substorm onset and expansion phase, but also occur during generally active aurora when it is difficult to characterize substorm phases. Because of this difficulty, we use the total hemispheric power, determined from Polar UltraViolet Imager (UVI) data, as a proxy for auroral conditions. Using FAST data, we calculate the total ion outflow as a function of species (H+, He+, and O+) in the PCB ion conics for 3 specific orbits during January-February 1997. In all cases, there is practically no O+ outflow at the polar cap boundary. However, the distance from the polar cap boundary (in degrees latitude) where O+ outflow starts to become significant shows a dependence on hemispheric power. During more active aurora, the proportion of O+ outflow extends closer to the polar cap boundary, while during quiet times, the ion composition near the polar cap boundary is primarily H+ and He+. We believe the O+ outflow rate is dependent on auroral activity level, consistent with earlier studies, and that the change in the poleward extent of O+ outflow is a reflection of changes in O+ outflow and not of changes in the PCB ion conic outflow, which consists mostly of light ions.

1. Introduction

The question of ion outflow has been a long-standing one, with important implications to the global dynamics of the magnetosphere. As one of the largely varying contributors to the total ionospheric outflow, the auroral ion outflow is worthy of investigation, particularly during substorms. Auroral ion outflow occurs primarily in the form of ion conics. In particular, *Tung et al.* [2001] found that the ion outflow on the auroral polar cap boundary, in the form of ion conics, often accounts for the majority of the ion outflow over the entire aurora. The Polar Cap Boundary ion conic (hereafter referred to as "PCB ion conic") occurs during substorm expansion phase in isolated substorms, but also occurs during generally active aurora, when it is difficult to classify substorm phases. In this study, we classify active aurora using a proxy derived from Polar UltraViolet Imager (UVI) data known as total hemispheric power. Because the LBHL (Lyman-Birge-Hopfield-Long) wavelength is not strongly absorbed in the atmosphere, the counts in each of the pixels is proportional to the input electron energy flux. The total hemispheric power proxy allows classification of auroral activity at all times that the auroral oval is in the field of view of UVI. It has an advantage over the A_E index in that the total hemispheric power is a global quantity and will not miss local enhancements in the aurora when the entire auroral oval is in the field of view.

The composition of auroral ion outflow has been studied by *Yau et al.* [1985] and has been shown to depend on auroral activity level. In the current study, we find that the latitudinal extent of O+ ion outflow depends on the auroral activity level, as determined by UVI total hemispheric power.

2. Satellites and Instrumentation

In this study, we use data from both the Fast Auroral SnapshoT (FAST) and the Polar satellites. On the FAST satellite, we use data from the Time-of-flight Energy Angle Mass Spectrograph (TEAMS) instrument and on Polar, we use the UltraViolet Imager (UVI).

The FAST satellite was launched August 21, 1996 into an 83° inclination orbit, with an apogee of 4175 km and a perigee of 350 km altitude. During the FAST campaign period of January-February 1997, FAST's orbit was in a roughly noon-midnight direction, with apogee over the northern hemisphere.

The TEAMS instrument has a 180° planar field of view and is mounted such that over a spacecraft spin, the entire 3D distribution is sampled every spin (~5 sec). Energy resolution of ($\Delta E/E = 0.15$) is achieved by a top-hat electrostatic analyzer, and mass resolution (E/q measurement) by a time-of-flight section in series with the top-hat detector.

The Polar satellite was launched February 21, 1996, into a 90° inclination orbit with apogee of geocentric altitude 9.1 R_E and a perigee of geocentric altitude 2.8 R_E. The UVI is mounted on a despun platform, so that images can be taken during all phases of the spin and no complicated despin procedures are necessary to process the images. However, a small misalignment in the despin platform axis with the spacecraft spin axis produces a wobble, causing smearing of the images in one direction. In the total hemispheric power calculation, the wobble affects only the pixels near the edge, and thus has a minor effect on the final value. Furthermore, if the entire auroral oval is in the field of view, the edge pixels mostly have very low count rates (*i.e.* they are not part of the auroral oval) and thus have a minimal effect on the final value of total hemispheric power.

3. Data

We present FAST TEAMS ion outflow data for 3 PCB ion conic events, from FAST Orbit 1865 (February 9, 1997), Orbit 1800 (February 3, 1997), and Orbit 1648 (January 20, 1997), during the FAST campaign period January-February 1997. In addition, we also show the total hemispheric power, as a proxy for auroral activity level, as obtained from the UVI instrument on Polar.

Figure 1 presents FAST TEAMS data from Orbit 1865, on February 9, 1997. Panels 1, 3, and 5 show energy spectrograms of the H+, He+, and O+ measurements. The PCB ion conic can be seen from 21:40 to 21:41. We calculate total ion outflow as a function of species by taking the integral of the number flux over all pitch angles, for energies > 20 eV. The data are presented in panels 2, 4, and 6, where the red indicates upgoing flux and the green indicates downgoing flux. In panels 7, 8, and 9, we show the fractional contribution to total upgoing or downgoing number flux for the 3 ion species H+, He+, and O+, for times when all 3 species show net number flux in the same direction. The fractions are summarized in panel 10, where the heights of the blue, green, and red bars represent the fraction of H+, He+, and O+ number flux. There is an O+ component to the total ion outflow for almost the entire auroral pass. The O+ contribution becomes small (*i.e.*, < 10%) near the PCB.

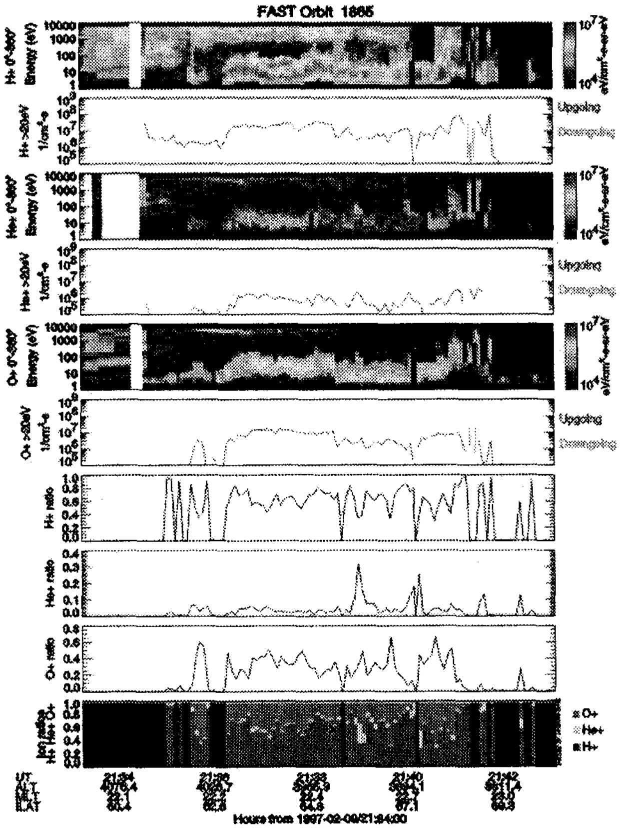

Figure 1. FAST TEAMS ion data from Orbit 1865, on February 9, 1997. Panels 1, 3, and 5 show H+, He+, and O+ energy spectrograms during this northern nightside auroral oval pass. Below each energy spectrogram is the integral of the ion number flux over all pitch angles, for energies > 20 eV. Net upgoing number flux is plotted in red, while net downgoing number flux is plotted in green. Where all 3 species have number flux in the same direction, the proportion of each species is plotted in panels 7, 8, and 9. This information is summarized in panel 10, which shows H+ in blue, He+ in green, and O+ in red. The PCB ion conic is observed from 21:40 to 21:41.

In Figure 2 is shown the total hemispheric power for several hours on February 9, 1997 preceding and including the PCB ion conic shown in Figure 1. The total hemispheric power is calculated using UVI images taken with the LBHL filter, because these emissions are not strongly absorbed in the atmosphere. Furthermore, the calculations are performed using the images accumulated for the 36.8 second integration period which, because of the long accumulation times, have the best statistics. Below the hemispheric power plot is a plot indicating the fraction of the auroral oval that is in the field of view (FOV). The quality flag is broken into three categories: 1=part of the auroal oval is in the FOV, 2=entire nightside auroral oval is in the FOV, and 3=entire auroral oval is in the FOV. In all cases, the actual total hemispheric power is greater than or equal to the value calculated using UVI. Though the auroral oval is not fully in the field of view all of the time, it is clear that the total hemispheric power is fairly high this day, reaching levels of 100-150 GW, with peaks reaching 250 GW.

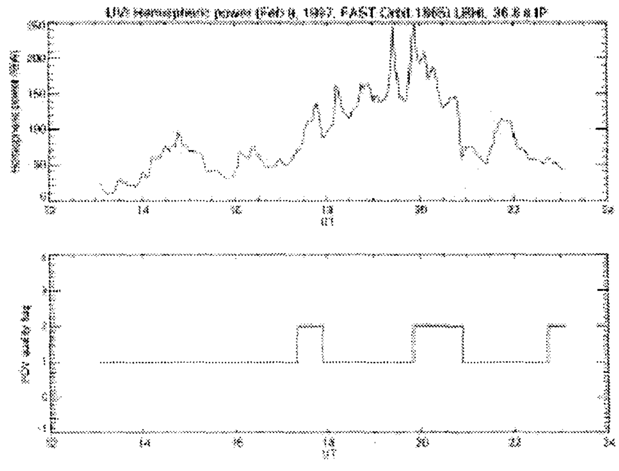

Figure 2. UVI Hemispheric power on Feburary 9, 1997. The UVI hemispheric power is calculated from UVI images taken with the LBHL filter for 36.8 sec integration period. Because the field of view of UVI varies with the Polar orbit, the portion of the auroral oval visible to the imager is indicated by the FOV quality flag (1=part of auroral oval is in the field of view, 2=entire nightside auroral oval is in the field of view, and 3=entire auroral oval is in the field of view).

Figure 3 presents TEAMS data from Orbit 1800, on February 3, 1997. The PCB ion conic is seen from 21:28 to 21:29. In this case, notice from panel 10 that after about 21:27, there is very little O+ in the ion outflow. The O+ ion outflow is more equatorward relative to the polar cap boundary than in Figure 1.

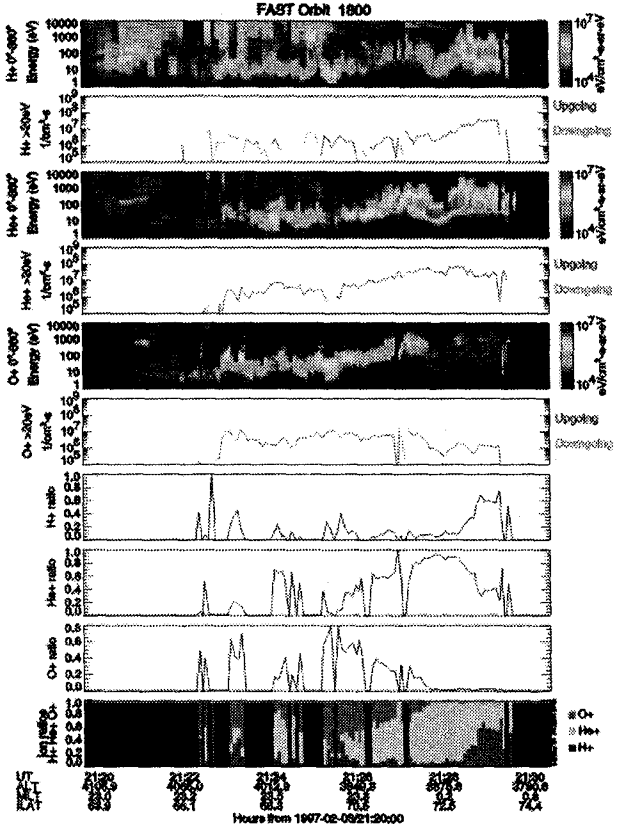

Figure 3. Same format as Figure 1, but for FAST Orbit 1800 on February 3, 1997. The PCB ion conic is observed from 21:28 to 21:29.

Figure 4 presents the total hemispheric power for February 3, 1997 for the several hours preceding and including the time of the PCB ion conic shown in Figure 3. This is a much more quiet day than February 9, 1997, with hemispheric power around 10-20 GW for most of the period.

Figures 5 and 6 show the corresponding FAST and UVI data for another PCB ion conic observed on January 20, 1997, on FAST orbit 1648. This is another quiet day, with total hemispheric power below 20 GW for the period before the PCB ion conic. We observe from the FAST data that significant O+ contribution to the total ion outflow ends approximately 2 degrees invariant latitude from the polar cap boundary.

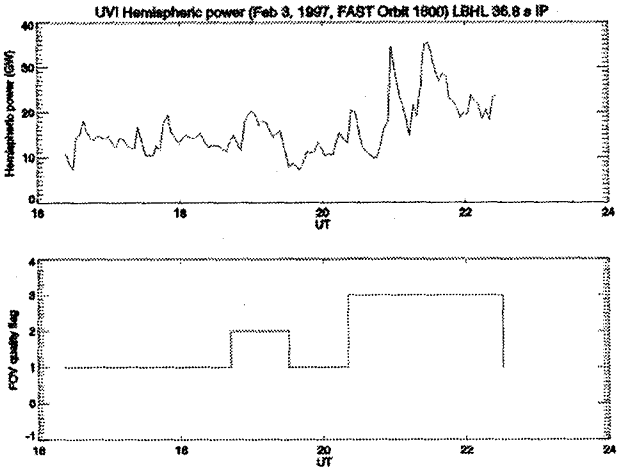

Figure 4. Same format as Figure 2, but for February 3, 1997.

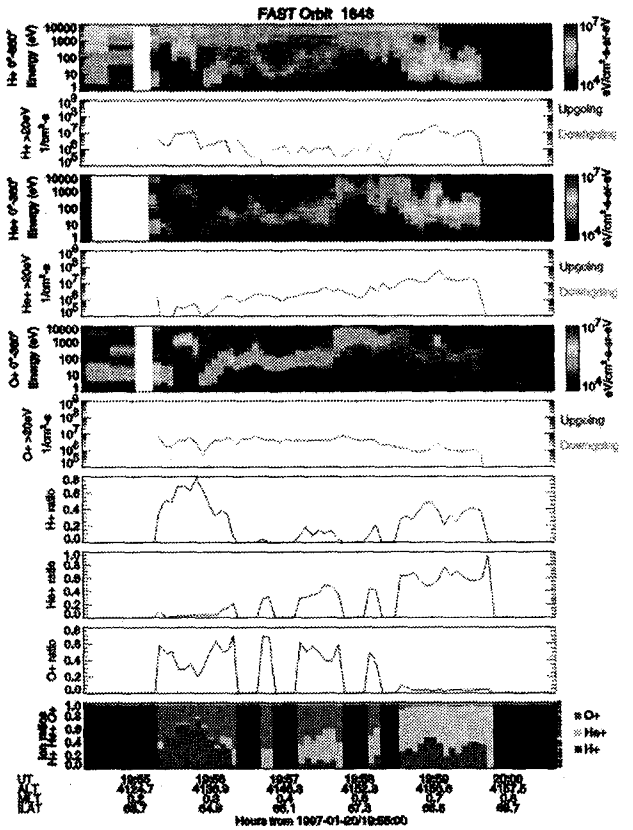

Figure 5. Same format as Figure 1, but for FAST Orbit 1648 on January 20, 1997. The PCB ion conic is observed from 19:59 to 20:00.

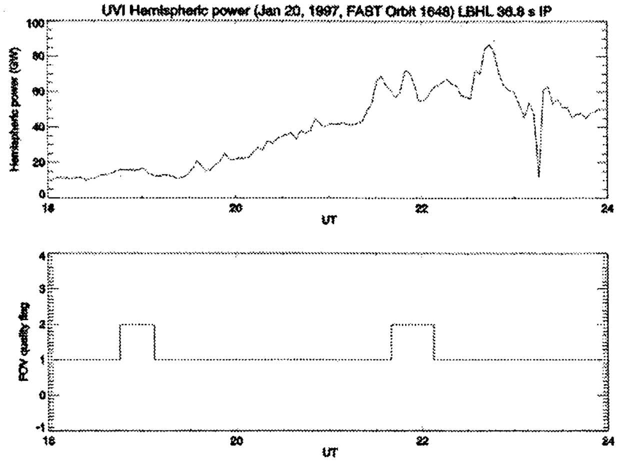

Figure 6. Same format as Figure 2, but for January 20, 1997.

4. Discussion

The main observation is made by comparing Figure 1, which shows a PCB ion conic from FAST orbit 1865 during a relatively active time as determined from UVI hemispheric power, with Figures 2 and 3, which show PCB ion conics during relatively quiet times. The proportion of O+ in the ion outflow is significant up to about < 1 degree from the PCB in Figure 1, while in Figures 2 and 3, the O+ proportion drops off more than twice as far, > 2 degrees, from the PCB. This is suggestive that the poleward extent of O+ outflow is dependent on activity level.

Closer observation of Figures 1, 3 and 5 shows that the H+ outflow at the polar cap boundary does not change significantly between the different orbits. It is the O+ outflow that changes more. Thus, the difference in O+ extent is possibly a reflection not of the polar cap boundary ion conic but of auroral ion heating in the other parts of the aurora.

In general, it has been difficult to quantify the poleward extent of O+ outflow. Using a simple criterion such as the poleward most location where the O+ outflow exceeds 10% leads to reasonable results most of the time, as in the examples shown. However, on some orbits, this criterion leads to a result where the O+ outflow is several degrees (> 4) from the polar cap boundary because of a combination of data gaps and noise.

A more detailed study will not only need to come up with a carefully conceived method of quantifying the distance from the polar cap of O+ outflow, but will also need to include additional events from a different period of the solar cycle. *McFadden et al.* [2001] observed PCB ion conics from 2000, closer to solar maximum, and report that the composition consists of a significant component of O+. It is possible that the presence of O+ in the PCB ion conic will cause the PCB ion conic outflow to be affected by activity level, contrary to the results presented here.

5. Summary and Conclusion

Earlier studies have reported that, during January-February 1997 (solar minimum), PCB ion conics primarily consist of light ions. In the current study, we have investigated the poleward extent of O+ ion outflow as a function of general auroral activity level. We have found that the O+ contribution to the total outflow remains large up to within a degree of the polar cap boundary during active aurora, while the poleward extent of significant O+ contribution during quiet times remains farther from the polar cap boundary. This is primarily due to an increase in the O+ ion number flux during active aurora, rather than a change in the H+ ion outflow in the PCB ion conic. Future work will examine the effect statistically and during solar maximum, when significant O+ outflow is observed near the PCB.

References

McFadden, J.P., Y. K. Tung, C.W. Carlson, R.J. Strangeway, E. Moebius, and L.M. Kistler, FAST Observations of Ion Outflow Associated with Magnetic Storms, in *Space Weather*, Geophysical Monograph 125, American Geophysical Union, 413, 2001.

Tung, Y.-K., C.W. Carlson, J.P. McFadden, D.M. Klumpar, G.K. Parks, W.J. Peria, and K. Liou, Auroral polar cap boundary ion conic outflow observed on FAST, *J. Geophys. Res.*, **106**, 3603, 2001.

Yau, A.W., E.G. Shelley, W.K. Peterson, and L. Lenchyshyn, Energetic auroral and polar ion outflow at DE 1 altitudes: magnitude, composition, magnetic activity dependence, and long-term variations, *J. Geohpys. Res.*, **90**, 8417, 1985.