Comparison of Photoelectron Theory Against Observations

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Presented here are comparisons of a superthermal electron interhemispheric transport model with satellite data and previous transport model results. Good agreement is shown with the results of the two-stream superthermal electron transport model, as well as with other ionospheric calculations when the same assumptions have been applied. The concept of plasmaspheric transparency is considered, and a method of applying transparencies calculated by this model to ionospheric transport models is presented. Explicit comparisons are made with energy spectra from the Atmospheric Explorer E satellite and pitch angle distributions from the Dynamic Explorer 2 satellite. Implicit comparisons are made by examining the influence of superthermal electrons in the formation of observed thermal plasma quantities. This type of comparison is performed with Dynamic Explorer 1 and Akebono observations.

INTRODUCTION

This study tests the results of a time-dependent, interhemispheric transport model with observations and other superthermal electron transport models to see how well our results compare. This model [*Khazanov et al.,* 1993; *Khazanov and Liemohn,* 1995; *Liemohn and Khazanov,* 1995; *Liemohn et al.,* 1997] unifies the spatial regions of the ionosphere and magnetosphere into a single calculation scheme. The algorithm was developed to model superthermal electron fluxes without any restrictions on space or time in the calculation. It handles photoionization and impact ionization sources, elastic and inelastic scattering with atmospheric neutral particles, interactions with the thermal plasma, inhomogeneities in the geomagnetic field, and internally and externally imposed forces, such as the ambipolar electric field. This non-steady-state kinetic model has been used to investigate the role of superthermal electrons on plasmaspheric refilling, especially during the initial transient stages of the refilling process.

Recently, a driver program has been created that can combine this model with any thermal plasma model, and this approach was used by *Liemohn et al.* [1997] to self-consistently coupling collisional and electrodynamical interactions between the superthermal electrons and thermal plasma species. Collisional coupling between plasma species includes Coulomb interactions, and plays a dominant role in the ionosphere and along filled flux tubes. Electrodynamic coupling encompasses electric fields and potentials, as well as inclusion of the superthermal electron population in the quasineutrality current balance conditions, and often dominates in the collisionless regime, especially along depleted or open flux tubes. In that study, the kinetic model was coupled with the time-dependent, field-aligned, hydrodynamic thermal plasma model of *Guiter et al.* [1995] to examine the influence of electrodynamic coupling on plasmaspheric refilling.

The comparisons with models is limited to the ionosphere, because that is where most of the modeling efforts have been focused. The interhemispheric transport calculation of the present model, however, allows for the calculation of plasmaspheric transparencies. This is the fraction of particles that reach the topside of the conjugate ionosphere after transversing the plasmasphere, and was shown in *Khazanov and Liemohn* [1995] to be a complicated function of the atmospheric sources and scattering processes as well as the flux tube thermal plasma content. A method for using plasmaspheric transparencies calculated by the present model in ionospheric transport calculations is discussed.

Explicit data comparisons with Atmospheric Explorer E (AE-E) and Dynamics Explorer 2 (DE 2) data are limited to several cases: the local equilibrium region, the transition region, and the transport dominated region. The local equilibrium region contains those altitudes dominated by collisions, where local production and loss chemistry is the dominant factor in determining the distribution function. This region is typically located below about 200 km in the ionosphere. Above this is a transition region where plasma transport begins to have a significant role in the development of the distribution, while local effects are also still important. The third region is above this transition region, where the collisional scale lengths become larger than the transport scale lengths. In this region, motion of the particles along the field line is the major contributor to the formation of the distribution function. The transport-dominated region extends out into the magnetosphere, and, along closed field lines, connects to the ionospheric transition region of the conjugate hemisphere.

Implicit comparisons can also be made with satellite data, comparing observations of thermal plasma parameters with results from this model. The first is with DE 1 data during quiet times, when collisional effects should dominate, and the second is with Akebono data in the high-latitude region, where electrodynamic coupling should be the major interaction mechanism between the superthermal electrons and the thermal plasma.

COMPARISONS WITH OTHER MODELS

It is also useful to compare the results of this model with other commonly used methods of superthermal electron transport modeling for cases when certain restrictions to this model can be applied to match its results with previous calculations. *Cicerone et al.* [1973] performed a comparison among three quite different approaches: a diffusion equation formulation [*Nisbet*, 1968; *Swartz*, 1972]; a two-stream approximation of the general transport equation [*Nagy and Banks,* 1970]; and a Monte Carlo technique to simulate trajectories [*Cicerone and Bowhill,* 1970, 1971]. An updated version of the two-stream model is available and will be discussed later. Here, however, a comparison with published results is desired to show the closeness of the ionospheric models when they use identical input parameters. They give the atmospheric and ionospheric density distributions, so it is relatively easy to compare with results from this model. Figure 1 shows this comparison for the 0° solar zenith angle case of *Cicerone et al.* [1973]. The "net flux" quantity shown here is the net directional flux defined as

$$\begin{aligned}\phi_{NET}(s,E) &= \int_{\varphi=0}^{2\pi}\left[\int_{\theta=0}^{\pi}\phi(s,E,\theta)\cos\theta\sin\theta d\theta\right]d\varphi \\ &= 2\pi\int_{\mu=-1}^{1}\phi(s,E,\mu)\mu d\mu\end{aligned} \tag{1}$$

and represents a differential bulk flow of the photoelectrons. Here, ϕ is the differential flux of superthermal electrons, s is distance along the field line, E is kinetic energy, θ is pitch angle, φ is velocity azimuthal angle, and μ=cosθ. As in the earlier comparison, "N-S" refers to the diffusion equation formulation, "N-B" to the two-stream model, and "C-B" to the Monte Carlo technique. Two curves from our model are shown: one includes the plasmasphere and conjugate ionosphere; while the other has no downward flux from above 580 km. The latter case should be consistent with the assumptions of the other three models. While the results of the present model are close to the earlier model results below about 30 eV, they are somewhat different above this energy, although never by more than a factor of three. This is not unexpected, however, because the new model uses updated solar spectra and cross section information [from Dr. Solomon, private communication, 1994]. Without rewriting the cross section calculation of our code to match theirs (or vice versa), this is the closest comparison that can be presented with the *Cicerone et al.* [1973] results. A comparison with the multistream model of *Oran and Strickland* [1978] (such as that done by *Winningham et al.* [1989]) is underway and will be the subject of a future publication.

There is, however, another alternative for comparison with the two-stream model of *Nagy and Banks* [1970]. Our model uses the same solar spectrum and cross section calculations as Dr. Solomon's two-stream model, and so a direct comparison can be made between these models. Such a comparison is shown in Figure 2 for conditions similar to that of the *Cicerone et al.* [1973] study. Here, the IRI model [*Bilitza*, 1990] is used for the thermal plasma density, and the MSIS model [*Hedin*, 1991] is used for the neutral atmosphere profiles for day 178 of 1983 at L=2 (41° invariant latitude), which is a similar location in the solar and annual cycle to the previous comparison. The plots on the top are upward directional fluxes, and the plots on the bottom are downward directional fluxes,

$$\phi_{UP} = 2\pi\int_{\mu=0}^{1}\phi\mu d\mu \quad \text{and} \quad \phi_{DOWN} = 2\pi\int_{\mu=0}^{-1}\phi\mu d\mu \tag{2}$$

which, when subtracted, would yield the net flux quantity shown in Figure 1 ($\phi_{NET}=\phi_{UP}-\phi_{DOWN}$). The results for both models are for no downward flux above 580 km, making them single-ionosphere calculations. There appears to be close agreement between the two models, especially at low altitudes. Even at 580 km, the upward fluxes never differ by more than 20%. The downward results in Figure 2f arise from two sources: local photoionization and local backscattering, since there are no particles precipitating from above. Thus, this discrepancy is due to differences in the collision operators: the two-stream model uses backscatter probabilities; while the present model uses the Boltzmann equation for scattering with neutrals and the Fokker-Planck equation for scattering with the thermal plasma.

The absence of any downflowing superthermal electron flux, however, is highly unlikely on the dayside. Even if the conjugate ionosphere is in darkness, backscattering due to Coulomb scattering and elastic collisions with atmospheric neutrals will provide some amount of downflowing flux [*Khazanov and Liemohn,* 1995]. However, the two-stream model cannot account for the changing magnetic field and the trapping of particles along the flux tube, so simply extending this ionospheric model into the plasmasphere will produce unphysical results.

Plasmaspheric transport has been included in two-stream calculations through the use of a plasmaspheric transparency, *T(E)* [e.g., *Lejeune,* 1979]. There are several ways to define this quantity, so the first definition will be that of *Takahashi* [1973] as the ratio of particle fluxes precipitating into one ionosphere divided by the particle fluxes flowing out of the conjugate ionosphere,

$$T(E) = \frac{\int_0^1 \mu\phi\left(s_{2,top}, E, \mu\right) d\mu}{\int_0^1 \mu\phi\left(s_{1,top}, E, \mu\right) d\mu} \tag{3}$$

where $s_{1,top}$ is the location of the "top" of one ionosphere and $s_{2,top}$ is the altitude of the location of the "top" of the conjugate ionosphere. Note that this is not the probability of a single particle reaching the conjugate hemisphere, but rather is an attenuation factor such that the downward flux entering the conjugate ionosphere is equal to the upward flux leaving the first ionosphere multiplied by *T(E)*. Such a quantity can be used by an ionospheric transport model to parameterize the plasmaspheric processes, and a calculation in the conjugate ionosphere could then be conducted with a precipitating flux at the upper boundary.

Another definition for plasmaspheric transparency that could be used with ionospheric models is the ratio of the flux flowing down from the plasmasphere to the flux flowing up into the plasmasphere,

$$T^*(E) = \frac{\int_{-1}^0 \mu\phi\left(s_{1,top}, E, \mu\right) d\mu}{\int_0^1 \mu\phi\left(s_{1,top}, E, \mu\right) d\mu} \tag{4}$$

Notice that both integrals are at the same spatial location: the top of one of the ionospheres. $T^*(E)$ is an attenuation factor to obtain the flux entering an ionosphere given the flux leaving that same ionosphere. With this quantity, an ionospheric model can iterate to a solution in one ionosphere, without having to perform a calculation in the conjugate ionosphere.

Both of these quantities can be calculated with our interhemispheric model. Figure 3 shows two plasmaspheric transparencies for the same time as Figure 2, except the calculation is extended along the entire tilted dipole field line. The results are for a "filled" flux tube, when the thermal plasma density along the field line can be assumed to be proportional to the magnetic field [*Newberry et al.*, 1989]. Also, $s_{1,top}$ is taken in the northern ionosphere and $s_{2,top}$ in the southern ionosphere. The solid line shows $T(E)$ with both ionospheres illuminated (S. I. stands for "southern illumination"), while the dotted line shows $T(E)$ with the southern hemisphere source term artificially omitted. There is a difference between these two results at low energies. The features of these curves are due to many things, including the features of the photoelectron production spectra of both ionospheres as well as the scattering processes included in the plasmasphere and both ionospheres/thermospheres.

The transparency from (4) is also shown in Figure 3. The dashed line is $T^*(E)$ with southern hemisphere illumination, and the dash-dot-dot-dot line is $T^*(E)$ without this source included. There is quite a difference between these two lines. The only difference between $T(E)$ and $T^*(E)$ with southern illumination is because the photoelectron sources are not exactly symmetric due to the tilt of the dipole. The difference between these quantities without the southern source is drastic, since the numerator in (4) is produced only by backscattered electrons that started in the northern ionosphere. From these results, it can be concluded that the high-energy particles leaving the plasmasphere are primarily unhindered through the plasmasphere, with backscattering occurring in the conjugate ionosphere, while the low-energy electrons that leave the plasmasphere are mostly those backscattered in the plasmasphere and not from the conjugate ionosphere. Keep in mind that these results are for a filled L=2 flux tube, and will be different for other conditions.

These transparency results can now be used in the two-stream model. As mentioned above, these transparencies are dependent on the ionospheric and thermospheric processes, and so using these quantities with the two-stream model is not self-consistent. However, as seen in Figure 2c, the upward fluxes at 580 km for the two models are quite close, and so it is expected that the results will not be far from a self-consistent calculation.

Figure 4 shows results from such a calculation. Shown here are downward directional fluxes, similar to those shown in Figure 2f, using $T^*(E)$ from Figure 3 in the two-stream model to attenuate the outflowing fluxes for use as a precipitating upper boundary condition, and then iterating to a converged solution. Notice that the results of the two models are quite close, never differing by more than 30%. Also notice that all of these results are greater than either of the results plotted in Figure 2f.

This shows that a physical calculation of plasmaspheric and conjugate effects can be included in a single-ionosphere transport model by using an interhemispheric transport model to calculate the necessary parameters. Although the calculation is not self-consistent between the spatial regions, it can improve the accuracy of the results from the ionospheric model, especially in the transition and transport-dominated regions of the upper ionosphere. If only one calculation is required for a given set of ionospheric conditions, then the potential gain is not that big. However, if many calculations are needed for similar conditions, then a few results from a spatially-unified model could be used to enhance the accuracy of the ionospheric model's results.

COMPARISON WITH OBSERVATIONS

The true test of any numerical model, however, is how well it can reproduce observations and explain the processes occurring in the plasma responsible for the formation of the distribution functions. Since *in situ* measurements of superthermal electron distributions have primarily been conducted in the ionosphere, we will limit our presentation to the three ionospheric spatial regions mentioned above: the collision-dominated region, the transition region, and the transport-dominated region.

The Atmospheric Explorer satellites offer a plentiful supply of superthermal electron energy spectra. The electron spectrometers on the AE satellites are ideal for comparison because of the fine spectral resolution achieved in the low-energy range. Although the data is spin-averaged, this is not a big problem since the satellites flew through the low to middle ionosphere, where the distribution function is nearly isotropic. Figure 5 shows omnidirectional fluxes from the AE-E satellite and model results for similar conditions. The data in this plot is reproduced from *Doering et al.* [1976], for day 355 of 1975 at 182 and 365 km altitude. This first altitude is in the region where collisions with neutrals dominate the formation of the distribution function, and local production and loss mechanisms are the major processes in the calculation. The second altitude is in the transition region, where transport is starting to have a significant influence on the distribution. The solar zenith angles for the two spectra are 50˚ and 37˚, respectively. Since AE-E flew in a nearly equatorial orbit, the model comparisons are made at 0˚ geographic latitude, choosing an appropriate morningside local time with the given solar zenith (because the data collection occurred there, *Doering et al.* [1976]). As above, initial profiles for the thermal plasma are taken from the IRI model and atmospheric parameters are taken from the MSIS model.

In Figure 5a, the spectra agree closely for most of the energy range. The model predicts a slightly higher flux in the 5-15 eV range, but this difference is less than a factor of two. Figure 5b also shows good agreement, with the model predicting more definition in the 20-30 eV range and lower fluxes above 30 eV by a factor of less than two. These differences could be explained by uncertainties in the experimental data, differences in the neutral atmosphere or ionospheric plasma profiles, or uncertainties in the collisional cross sections used in the model. The larger fluxes at low energy and the increased definition of the production peaks in the model results indicate that the thermal plasma density from IRI is probably lower than the actual densities; a higher plasma density would act to smooth out these features of the distribution function. It is thought that this difference is not due to detector resolution, because $\Delta E/E$ was 2.5% and the production peaks clearly appear in the low altitude measurements. The comparison does show, however, that the model accurately calculates the main features of the photoelectron spectrum in the local equilibrium and transition regions of the ionosphere.

At higher altitudes, the pitch angle dependence of the distribution function becomes more important. This makes a comparison with AE data less informative in the upper ionosphere and plasmasphere. Therefore, a direct comparison with data for this region should be made with DE 2 results from the Low Altitude Plasma Instrument (LAPI). LAPI had less energy resolution than the AE electron spectrometers (with a $\Delta E/E$ of 32%), but had a much narrower field of view and allows for pitch angle distribution comparisons. Figure 6 shows this comparison for the 104th day of 1982 at a local time of 9.3 h and altitude of 690 km [data from R. E. Erlandson, private communication, 1994; error bars from *Winningham et al.*, 1989]. Note that the pitch angle distribution is defined by the data, with 0˚ being downstreaming particles and 180˚ being the upflowing electron fluxes. The distributions are shown at energies of (a) 5 eV, (b) 9 eV, (c) 15 eV, (d) 27 eV, and (e) 48 eV. Notice that the model compares reasonably well for most of the cases shown. There is quite a bit of disagreement in the 5 eV results, as well as part of the 9 eV results, but this could be due to spacecraft charging effects or other processes not included in the model. The trends in the data distributions of the other energies are reflected in the model results, and the magnitudes of the model results are not far from the measured values (within a factor of two).

The availability of superthermal electron velocity-space observations is quite limited outside the ionosphere, and so other methods of comparing results with data will be considered. These are indirect comparisons, where the influence of superthermal electrons on the thermal plasma is used to compare with measurements. Two examples of this will be presented here for the two limits of interaction between the superthermal electrons and the thermal plasma: Coulomb collisions only and electrodynamic coupling only. The topic of when to use either of these limits, or a combination of the two, is discussed in detail in *Liemohn and Khazanov* [1997].

One such comparison is shown through the calculations of *Newberry et al*. [1989]. In that study, a comparison was made between data from the retarding ion mass spectrometer (RIMS) on the DE 1 satellite and the Field Line Interhemispheric Plasma (FLIP) model during quiet times (when geomagnetic activity levels were low). The FLIP model solves hydrodynamic equations for the thermal plasma along a flux tube, combined with a superthermal electron two-stream transport model to calculate heating rates in the thermal plasma energy equations. This model includes a phenomenological factor (trapping factor) to represent the amount of energy lost to the plasmasphere from the photoelectrons. This factor is analogous to the transparencies discussed in the previous section. Without this trapping factor, the observed ion temperatures could not be reproduced, and it was concluded that good agreement is achieved between the calculated and measured ion temperatures when ~55% of the total photoelectron flux is trapped in the plasmasphere.

We conducted a similar study with our model and used the thermal electron profile in the ionosphere and plasmasphere from *Newberry et al*. [1989], and we found that the portion of energy absorbed in the plasmasphere due to Coulomb losses with the thermal plasma is 0.53. This shows that our calculations are in agreement with phenomenological modeling and measurements of the thermal structure of the plasmasphere during quiet times. The accuracy of the comparison also indicates that Coulomb interaction with the thermal plasma is the dominant process acting on the superthermal electrons in the plasmasphere where the data was collected.

Another indirect comparison can be made for the other coupling limit, when Coulomb collisions are expected to play a secondary role to electrodynamic interactions with the thermal plasma. This situation is expected in the plasmasphere during and after a geomagnetic disturbance, when the thermal plasma is depleted and the superthermal electrons will be a significant population. Another scenario is along open field lines, when the flow of superthermal electrons is unbalanced by flows from a conjugate source region and the thermal plasma cannot build up to the "filled" levels that were possible at lower latitudes. Data from the polar-orbiting satellite Akebono offers the opportunity for an indirect comparison at high-latitudes above the collisional ionosphere, where electrodynamic coupling would be expected to play a major role in the interactions between the thermal and superthermal plasma populations.

To compare model results with electron temperature measurements in the limit of electrodynamic coupling only, a slightly different method must be used: the model results are a two-part calculation. First, superthermal electron densities at 500 km are obtained from the numerical model used for the previous comparisons, assuming a polar cap latitude (75˚ up to 90˚) with photoionization as the primary source of superthermal electrons (i.e., no precipitating energetic electrons creating secondary superthermal electrons). Then an analytical solution to the collisionless, steady-state kinetic equation is used for the superthermal electrons and thermal ion calculation, which is combined with a fluid treatment for the thermal electrons. This yields a self-consistent calculation of the plasma along a field line that includes the electrostatic potential in the equations of all the plasma species. For details on the second part of this calculation, please see *Khazanov et al.* [1997]. The relative concentration of photoelectrons at the 500 km interface level, n_{p0}, varies with solar zenith angle and is thereforeanalogous to latitude (decreasing with increasing latitude).

Figure 7 shows such a comparison of this type of calculation with Akebono data from *Abe et al.* [1993]. The data is from April 28 and May 10, 1991, as the satellite passed from the dayside to the nightside at progressively higher altitudes. These two polar passes represent high and low geomagnetic activity (April and May, respectively). Data fluctuations were presumed to be latitudinal or local time variations in the ionospheric conditions. Shown with the data are three curves at different levels of n_{p0} (0.02%, 0.03%, and 0.06%), that were calculated using the *Khazanov and Liemohn* [1995] model for the conditions of an illuminated polar cap at various latitudes. Only those results are shown that cover the extent of the data, because the data was taken as the satellite crossed through the polar cap at a constantly changing altitude, latitude, and local time. This shows that the interaction between the superthermal electrons and thermal plasma through the electrostatic potential can produce electron temperatures comparable to observed values in the polar cap, where this is expected to be the dominant coupling mechanism.

DISCUSSION

We have shown that our kinetic, time-dependent, spatially-unified superthermal electron transport numerical model compares reasonably well with previous ionospheric transport models. When identical input parameters are used, this model compares very well with the two-stream kinetic model of *Nagy and Banks* [1970], even though our model includes pitch angle diffusion for the scattering terms and N-B uses backscatter probabilities. When plasmaspheric transparencies are used to obtain a realistic down-flowing flux at the upper boundary of the two-stream model, the two models are in even better agreement, especially in the upper ionosphere.

Plasmaspheric transparency can be defined several ways, and two such definitions have been shown and used in this study. With a plasmaspheric transparency calculated from a spatially-unified model such as ours, the accuracy of the results from a single-ionosphere model can be improved. It will not be a spatially self-consistent model, but if the boundary conditions do not change much between calculations, this type of calculation could be beneficial.

We also illustrated the ability of this model to reproduce superthermal electron observations. Comparisons with Atmospheric Explorer energy spectra were shown for the local equilibrium and transition regions of the ionosphere, and comparisons with Dynamic Explorer pitch angle distributions were shown in the upper ionosphere. There is good agreement is in each of these comparisons.

Finally, we showed that this model can be used to reproduce thermal plasma data, measuring the influence of the superthermal electrons on the thermal plasma through collisional and electrodynamic processes. Dynamic Explorer data was used to show this during low geomagnetic activity, and it was determined that Coulomb collisions are the primary interaction mechanism in the plasmasphere during quiescent times. A comparison with Akebono electron temperature data illustrated that electrodynamic coupling processes are dominant along polar cap field lines. The determination of when electrodynamic coupling plays an important role in the interaction between superthermal electrons and thermal plasma is discussed in *Liemohn and Khazanov* [1997].

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FIGURE CAPTIONS

Figure 1. Comparison of net directional fluxes for this model and three others from *Cicerone et al.* [1973]. Results are for the 0° solar zenith angle case at the top of the ionosphere (580 km) of the previous study, with no downward flux above this altitude (except for one case for this model, which includes plasmaspheric and conjugate effects).

Figure 2. Upward and downward fluxes for this model (solid lines) and an updated two-stream model (dotted lines) [S. C. Solomon, private communication, 1994] at various ionospheric altitudes. Results are for noon on day 178 of 1983 at 41° invariant latitude, with no downward fluxes above 580 km.

Figure 3. Plasmaspheric transparency versus energy from equations (3) and (4) for similar conditions to Figure 2, with $n_e \propto B$ in the plasmasphere, with and without conjugate hemisphere illumination.

Figure 4. Downward fluxes for this model and an updated two-stream model at 580 km, with and without conjugate hemisphere illumination. Results are analogous to Figure 2f, except plasmaspheric and conjugate effects are included in our model, and the transparencies in Figure 3 have been used in the two-stream results.

Figure 5. Comparison of model results (solid lines) with AE-E data (dashed lines) at (a) 182 km and (b) 365 km altitude on day 355 of 1975. The satellite data is reproduced from *Doering et al.* [1976].

Figure 6. Comparison of model results with DE 2 LAPI pitch angle distributions. Data courtesy of R. E. Erlandson [private communication, 1994].

Figure 7. Comparison of results for several values of n_{p0} with data from *Abe et al.* [1993], from April 28 and May 10, 1991.

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Figure 3. Plasmaspheric transparency versus energy from equations (3) and (4) for similar conditions to Figure 2, with $n_e \propto B$ in the plasmasphere, with and without conjugate hemisphere illumination.

Figure 4. Downward fluxes for this model and an updated two-stream model at 580 km, with and without conjugate hemisphere illumination. Results are analogous to Figure 2f, except plasmaspheric and conjugate effects are included in our model, and the transparencies in Figure 3 have been used in the two-stream results.

Figure 5. Comparison of model results (solid lines) with AE-E data (dashed lines) at (a) 182 km and (b) 365 km altitude on day 355 of 1975. The satellite data is reproduced from *Doering et al.* [1976].

Figure 6. Comparison of model results with DE 2 LAPI pitch angle distributions. Data courtesy of R. E. Erlandson [private communication, 1994].

Figure 7. Comparison of results for several values of n_{p0} with data from *Abe et al.* [1993], from April 28 and May 10, 1991.

FIGURE 1

File Name : C73comp.ps
Title : Graphics produced by IDL
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CreationDate : Wed Aug 27 18:09:32
Pages : 1

FIGURE 2

File Name : TScomp.ps
Title : Graphics produced by IDL
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CreationDate : Tue Dec 17 09:38:46 1996
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FIGURE 3

File Name : trans.ps
Title : Graphics produced by IDL
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FIGURE 4

File Name : TScomp2.ps
Title : Graphics produced by IDL
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CreationDate : Wed Aug 27 18:12:4
Pages : 1

FIGURE 5

File Name : G96_5.ps
Title : Graphics produced by IDL
Creator : IDL Version 4.0.1 (MacOS Pc
CreationDate : Wed Aug 27 18:19:0(
Pages : 1

FIGURE 6

File Name : G96DE2.ps
Title : Graphics produced by IDL
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CreationDate : Wed Jul 30 10:35:21 1997
Pages : 1

FIGURE 7

File Name : Abe93.ps
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