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# The Role of Ionospheric Plasma in the Magnetosphere

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## Model Studies

During the course of this project we have made a great deal of progress developing and using a new plasma modeling technique which we now refer to as the Generalized Semikinetic (GSK) model. It has been used to study the development of plasma flows in the plasmasphere, the polar cap and auroral zones and the transition region. Below we describe some of the major accomplishments of this grant.

### I. Plasmasphere

One of our graduate students (J. Lin) has been studying the outflow of ionospheric plasma during flux tube refilling — particularly the effects of wave particle heating and scattering of the ionospheric ions. Most of the ion heating, and some of the scattering, results from the interaction of these outflowing ions with a hot low density plasma assumed to be present in the outer plasmasphere when refilling starts. This plasma generates electromagnetic waves which can heat the ions perpendicular to the magnetic field as well as scatter them. We have shown that the combination of these two processes can enhance the rate at which plasma will accumulate in the outer plasmasphere [*Lin et al.*, 1991].

In late 1991 Dr. Wilson developed a method for including the effects of Coulomb self collisions into the semikinetic plasmasphere refilling model. Initial results for this model appeared in a '92 JGR paper [*Wilson et al.*, 1992]. This model was upgraded to include part of the processes occurring in the topside ionosphere. These include the charge exchange production and loss of $H^+$ as well as collisions between the Hydrogen ions and a static $O^+$ population. Studies using this model are eliciting the effects of ionospheric processes on plasmasphere refilling in the baseline refilling scheme (i.e. no wave-particle heating), and have served as a comparison to Lin's refilling studies which do include wave-particle interaction effects. One of the main results from this model is a theoretical estimate of the length of time needed for the ions in the refilling plasmasphere to obtain nearly isotropic velocity distributions [*Wilson et al.*, 1993]. We find that diurnal effects can significantly increase the refilling time and that counterstreaming beams can survive for over 30 hours on a L=4.5 flux tube. Even after the beams coalesce the ions remain highly anisotropic with the parallel temperature high than the perpendicular temperature.

Initially Lin's plasmasphere refilling model was fairly simple, since it ignored collisions and assumed that the electrons were isothermal and Boltzman distributed. During the course of this project the model was upgraded to include Coulomb collisions, multi-moment electron fluid description, and electron heating. Results from the upgraded model suggest that it will be fairly easy, with localized ion and electron heating near the magnetic equator, to set up potential structures which reflect ions away from the equatorial regions while still feeding ions to the trapped region. In *Lin et al.*, [1992] such potentials were included in an ad hoc fashion but the upgraded model [*Lin et al.*, 1993a,b] develops such potentials in a self-consistent fashion. Joyce has found in her studies that the amount of electron heat flow can have a dramatic effect on the results. If the heat flow is small and the electrons are heated in a localized region near the equator, large potential drops can occur near the equatorial region reflecting ionospheric ions back towards the ionosphere. She has also found that turning off the input plasma flow results in a trapped population which can persist for some time.

Much of this work has been recently summarized and discussed as a prototype for understanding the basics of magnetopshere-ionosphere coupling [*Horwitz et al.*, 1993b].

## II. Polar Wind

Much of the work in this area was done by one of our graduate students, C. W. Ho. In one of these studies [*Ho et al.*, 1991] we examined the temporal evolution of plasma on a flux tube which experiences a brief period of elevated electron temperatures which could result from energetic electron precipitation. This processes can generate $H^+$ and $O^+$ beams when the electron temperature is raised to 50000 K for a period of time that is short compared to the $O^+$ transport times. In another study [*Ho et al.*, 1992] we have examined the effects on an outflowing plasma of an imposed (nonself-consistent) electron temperature profile which increases with altitude. We have looked at various cases when the electron temperature increases over a short or long distance along the flux tube, when the upper boundary electron temperature is only slightly or very much above the ionospheric temperature, and when the electron temperature profile is controlled by heat conduction. In most cases we find some impediment of plasma outflow although for relatively low upper boundary electron temperatures the $O^+$ outflow is enhanced. This work is a more extensive study based on our previous efforts [*Wilson et al.*, 1990; *Ho et al.*, 1991].

Later Mr. Ho moved on to a study designed to compare the results of the semikinetic model and a generalized transport model used by Dr. Nagendra Singh [*Ho et al.*, 1993a,b]. Results showed that the time evolution of the flow of $H^+$ along open field lines is significantly different for the two models even when they start with identical initial conditions (as far as the moments are concerned). One of the major differences was the lack of steep gradients in the semikinetic results in regions where the generalized transport model produced shocks. Adjusting the heat flow in the generalized transport model helps to reduce, but not eliminate, these differences.

One small project pursued in late 1992 was a comparison of the steadystate density profile produced by a semikinetic model and the empirical electron density profile of [*Persoon et al.*, 1983]. It was found that when the *Chandler et al.* [1991] results were used as boundary conditions for the $H^+$ and $O^+$ densities at 4000 km that warm (9000 K electron; 5000 K ion) base temperatures were needed to get a good match. Under these conditions it was shown that $O^+$ would be the dominate ion up to a geocentric distance of 8 Re.

Recently we have examined the effect of the centrifugal force on polar outflow for flux tubes convecting across the polar cap [*Scarbro, et al.*, 1993]. We have found that for convection electric fields in the 25–75 mV/m range the outflow of $O^+$ ions is significantly enhanced with drift speeds in the 2–10 km/s range.

## III. Plasma Flows in the Auroral Zone

In most of the early work with our time-dependent semi-kinetic plasma model we have treated the electrons as a massless neutralizing fluid which was Boltzmann distributed and isothermal. In Ho's work discussed above, the isothermal restriction was dropped. Recently another of our graduate students (D. Brown) has developed an electron description code which treats the electrons as a streaming fluid. The code solves the continuity, momentum and parallel and perpendicular energy equations and uses semi-heuristic heat conductivities. It has been applied to study the effects of currents flowing along polar field lines and we were able to generate conics in a self-consistent fashion when we included wave particle perpendicular heating [*Brown et al.*, 1991]. The waves responsible for the heating are generated by the outflowing plasma itself when and where the model produces conditions necessary for the current driven instability to grow.

During much of this project D. Brown worked to develop a two species electron description which will allow us to include an energetic population from the magnetosphere in addition to a cool population from the ionosphere. In unrestricted form such a description would allow the determination of the electric field assuming some current level and an overall charge neutrality between the total ion and total electron density. This goal was not achieved but an intermediate methods was developed. The model includes the hot magnetospheric plasma population as a population in quasi-equilibrium, remaping both the electrons and ions to each point along the flux tube from an assumed distribution at the upper boundary. After doing this mapping the ionospheric ion particles are moved through a time step and the thermal electron bulk parameters are found again. This approach is not entirely self-consistent since each electron population is required to maintain charge neutrality with its respective ion population. Work continues to remove this restriction.

Dave Brown has been working with his coupled ionosphere-magnetosphere model studying the way outflow develops when the flux tube connects to a region containing hot plasma. He found that a "pressure cooker" develops where a downward electric field traps ions in a region where they are being perpendicularly heated by ion cyclotron waves. (This occurs when there is a significant difference between the hot ion and electron anisotropy.) The ions make a number of passes through the heating region until they gain enough energy to escape out the top of the flux tube. While this goes on the potential barrier to the upflowing ions is eroded by the low energy ionospheric plasma. Results of this study were presented at the 3rd Huntsville Magnetosphere/Ionosphere Plasma Models meeting and the 1992 AGU fall meeting.

## IV. The Transition Region

With the ability to include Coulomb collisions in the semikinetic model it was soon realized that the topside ionosphere-magnetosphere transition region (where the plasma goes from being collision dominated to collisionless) could be studied in a rigorous manner. Our first efforts in this area [*Wilson*, 1992] were to study the steadystate outflow of $H^+$ as it develops in the transition region where it is being accelerated by the strong ambipolar electric field set up by the steep $O^+$ density gradient. We found that the $H^+$ velocity distribution would depart significantly from Maxwellian, particularly in the region where the flow Mach number goes through 1. In this region the heat flow can be quite large and goes through a rapid shift from negative to positive values with increasing altitude. When subsonic outflow occurs the velocity distribution can have even greater departures from Maxwellian than in the supersonic case. The charge exchange production and loss of $H^+$ is also included in the model but did not alter the main results by much.

The transition region model has been upgraded to include the effects of ion-neutral collisions and ion production and loss. Currently the model is being applied to the low altitude region (200 – 1000 km) in a study of the response of $O^+$ to the effects of $\mathbf{E}\times\mathbf{B}$ drifts of from 1–5 km/s. Such drifts can produce a significant amount of $O^+$ heating and $O^+$ upflow. We are in the preliminary stages of comparing results of this model with DE-2 measurements made in this same altitude range. Last fall (September) an $O^+$ transition region model which ignored the effects of ion-neutral collisions (applied in the 500–3000 km altitude region) was used to study the type of upflows which develop when the low altitude temperature changes with time. At low altitudes a single distribution is present but at higher altitudes two distinct populations exist. Ion-neutral collisions at low altitude can produce toroidal velocity distributions which will produce enhanced $O^+$ upflows with speeds comparable to what is seen in radar data.

## V. Model Data Comparisons

As part of his dissertation, C. W. Ho has conducted a study of $O^+$ bulk parameters in the polar cap magnetosphere, as determined by the RIMS instrument. Although the data is somewhat sparse, he has been able to determine what typical $O^+$ densities, drift velocities and temperatures exist over the polar cap. These results, along with other data about the polar cap, have been compared to model results. As was discussed above in the polar wind section the $O^+$ model densities compare well with data when the topside ionosphere is assumed to have the densities reported by *Chandler et al.* [1991] and is fairly warm. Model $O^+$ velocities in the polar cap tend to fall below the data values unless the centrifugal force is included.

As part of her dissertation J. Lin has expanded her studies to include analysis of DE-1 RIMS data from near field-aligned equatorial crossings. She has tried to determine if the presence of equatorially trapped ions can indicate the degree to which parallel ion streams coming from the ionosphere will be reflected near the equator. Her results are not conclusive yet but it appears that the more anisotropic the trapped ions are the more readily will the field-aligned streams be reflected. Results of her modeling work and data analysis work were presented the summer (1992) Cambridge Geoplasmas meeting, the 3rd Huntsville Magnetosphere/Ionosphere Plasma Model meeting and the AGU fall meeting.

## Talks

Brown, D. G., J. L. Horwitz, G. R. Wilson, D. L. Gallagher, Effects of currents on polar plasma outflow: a time-dependent semi-kinetic description, presented at the AGU

Fall Meeting, San Francisco, CA, December 3–7, 1990.

Brown, D. G., G. R. Wilson, J. L. Horwitz, and D. L. Gallagher, A 'self-consistent' model of plasma heating and transport on auroral field lines, presented at the AGU Spring Meeting, Baltimore, MD, May 28–31, 1991.

Brown, D. G., G. R. Wilson and J. L. Horwitz, Synergism of magnetospheric particle anisotropies and wave heating in auroral ion beam formation and the "pressure cooker": A dynamic semikinetic model, presented at the 3rd Huntsville Workshop on Magnetosphere/Ionosphere Plasma Models, Guntersville, AL, October 5–8, 1992.

Brown, D. G., G. R. Wilson and J. L. Horwitz, Mesoscale auroral plasma transport (MAPT): Effects of magnetospheric populations and wave heating in a time-dependent semikinetic model, presented at the AGU Fall Meeting, San Francisco, CA, December 7–11, 1992.

Ho, C. W., J. L. Horwitz, N. Singh, and G. R. Wilson, Comparison of generalized transport and semikinetic model: Prediction for evolution of a density enhancement in the polar wind, presented at the 1992 Cambridge Workshop in Theoretical Geoplasma Physics, Cambridge MA, August 10–14 1992.

Ho, C. W., J. L. Horwitz, N. Singh and G. R. Wilson, Comparison of semikinetic and hydrodynamic models in the study of time-dependent phenomena in the polar wind, presented at the 3rd Huntsville Workshop on Magnetosphere/Ionosphere Plasma Models, Guntersville, AL, October 5–8, 1992.

Ho, C. W., J. L. Horwitz, R. H. Comfort, M. Loranc and M. O. Chandler, Statistical survey of $O^+$ bulk parameters in the midaltitude polar cap magnetosphere, presented at the AGU Fall Meeting, San Francisco, CA, December 7–11, 1992.

Ho, C. W., J. L. Horwitz, M. Loranc, and T. E. Moore, Characterization of core $O^+$ density, flow velocity and temperature in the 3–5 Re polar cap, presented at the AGU Spring Meeting, Baltimore, MD, May 24–28, 1993.

Horwitz, J. L., G. R. Wilson, J. Lin, D. G. Brown and C. W. Ho, Plasma transport in the ionosphere-magnetosphere system using semikinetic models, presented at the Rarefied Gas Dynamics Symposium #18, Vancover, BC, July, 1992.

Horwitz, J. L., G. R. Wilson, and N. Singh, Core plasma evolution on L=4–7 flux tubes: A starting point for understanding magnetosphere-ionosphere coupling, presented at the 1992 Cambridge Workshop in Theoretical Geoplasma Physics, Cambridge MA, August 10–14 1992.

Horwitz, J. L., J. Lin, D. G. Brown and G. R. Wilson, Core plasma evolution at L=4–7: Hemispheric "decoupling" by equatorial ion and electron heating, presented at the AGU Fall Meeting, San Francisco, CA, December 7–11, 1992.

Horwitz, J. L., G. R. Wilson, D. G. Brown, C. W. Ho, and J. Lin, Generalized semikinetic (GSK) models for space plasma transport, presented at the AGU Spring Meeting, Baltimore, MD, May 24–28, 1993.

Lin, J., J. L. Horwitz, G. R. Wilson, and D. G. Brown, Early stage plasmasphere refilling: Effects of spatial and temporal variations in ion and electron heating and

ionospheric inflow, presented at the 1992 Cambridge Workshop in Theoretical Geoplasma Physics, Cambridge MA, August 10–14 1992.

Lin, J., J. L. Horwitz, D. G. Brown, and G. R. Wilson, Hemispheric "decoupling" in plasmasphere refilling by equatorial ion and electron heating, presented at the 3rd Huntsville Workshop on Magnetosphere/Ionosphere Plasma Models, Guntersville, AL, October 5–8, 1992.

Lin, J., J. L. Horwitz, R. C. Olsen and B. L. Giles, Properties of the latitudinal transition from field-aligned to trapped core ions in the equatorial inner magnetosphere, presented at the AGU Fall Meeting, San Francisco, CA, December 7–11, 1992.

Lin, J. L., J. L. Horwitz, R. C. Olsen, C. J. Pollock, and D. L. Gallagher, Streaming/trapped ion interface in the equatorial inner magnetosphere, presented at the AGU Spring Meeting, Baltimore, MD, May 24–28, 1993.

Neergaard, L., J. L. Horwitz, R. H. Comfort, M. O. Chandler and P. C. Anderson, Plasmasphere-Ionosphere coupling: Ion heat fluxes and correlations among ion temperatures, composition and field-aligned flows from DE-1/2, presented at the AGU Fall Meeting, San Francisco, CA, December 7–11, 1992.

Wilson, G. R., The effects of Coulomb self collisions on the refilling of a plasmaspheric flux tube: A kinetic perspective, presented at the AGU Spring Meeting, Baltimore, MD, May 28–31, 1991.

Wilson, G. R., Semikinetic modeling of the topside ionosphere-magnetosphere transition region, presented at the AGU Fall Meeting, San Francisco, CA, December 9–13, 1991.

Wilson, G. R., J. L. Horwitz, J. Lin, Semikinetic modeling of plasma flow on outer plasmaspheric field lines, COSPAR 29th Plenary Session, Washington DC, 28 August–5 September, 1992.

Wilson, G. R., J. L. Horwitz, C. W. Ho, D. G. Brown, R. W. Schunk and A. R. Barakat, Recent theoretical progress in the study of the outflow of core plasma from the high latitude ionosphere, presented at the 3rd Huntsville Workshop on Magnetosphere/Ionosphere Plasma Models, Guntersville, AL, October 5–8, 1992.

Wilson, G. R., The outflow of $O^+$ through the topside transition region, presented at the 3rd Huntsville Workshop on Magnetosphere/Ionosphere Plasma Models, Guntersville, AL, October 5–8, 1992.

Wilson, G. R., N. Singh, and J. L. Horwitz, Comparison of hydrodynamic and semikinetic models for plasma flow along closed field lines, presented at the AGU Fall Meeting, San Francisco, CA, December 7–11, 1992.

Wilson, G. R., The generation of $O^+$ upflowing velocity distributions via $\mathbf{E}\times\mathbf{B}$ convection in the transition region, presented at the AGU Spring Meeting, Baltimore, MD, May 24–28, 1993.

## Papers

Brown, D. G., G. R. Wilson, J. L. Horwitz, and D. L. Gallagher, 'Self-consistent' production of ion conics on return current region auroral field lines: A time-dependent, semi-kinetic model, *Geophys. Res. Lett.*, *18*, 1841, 1991.

Ho, C. W., J. L. Horwitz, and G. R. Wilson, Effect of a sudden impulse in electron temperature on the polar wind: a time-dependent semi-kinetic model, in *Modeling Magnetospheric Plasma Processes*, ed. G. R. Wilson, AGU Geophys. Mono. # 62, pp. 105–110, 1991.

Ho, C. W., J. L. Horwitz, N. Singh, G. R. Wilson, and T. E. Moore, Effects of magnetospheric electrons on polar plasma outflow: A semi-kinetic model, *J. Geophys. Res.*, *97*, 8425, 1992.

Ho, C. W., J. L. Horwitz, N. Singh, and G. R. Wilson, Plasma expansion and evolution of density perturbations in the polar wind: Comparison of semikinetic and hydrodynamic models, *J. Geophys. Res.*, *98*, 13581, 1993a.

Ho, C. W., J. L. Horwitz, N. Singh and G. R. Wilson, Comparison of time-dependent semikinetic and hydrodynamic polar wind models: Initial polar wind expansion, density cavities and density enhancements, proceedings of the workshop on "*Controversial Issues and New Frontier Research in Geoplasmas*", in press 1993b.

Ho, C. W. and J. L. Horwitz, Warm $O^+$ polar wind and the DE-1 polar cap electron density profile, *Geophys. Res. Lett.*, *20*, 1715, 1993.

Horwitz, J. L., G. R. Wilson, J. Lin, D. G. Brown and C. W. Ho, Plasma transport in the ionosphere-magnetosphere system using semikinetic models, Proceedings of the 18th Rarefied Gas Dynamics Symposium, in press, 1993a.

Horwitz, J. L., G. R. Wilson, and N. Singh, Core plasma evolution on L=4–7 flux tubes: A starting point for understanding magnetosphere-ionosphere coupling, proceedings of the workshop on "*Controversial Issues and New Frontier Research in Geoplasmas*", in press, 1993b.

Lin, J., J. L. Horwitz, G. R. Wilson, and C. W. Ho, An early-stage plasmasphere refilling model based on a kinetic approach with trapping due to ion heating and pitch-angle scattering, in *Modeling Magnetospheric Plasma Processes*, ed. G. R. Wilson, AGU Geophys. Mono. # 62, pp. 151–156, 1991.

Lin, J., J. L. Horwitz, G. R. Wilson, C. W. Ho, and D. G. Brown, A semi-kinetic model for early stage plasmasphere refilling, 2: Effects of wave-particle interaction, *J. Geophys. Res.*, *97*, 1121, 1992.

Lin, J., J. L. Horwitz, G. R. Wilson and D. G. Brown, Early stage plasmasphere refilling: Effects of spatial and temporal variations in ion and electron heating and ionospheric inflow, proceedings of the workshop on "*Controversial Issues and New Frontier Research in Geoplasmas*", in press, 1993a.

Lin, J., J. L. Horwitz, G. R. Wilson and D. G. Brown, Equatorial heating and hemispheric decoupling effects of early L=4 core plasma evolution, *J. Geophys. Res.*, submitted 1993b.

Scarbro, H. D., C. W. Ho, J. L. Horwitz, G. R. Wilson, and T. E. Moore, Centrifugal acceleration of the polar wind, *J. Geophys. Res.*, submitted, 1993.

Wilson, G. R., C. W. Ho, J. L. Horwitz, and N. Singh, A new kinetic model for time dependent polar plasma outflow: Initial results, *Geophys. Res. Lett.*, *17*, 263, 1990.

Wilson, G. R., J. L. Horwitz, and J. Lin, A semikinetic model for early stage plasmasphere refilling, 1, Effects of Coulomb collisions, *J. Geophys. Res.*, *97*, 1109, 1992.

Wilson, G. R., Semikinetic modeling of the outflow of ionospheric plasma through the topside collisional to collisionless transition region, *J. Geophys. Res.*, *97*, 10551, 1992.

Wilson, G. R., J. L. Horwitz and J. Lin, Semikinetic modeling of plasma flow on outer plasmaspheric field lines, *Adv. Space Res.*, *13*, (4)107, 1993.