Final Report activities under Grant NASA-NAG5-6976

Ion Outflow Observations

The characteristics of out-flowing ions have been investigated under various circumstances. In particular the upwelling of ions from the cleft region has been studied to attempt to look at source characteristics (e.g. temperature, altitude). High altitude (6-8 Re) data tend to show ions species that have the same velocity and are adiabatically cooled (Fig 1.). Such ions, while representative of their source, can not provide an accurate picture. Ion observations from the TIDE detector on the Polar spacecraft show an energy (or equivalently a velocity) spectrum of ions as they undo the geomagnetic mass spectrometer effect due to convection-gravity separation of the different species. Consolidation of this type of data into a complete representation of the source spectrum can be attempted by building a set of maximum-phase-space-density-velocity pairs and attributing the total to the source.

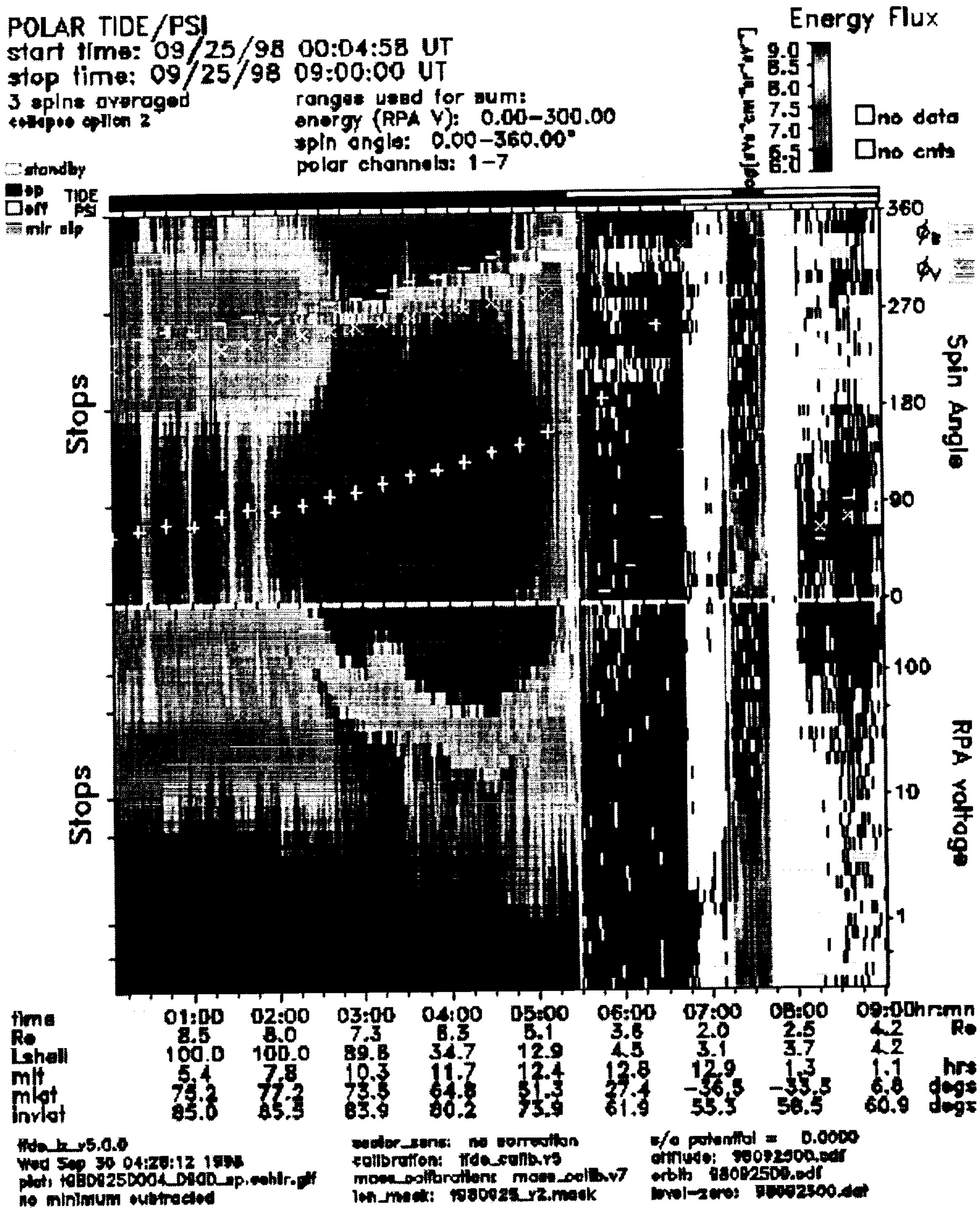

Figure 1 - Overview spectrogram of a Polar pass across the polar cap. Upwelling ion signatures are seen from ~0200 to 0530 UT.

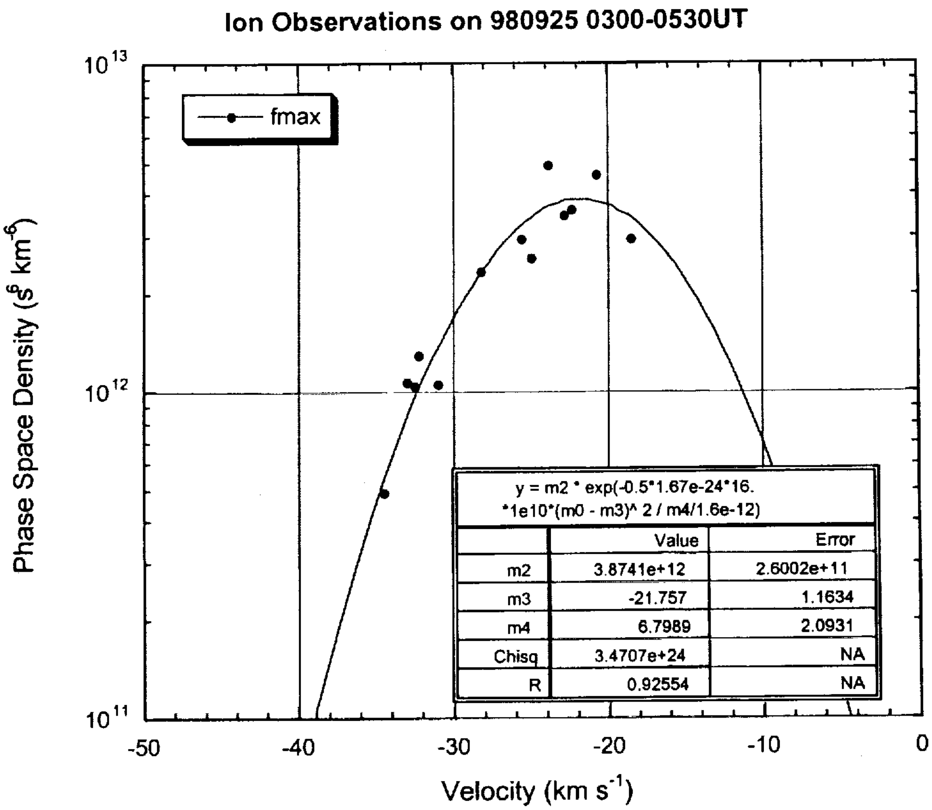

Figure 2 - Compilation of maximum phase space density vs. velocity for pass in Fig. 1 showing the velocity filtering effect of the convection of cusp outflows.

An example of such a compilation taken during enhanced outflow resulting from the impact of a CME on 24 September 1999 is shown in Fig. 1. These results were derived from a pass of the Polar spacecraft from high altitude (~8Re) to low altitude (~5Re) along a midnight-to-noon trajectory. The O+ energy was observed to fall to lower energies and then rise again as Polar moved towards the cleft (Fig. 1). Individual O+ velocity spectra were fitted to Maxwellian distributions to derived the drift velocity and the peak phase space density. Combining these pairs resulted in the velocity distribution shown in Fig. 2.

A separate study of the relationship between ion outflow characteristics and solar wind inputs was carried out on data from the same CME event on 24 September 1998. A significant correlation between outflow intensity and deviations in the solar wind ram pressure has been found. Further study will center on the physical processes that transfer the solar wind inputs to the F-region plasma and produce the observed outflows. The observed heavy ion outflow is consistent with GMS parabolic trajectories (Fig. 3). Polar appears to travel nearly parallel to this parabolic trajectory for ~1 hr. (In fact, O^+ is observed within ~15 degrees of the spacecraft ram direction.) The change in parallel speed of the O^+ during the period from 0300 to 0430 UT (Figure 2) yields an acceleration consistent with that calculated for centrifugal acceleration (~.014 km s^{-2}). The effects of velocity-filtering are clearly evident and indicate a finite width source (~1000 km or ~6 degrees at 1.4Re) (Figure 4). After this period Polar moved across the parabolic trajectories and observed nearly the full outflow distributions of H+, He+ and O^+.

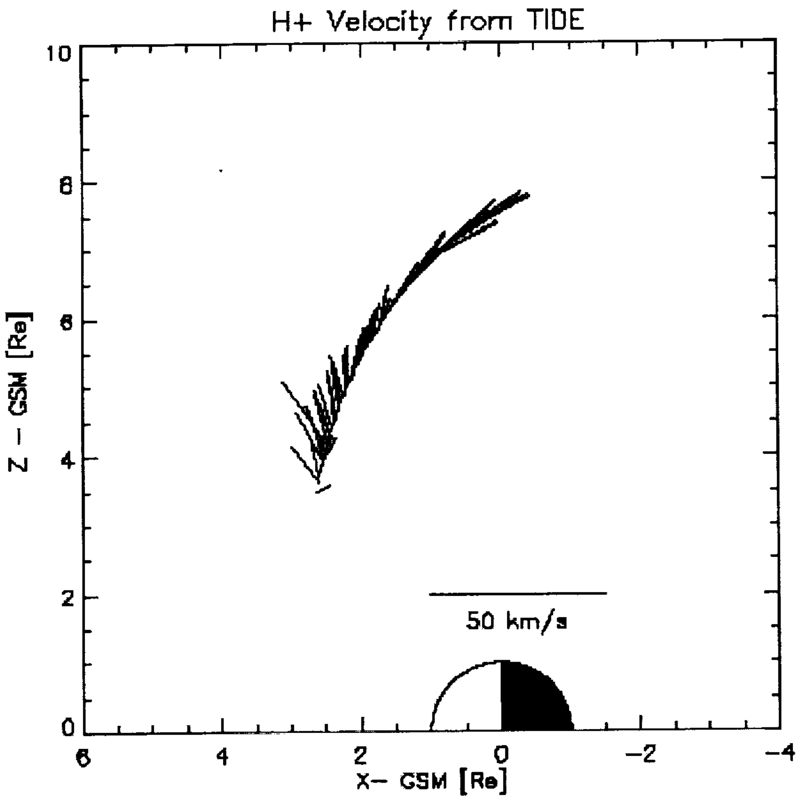

Figure 3 - Observed O+ velocity in the GSM x-z plane for 25 Sept. 1998 from 0230 - 0530 UT.

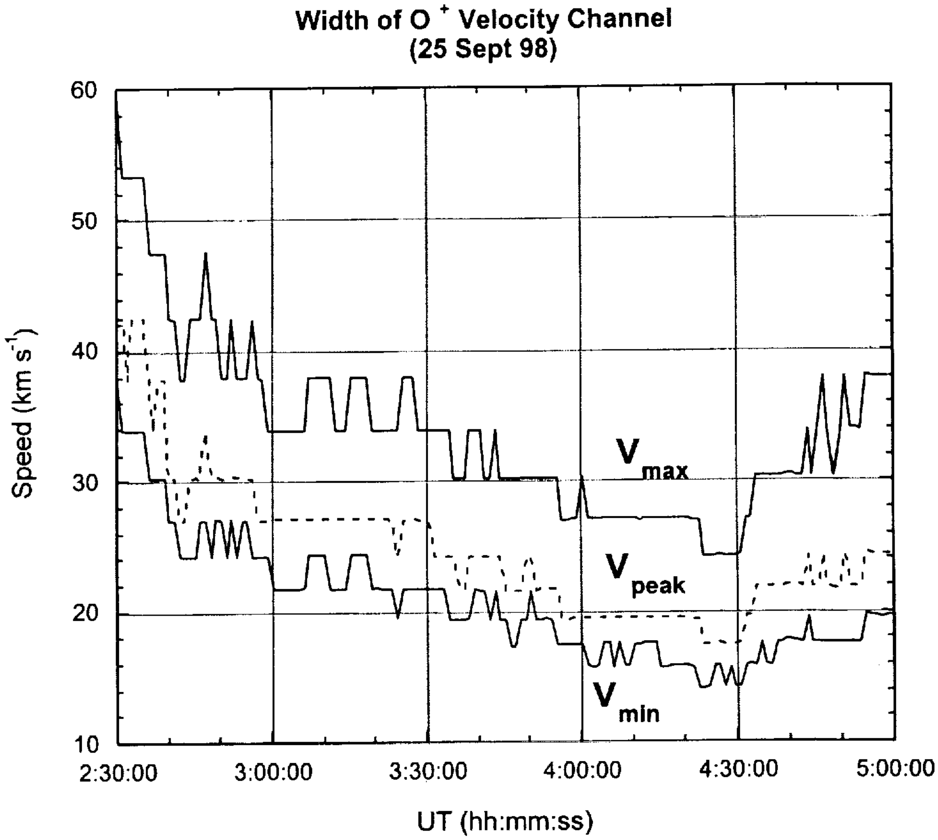

Figure 4 - Characteristics of the velocity filter effect on O^+ outflow. Shown are the maximum and minimum velocities observed and the location of the peak phase space density. The variation in Vpeak from ~0300UT to 0430UT is consistent with centrifugal acceleration. The variation from 0430UT to 0500UT is too large to result from centrifugal acceleration and is more likely to reflect the variation of outflow energization across the finite-width cleft source.

Studies have also been performed on ion characteristics at low altitudes. An example of such a pass is shown in Figure 5. Polar passed through the cusp/cleft region and observed energized conics of different temperatures in at least four distinct bands. The parameters derived from these distributions (Table 1) show different levels of heating and or cooling of the outflowing ions. The association with local broadband wave noise is clear in Figure 6, providing inputs for simulations of ion heating.

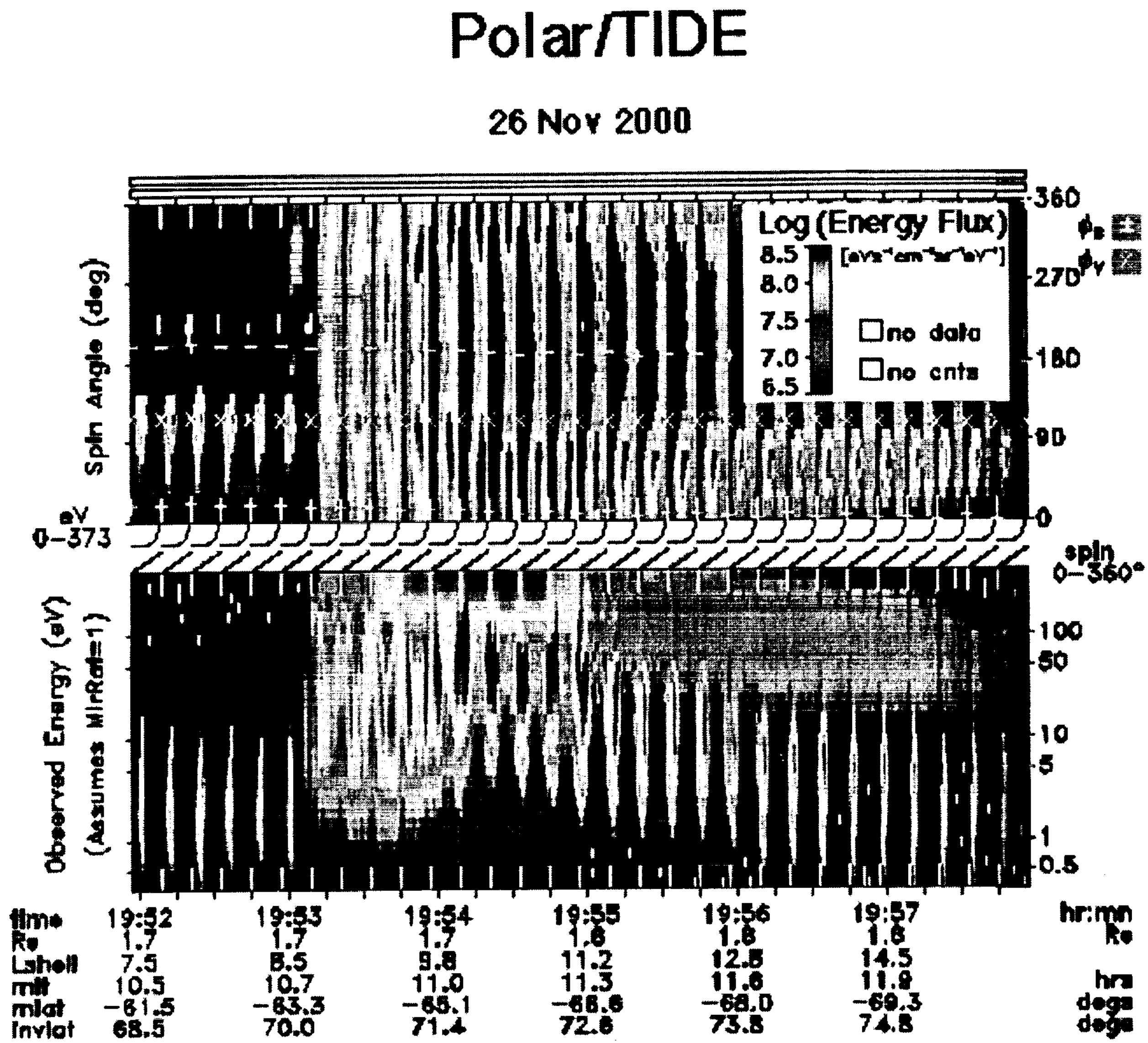

Figure 5 - Low altitude pass of Polar through and upwelling ion event.

O^+ Parameters for the Given Region

Region	B	C	D	E
Density (cm^{-3})	50	300	2	1
V_{para} ($km\ s^{-1}$)	5	10	6	3
V_{perp} ($km\ s^{-1}$)	1	5	5	4
kT_{para} (eV)	20	10	0.5	0.2
kT_{perp} (eV)	45	30	5	1.2

Table 1 - Ion parameters for the event shown in Fig. 5

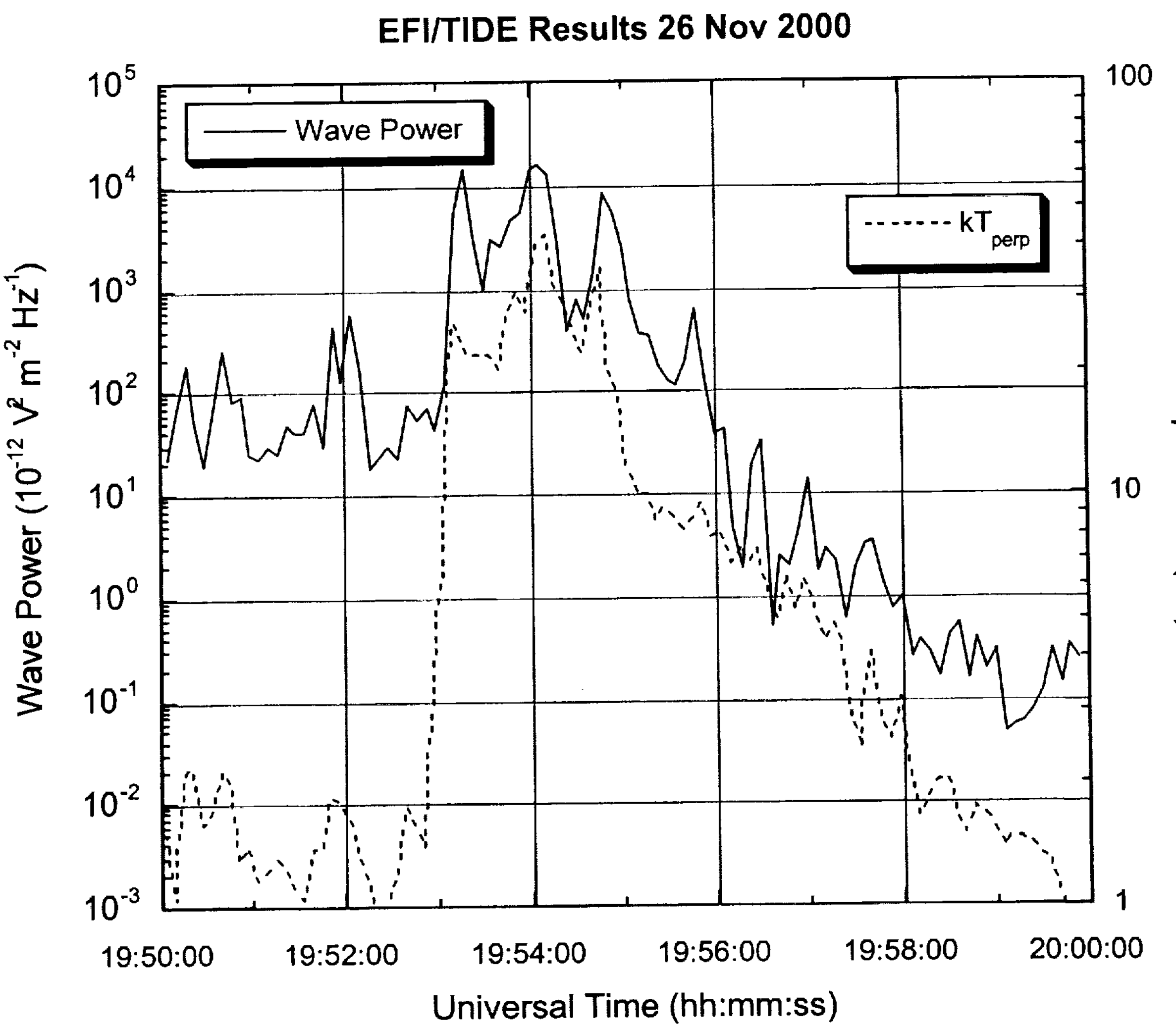

Figure 6 - Correlation of upwelling ion perpendicular temperature and low-frequency, broad-band wave power.

Close examination of the ion distribution functions (Figure 7) reveal the conic signatures. Through modeling of the instrument response it is possible to determine the degree of folding of the conic and estimate the altitude of the main heating. This example shows no noticeable folding implying local heating. A similar example, from June 2000, shows a magnetic field ratio of 0.6 which translates to a heating altitude of ~500 km (Fig. 8).

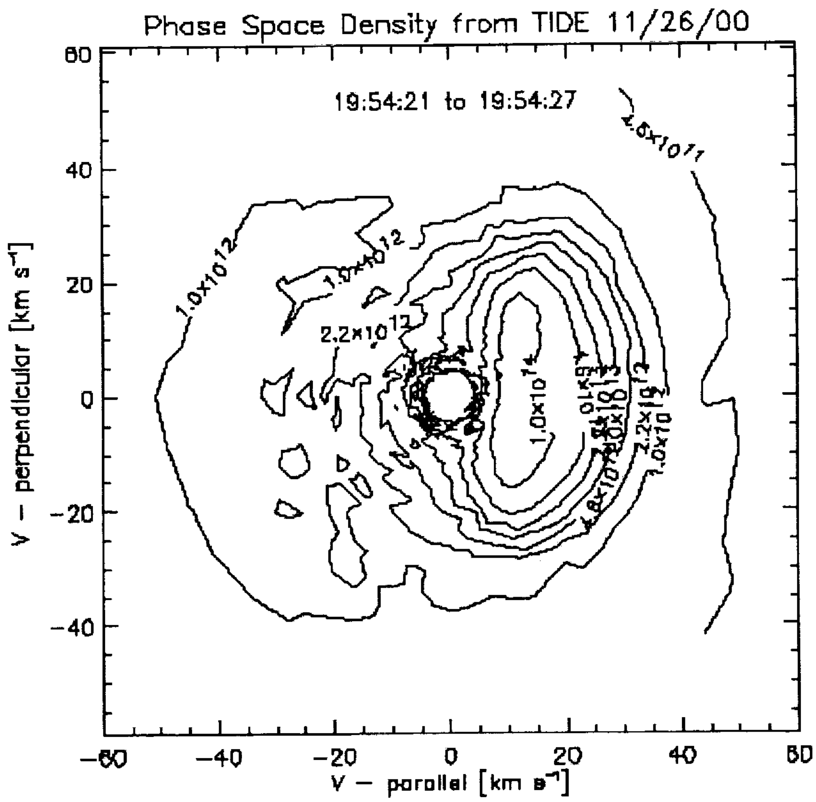

Figure 7 - Contours of phase space density in a plane parallel and perpendicular to the local magnetic field. Anisotropy is evident in the temperatures indicative of perpendicular heating.

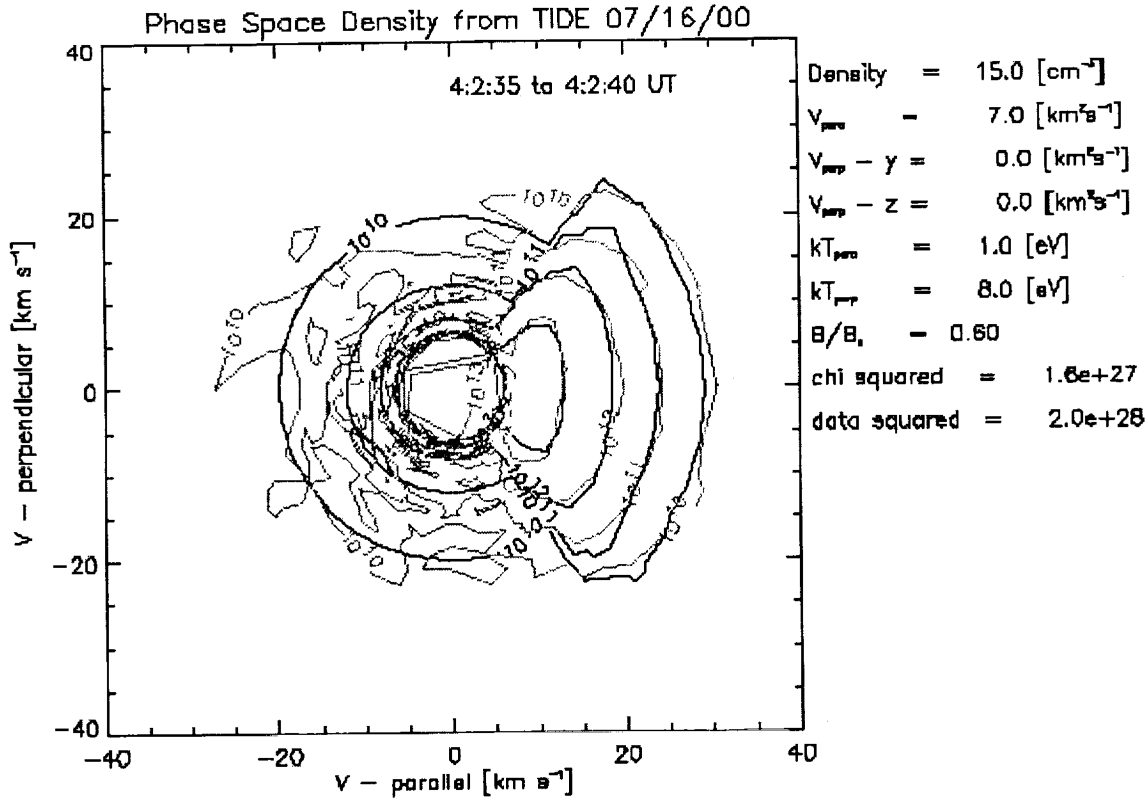

Figure 8 - Contours of phase space density in a plane parallel and perpendicular to the local magnetic field. Anisotropy is evident in the temperatures indicative of perpendicular heating. Folding indicates transport from a heating region well below the spacecraft.

A major goal for these studies is to provide velocity distributions for use in the kinetic model. Both the ion and electron velocity distributions derived from these ongoing studies will provide valuable inputs for the future modeling work.

Ion Outflow Modeling

A new time-dependent kinetic model of low-energy (thermal) ion outflow has been developed. It is an extension of our previous superthermal electron model [e.g., *Khazanov et al.*, 1993; *Khazanov and Liemohn*, 1995; *Liemohn et al.*, 1997], solving for the phase-space distribution function of a particular plasma species by directly solving the kinetic equation. The code now includes non-linear feedback processes in the Coulomb collision and ambipolar electric field terms. This type of transport model has not previously been used to calculate terrestrial thermal plasma motion, as the existing class of ion outflow models is primarily comprised of hydrodynamic and particle-tracking codes.

This new model has been used to study the effects of self-consistency and hot plasma influences on the early stages (few few hours) of plasmaspheric ion refilling [*Liemohn et al.*, 1999]. Of particular interest in this study was the influence of several processes on the source cone distribution function formation. The amount of material filling in this source cone region of velocity space (those velocity vectors that map directly to the ionospheres instead of mirroring in the plasmasphere) strongly influences the rate of the long-term refilling processes, because the efficiency of the late stage scattering depends on density of the scattering targets (that is, the thermal plasma being calculated by this model). It was found that a self-consistent ion temperature in the collision term can increase or decrease the equatorial plane density, depending not only on the choice of ion temperature in the static-background calculations but also on the form of the nonlinear representation.

Figure 1 shows equatorial density versus refilling time for a depleted L=4 field line. Note that the boundary and initial conditions are the same for all runs, and only the inclusion of various processes in the calculation is changing the resulting density. What this indicates is that self-consistent feedback must be rigorously included in the calculation of ion outflows in order to obtain the correct result. The inclusion of a self-consistent polarization electric field increases the early stage equatorial plane density by a factor of two. Figure 2 shows velocity space flux distributions of low-energy H^+ (0 to 12 eV) at several altitudes along a refilling L=4 field line. The left column of contour plots shows results without any self-consistent feedback in the calculation, while the right column shows results with self-consistent Coulomb collisions and electric field. Investigations of the effects of anisotropic hot plasma populations on the refilling rates shows that, after a slight initial decrease in equatorial density from clearing out the initial distribution, there is a 10 to 30% increase after 4 hours due to these populations. This increase is due primarily to a slowing of the refilling streams near the equator from the reversed electric field. This result is not intuitive, as it was expected that the hot ions near the equator would repel the outflowing thermal ions and thus decrease their equatorial density. However, the electric field resulting from the presence of these extra ions was not enough to overcome the thermal-plasma-generated potential drop along the field line, and thus only a small influence was detected.

Figure 1. Equatorial densities as a function of refilling time for an L=4 field line [*Liemohn et al.*, 1999]. The lines are defined with the following temperatures for the H+ "background population" in the Coulomb collision operator: solid, 0.3 eV constant isothermal; dotted, self-consistent, single fit; dashed, self-consistent, double fit; dash-dot, 0.5 eV constant isothermal; and dash-dot-dot-dot, 0.05 eV constant isothermal.

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Figure 2. Flux distribution functions at several spatial locations along an L=4 field line for simulations (left column) without any self-consistent processes included, and (right column) with both self-consistent Coulomb collisions and electric field. The contours are spaced 1.5 orders of magnitude apart, starting with the solid curve at 10^6 cm^{-2} s^{-1} eV^{-1} sr^{-1}. The velocities are given in km/s, and the dotted circle at the outer velocity indicates the upper energy boundary of the simulations.

The results in Fig. 3 show high-latitude ion density profiles with the inclusion of the ponderomotive force from Alfvén waves with various perpendicular electric fields. The two panels show results with low and high photoelectron concentrations at the base of the calculation (n_{p0}). Even for these very modest wave strengths, the influence on the outflowing oxygen ions can be dramatic, increasing the high-altitude density by orders of magnitude.

Papers published and presented which describe work fully or partially supported by Grant NASA-NAG5-6976:

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Khazanov, G. V., and M. W. Liemohn, Transport of photoelectrons in the nightside magnetosphere, *Journal of Geophysical Research*, in press, 2002.

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Elliott, H. A., R. H. Comfort, P. D. Craven, M. O. Chandler, and T. E. Moore, Solar wind influence on the oxygen content of ion outflow in the high-altitude polar cap during solar minimum conditions, J. Geophys. Res., 2000.

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Elliott, H. A., R. H. Comfort, P. D. Craven, M. O. Chandler, and T. E. Moore, Case study of solar wind and IMF influences on ionospheric outflow, Huntsville 2000 Workshop.

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