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Space Physics Guest Investigator

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Introduction

The outflow of ionospheric ions at high latitudes is an important component in the ionosphere-magnetosphere (I-M) coupling. A significant portion of the magnetospheric ions is from an ionospheric origin. The conventional wisdom is that the wave-particle interaction (WPI) is negligible outside the auroral regions. Therefor, in all the polar wind models developed so fat, this effect was neglected. However, a close study of the measured levels of the waves in the region above the polar cap indicate that the wave-particle interaction can play an important role in the behavior of the outflowing ions. A self consistent solution of the plasma and waves is beyond our current computational ability. A feasible alternative is to use the wave data from Plasma Wave Instrument aboard the DE-1 satellite. This data is introduced to an existing semi-kinetic code [e.g. *Barakat and Schunk, 1983*] using a Monte Carlo approach.

The objective of the research funded by the grant NAG5-1546 is to use the low-frequency wave spectrum measured by the Plasma Wave Instrument on the DE-1 spacecraft to include the WPI in the different polar wind models that are available at Utah State University. A Monte Carlo technique will be used to simulate the ion diffusion in the velocity space due to scattering by the waves. This will enable us to study the effect of WPI on the magnitude as well as the composition of the out flow of the ionospheric ions. In particular, in the first year the 1-D semi-kinetic code developed by *Barakat and schunk* (1983) will be modified in order to include the effect of the WPI. This code can help us answer questions such as: (1) Is the WPI enough to reduce the large temperature anisotropies predicted by the semi-kinetic model? (2) To what extent the ion velocity distribution and its moments are modified? etc...

A Ph.D. student was chosen to work on this project as part of his dissertation. We started the training of the student by gradual introduction of the different concepts that are needed to solve such problem (e.g. Monte Carlo technique, Semi-kinetic polar wind models). In the next two sections we present the concepts that the student was introduced to in order to be able to address the problem outlined above. The simulation of particle diffusion in velocity space is introduced in section 2, the general features of the Semi-kinetic model is given in section 3, and a survey of the data is presented in section 4. In section 5, the preliminary results of the code are presented, and the future plans are briefly discussed in section 6.

2. Diffusion in the Velocity Space

As we mentioned above the student was introduced to the basic concepts of the project in a gradual manner. In order to get experience in simulating ion diffusion in velocity space, he developed a Monte Carlo algorithm that simulates the effect of Coulomb collisions on the ion outflow in the polar wind. The effect of Coulomb collisions is similar to that of the WPI (form an algorithmic point of view) in that both of them can be represented by diffusion in the velocity space which can be simulated by a 'random walk' .

This model included the the effects of polarization electric field, gravitational forces, and the divergent geomagnetic field lines. It covered the collision dominated region, the collisionless region and the transition between the them. It was concluded that the transition region play an important role in determining the characteristics of the ion outflow. In this region, the gradient of drift velocity reaches a maximum, both the parallel and perpendicular temperatures maximize, the heat flow changes its sign, and the distribution function change in a rapid and complicated manner from Maxwellian (at the barosphere) to kidney shape (at the exosphere). A copy of this paper is enclosed.

3. Polar Wind Collisionless Model

The base for this work is the semi-kinetic model for the collisionless polar wind (exosphere) such as those developed by *barakat and Schunk* (1983). Understanding the code was an essential part of the student's training. He studied the code thoroughly in order to understand its algorithm. Then he ran the code for a given set of physical parameters ($T_e = T[O^+\} = T[H^+] = 3000$ K, $n[O^+] = 200$ cm^{-3}, $n[H^+] = 100$ cm^{-3}), and computed the potential energy Φ, the density n, the drift velocity u, the parallel and perpendicular temperatures ($T_{\parallel}$ and $T_{\perp}$), the parallel and perpenicular heat fluxes ($q^{\parallel}$ and $q^{\perp}$). A two folded objective was achieved by these runs. First, by reproducing the results given by *Barakat and Schunk* (1983), which can be used as a pinch mark to calibrate the new code. Second, the profile of Φ will be used as an input to the new (Monte Carlo) code.

4. Preliminary Data Study

As we pointed out earlier, the WPI results in a particle diffusion in the velocity space. During an interval of time Δt the particle perpendicular velocity is incremented by $\Delta v_{\perp}$ such that

$$<(\Delta v_{\perp})^2>= 2D'_{\perp}\Delta t$$

where $D'_{\perp}$ is given by

$$D'_{\perp}=\left(\frac{\eta q^2}{4m^2}\right)|E(\omega=\Omega_c)|^2$$

and where q and m are the ion charge and mass, respectively, Ω_c is the ion cyclotron frequency, andη is the proportion of the spectral density that corresponds to the left-polarized wave. $|E^2|$ is the spectral density of the wave.

A dimensional study of the above equations shows that the effect of WPI is significant if the normalized diffusion coefficient is of order of, or greater than unity ($D_\perp \geq 1$). Where $D_\perp$ [$\equiv r_0/v_{th}^3$ is the normalized diffusion coefficient , r_0 is the geocentric distance of the lower boundary, and v_{th} is ion thermal speed. A general literature survey was carried out in order to have a rough estimate of the significance of the WPI on the ion outflow. It was found that the normalized diffusion coefficient in the velocity space ($D_\perp$) ranges from 0.1 to 10. Therefor, we should expect that the WPI can have a significant effect on the ion outflow along the open geomagnetic field lines above the polar cap.

5. WPI Algorithm

After the student gained the necessary experience as explained above, he started to develop a Monte Carlo simulation for the polar wind ion outflow under the influence of the WPI. The range of simulation was taken high enough to neglect the effect of collisions. The electrostatic polarization field was taken from the results of the semi-kinetic code explained above. For simplicity, the value of $D_\perp$ was assumed to range from 0.01 to 10, and to be independent of altitude, latitude (provided that it is still in the polar cap), season, solar activity, and geomagnetic activity. This simplified approach should give us a rough idea about the magnitude as well as the nature of the effects of the WPI on the results.

In this first crack at the problem, we concentrated on the behavior of the H^+ ions. The main conclusions are:

1. At very weak WPI ($D_\perp \cong 0$), we reproduce the results of *Barakat and schunk* (1983).
2. Near the exobase (1.7 R_e), the shape of the H^+ velocity distribution is not affected by the WPI.

3. For higher altitudes ($\geq 5\ R_e$), the WPI reduces the anisotropy due to perpendicular heating. For relatively large values of WPI ($D_\perp \geq 0.1$), the heating due to WPI overcomes the adiabatic cooling, and hence, the ion perpendicular temperature increases with altitude near the top of the model.
4. The lower order moments (density and drift velocity) of H^+ ions are not very sensitive to WPI for moderate values of $D_\perp$ (≤ 1). For larger values of $D_\perp$ (≥ 1), the WPI can change these lower order moment in a quantitative, rather than qualitative, manner .(e.g. see fig. 1).
5. As the WPI becomes stronger, the ion perpendicular temperature increases especially at high altitudes. For strong enough WPI ($D_\perp > 1$), $T_\perp$ can become monotonically increasing(e.g. see fig. 2).
6. The parallel temperature decreases with $D_\perp$ for weak to moderate WPI ($D_\perp \leq 1$).For very strong WPI ($D_\perp >> 1$), the parallel temperature reaches a minimum and then increase very rapidly with altitude.

6. Future Plans

In the rest of the first year we plan to address the following points:

1. The behavior of the O^+ ions will be studied.
2. The resulting ion densities will be used to compute improved profiles for the polarization electric field, which in turn.will be used to compute new profiles of the ions densities. This iteration will be continued until we reach a consistent solution.
3. The code will be modified to be able to handle profiles of $D_\perp$ that are altitude dependent. The modified code will use more realistic profiles of $D_\perp$ (from measurements) to study the effect of altitude variation of $D_\perp$ on the results.

4. Finally if the time will permit, a larger data-base will be binned with respect to season and geomagnetic activity to investigate the dependance of the WPI strength on these two factors. Then the code will be used to study the effect of season and geomagnetic activity on the ion outflow characteristics.

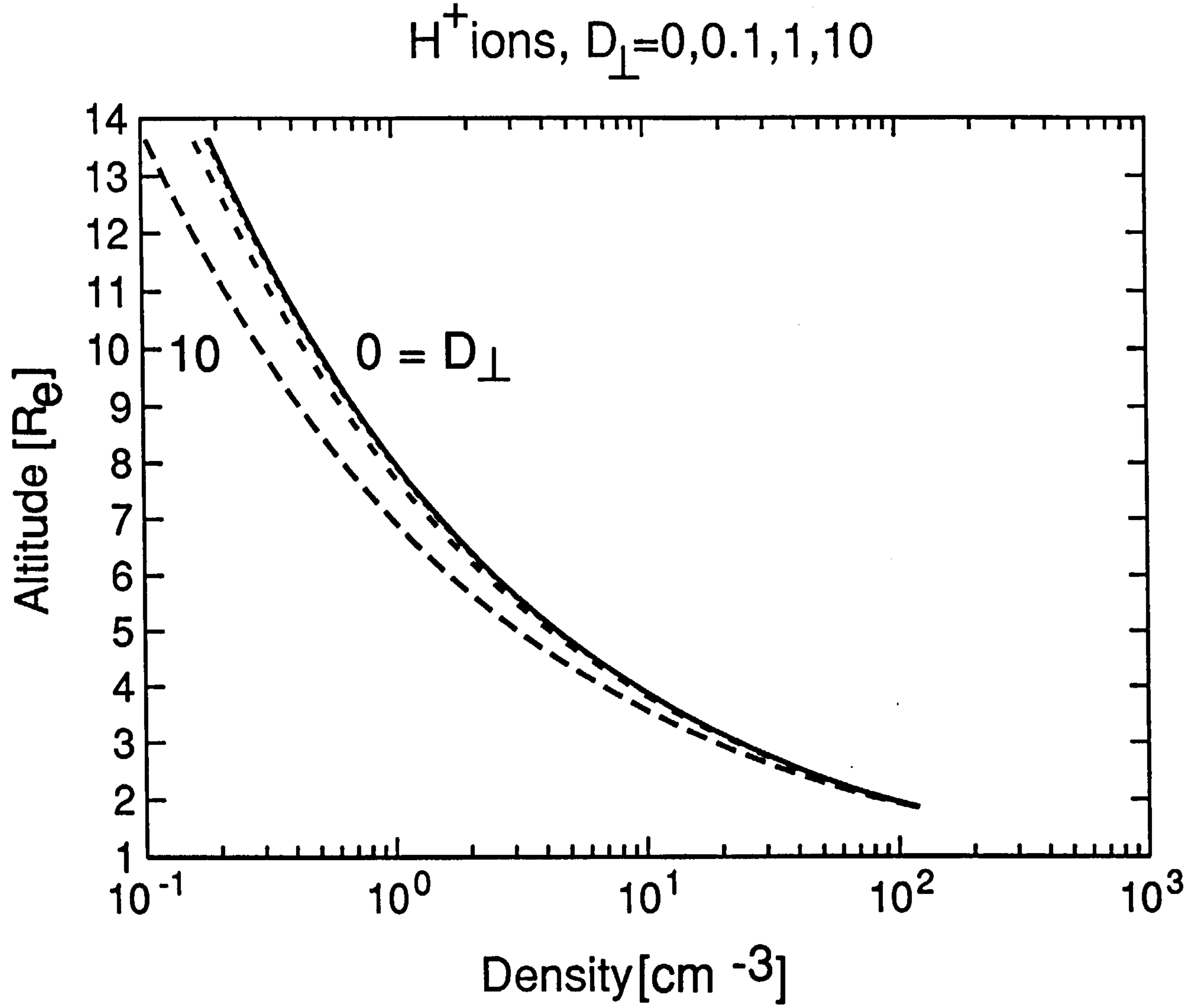

Figure 1. The effect of WPI on the H^+ density. The density profiles are given for different values of normalized diffusion coefficient in the velocity space [$D_\perp = 0, .1, 1,$ and 10].

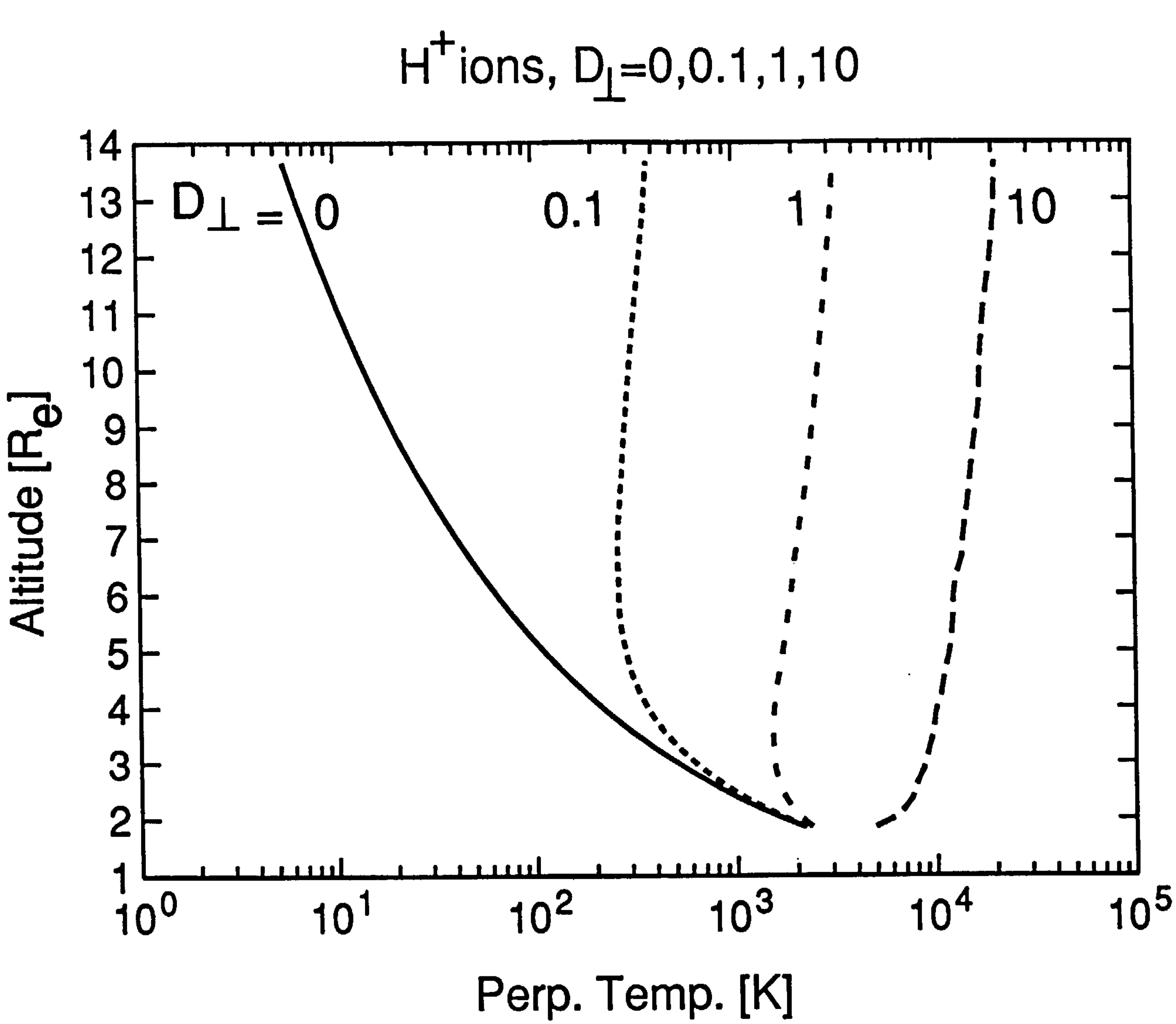

Figure 2. The effect of WPI on the H^+ perpendicular temperature. The temperature profiles are given for different values of normalized diffusion coefficient in the velocity space [$D_\perp = 0, 0.1, 1,$ and 10].