Aerospace Corp
P. O Box 92957
Los Angeles, Ca 90009

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FINAL REPORT

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P.I.: L. R. Lyons

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1. Magnetospheric Model

In order to develop a framework for evaluating auroral processes in terms of the large-scale magnetospheric electrodynamics, it is desirable to relate auroral phenomena to magnetospheric regions and boundaries, as well as to the convection pattern. A quantitative model of magnetospheric fields that is valid within auroral regions and the polar cap is needed for this purpose. The model should be able to relate the large-scale structure of magnetospheric electric fields in polar regions to the boundary Σ^* between open and closed magnetic field lines and to the IMF, and should thus be able to map structure in the large-scale electric field distribution to specific regions in the magnetosphere. Moreover, the model must be able to determine Σ^* accurately at ionospheric altitudes, and it must be able to map auroral and polar field lines to correct magnetospheric regions. However, the model need not be able to map field lines accurately from the polar cap and auroral zone to specific positions in space.

To obtain a realistic magnetospheric model we have successfully employed a new method, known as the source-surface method, to obtain a model for the Earth's magnetosphere, but so far we have neglected the penetration of the interplanetary field. A source surface is a surface on which either the normal or tangential component of magnetic field should ideally vanish. In

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our model, the source surface consists of the magnetopause and of a cross-magnetospheric surface that lies normal to the magnetic field in the tail. We connect a spherical-harmonic representation of the geomagnetic field in the volume surrounded by the source surface with a geometrical construction of the field lines in the tail. The component of the magnetic field normal to the magnetopause and the component of the magnetic field tangential to the cross-tail surface are minimized in a least-squares sense in this model. The model allows for any tilt angle.

2. Association Between Discrete Auroras and Ion Precipitation from the Tail Current Sheet

The model described above will gives us a theoretical framework for mapping auroral and polar cap field lines and for predicting convection patterns. We have also performed observational studies that help identify magnetospheric regions responsible for auroral phenomena.

Precipitating energetic ions contain potentially important information concerning their source. The ions have been observed to precipitate with isotropic pitch angle distributions at all local times and it has been suggested that the isotropic precipitation results from non-guiding center motion of particles in a current sheet, which effectively scatters the ions in pitch angle. Isotropy extends over all observable energies, as is expected from the current sheet motion.

An association between auroral arcs and energetic ion precipitation was initially reported using NOAA-6 observations. Now we have found that the regions of discrete aurora are almost exclusively confined to the region of isotropic ion precipitation at all local times studied. Energetic ($\geq$ 80 keV) ions were nearly always isotropic within the discrete auroral regions when their fluxes were sufficient to be observable. Additionally, the spatial association with isotropic ion precipitation was observed to nearly always extend to energies $\leq$ 3.9 keV, when deceleration by the $V_{\parallel}$ did not prohibit the $\leq$ 3.9 keV ions from being observable. This association between regions of discrete aurora and the ion precipitation is what is expected if field lines containing the aurora thread the tail current sheet at distances where ion motion significantly violates the guiding center approximation. This suggests that the generation of arcs occurs within the tail current sheet. On the other hand, no general association was determined between auroral arcs and isotropic energetic electron precipitation.

We have also found that throughout the local time interval studied, discrete auroras are generally associated with spatial structure and boundaries in the precipitating ions. This implies that arc generation may be associated with structure in the particle population within the tail current sheet. The data also occasionally show upward-going electrons, often associated with upward-going ion conics, that have been associated with downward going return currents. These return-current electrons bound regions of discrete arcs, and we find that they are also associated with the isotropic, structured ion precipitation. This suggests that both the upward field-aligned currents associated with arcs and nearby return currents both thread the tail current sheet.

The isotropic ion precipitation on the dayside extends to the highest observable energies as does the precipitation on the nightside, though the dayside precipitation is typically less intense and at higher invariant latitudes than is the nightside precipitation. Thus, the dayside precipitation, as well as the nightside precipitation, is of the form expected from nonguiding center motion in a current sheet. The only current sheet on the dayside of the magnetosphere is the magnetopause, which implies that the dayside ion precipitation results from ions which have interacted with the magnetopause current sheet. These ions must flow from the magnetopause towards the earth along field lines which penetrate the magnetopause.

3. Auroral Arc Scale Sizes and Structure

We have iniktiated an observational study of auroral arc latitudial scale sizes using precipitating electron data from a DMSP satellite. Our approach is based on applying time series analyses to the data. We have analyzed four passes of data containing polar cap arcs, and have found that the power as a function of wave number k varies approximately as k^{-1} for $1/k < 70$ km. This indicates significant power at latitudinal widths well below the inverted V width of ~ 100 km, thus demonstrating the need to understand the formation of the narrower arc structure. At wavelengths above 70 km, the power series were independent of k.

We have obtained a class of non-linear exact solutions of our auroral arc model. These solutions, while static, treat variations with respect to longitude, and they allow for sinusoidal ripples in the E-W direction as can result from KH instabilities. We have derived one non-linear solution that is marginally stable to KH and has E-W wavelengths on the order of the inverted-V latitudinal width. Shorter KH waves were found to be damped, while longer waves can grow.

4. Polar Cap Size Variation

It has been shown that the polar cap boundary varies, where the boundary has been inferred from observations of the poleward boundary of the auroral oval. For example, the midnight polar cap boundary has been observed to often lie above 70° latitude during quiet periods, but has been observed at latitudes < 60° during geomagnetic storms. Also, the area of the polar cap has been observed to increase and decrease during individual substorms, the poleward boundary of the aurora showing displacements as much as ~ 10°. Assuming the poleward boundary of the auroral zone is approximately coincident with the boundary between open and closed field lines, these observations imply that the boundary between open and closed field lines varies significantly with geomagnetic activity.

We have considered the fate of particles trapped on field lines near Σ^* as the polar cap expands. When trapped particles extend out to near Σ^* closed field lines containing trapped particles can become open as the polar cap expands. This will result in the escape of previously trapped particles along freshly open field lines. Such escape will result in tailward flowing electrons and ions of all energies along the outer boundary of the plasma sheet. The flow will continue beyond the far earth neutral line.

5. Low-Altitude Auroral Boundary

Changes in the size of the polar cap should be accompanied by changes in the convection $\underset{\sim}{E}$. These changes can have significant effects on particle trajectories in the magnetosphere. The low latitude auroral boundary can be thought of as the low-altitude manifestation of convection boundaries for magnetospheric particles of moderate energy, although the detailed shape of the boundary might be modified locally by spatial or temporal variations of precipitation rates. We presented the results of statistical analyses and case studies of the auroral boundary using precipitating particle data acquired by the NOAA spacecraft. The ability of standard convection models to account for the observed boundary characteristics was analyzed with emphasis on the roles of convection strength and time dependence. It was found that, within reasonable parameter limits, steady-state convection patterns for moderate energy electrons generally fail to account for certain observed characteristics of boundary shapes. Further, it was demonstrated that time-dependent transitions between various levels of activity can lead to characteristic boundary shapes that are quite dissimilar to steady-state solutions, and to some extent can provide a resolution between observed and computed boundary shapes for time scales pertinent to magnetospheric activity. The length of time after the onset of enhanced convection was found to be at least as important as the instantaneous level of activity as an ordering parameter for the shape of the low-latitude auroral boundary.

6. Auroral Wave-Particle Interactions

We have also analyzed the generation of plasma waves in auroral regions. It has been suggested that auroral Z-mode radiation is generated by cyclotron resonance with the accelerated auroral electrons responsible for discrete auroras. We have analyzed such generation of Z-mode radiation, and have suggested that resonance with accelerated auroral electrons is not required to account for Z-mode radiation at high altitudes (~ 2-5 R_e). We propose that the waves are generated by resonance with the electrons which form the diffuse aurora.

We investigated the generation of the broadband electrostatic noise which is observed to peak in intensity within the plasma sheet boundary layer. The instability due to single and double ion beams has been considered. We suggest that the two-beam instability is responsible for the peak in electrostatic noise within the plasma-sheet boundary layer. The two beams consist of the warm beaming ions of the form associated with the plasma sheet boundary layer and the much colder upgoing beams of ions accelerated from the ionosphere.

Third, we have investigated the role of ion conic damping of auroral hiss in forming ion harmonic frequency structure in auroral-zone waves. This work was extended to investigate electrostatic harmonic emissions due to positive gradients in ion velocity distributions.

An important aspect of magnetotail dynamics is understanding the source of the hot ion component of the central plasma sheet. Observations suggest that ions from the PSBL are scattered in pitch angle and energy, and that the scattered ions drift away from the boundary to form the central plasma sheet. A study has been performed to evaluate the scattering of boundary layer ions by the broadband electrostatic noise observed within the boundary layer.

The dispersion of the electrostatic waves is essentially unmagnetized. Thus, it was necessary to first derive general relations for ion diffusion from interactions with electrostatic waves having unmagnetized dispersion, but assuming that wave and particle distributions in space are organized by the geomagnetic field. General equations for diffusion in speed and pitch angle have been obtained, and they have been applied to calculate diffusion coefficient for boundary layer ions.

We found that the characteristic time for boundary layer ions to diffuse in energy and pitch angle is ~ 15 min, which is of the order of an ion bounce period. This is just the time scale for diffusion that is required to maintain an observable boundary layer, while still having the central plasma sheet formed from boundary layer ions. Significantly faster diffusion would smooth out the boundary ion distribution before its distinct feature could be detected, whereas significantly slower diffuse would not be sufficient to form the central plasma sheet.

7. Thermospheric Interactions

The major thermospheric model we have employed is a sophisticated two-dimensional numerical model. This model has sufficiently high spatial resolution to study the thermospheric response to the energy input associated with specific auroral features. The model is time-dependent and describes nonlinear, nonhydrostatic, viscous flow in a rotating planar atmosphere. Composition-dependent quantities such as the mean gas constant and specific heats are prescribed functions of altitude. This high-resolution model is designed to perform simulations over a limited area. Therefore, boundary conditions are employed which prevent fast moving waves from reflecting back into the domain of interest and contaminating the solution.

Our model differes significantly from other sophisticated, time-dependent high-resolution models in that these models use pressure coordinates, and are necessarily hydrostatic, while our model employs geometric height coordinates and is nonhydrostatic. Hydrostatic models are inappropriate for simulating the initial response to the sudden onset of forcing or for simulating forced convection associated with small-scale (width $\lesssim$ 50 km) auroral features.

The neutral response to changes in the energy source associated with the appearance of a symmetric, stable, discrete auroral arc was simulated using our sophisticated two-dimensional numerical model. The simulation was carried out for an interval of 1 hour after the onset of the changed forcing, and the bottom panel of Figure 8 shows the zonal winds after 1 hour as an example of the simulation results. The main findings of our study were (1) the zonal ion-drag force drives strong (~ 200 m/s) counterstreaming zonal winds on opposite sides of the arc, and this flow is Kelvin-Helmholtz unstable; (2) the zonal flow within the arc is accelerated to ~ 40% of the electric-field drift velocity in the region of high Pedersen conductivity; (3) the nonhydrostatic interplay of buoyancy and vertical pressure gradient forces sets up a large-scale buoyancy-like oscillation; (4) the adiabatic circulation driven by the meridional ion-drag force contributes to a net cooling in the lower region of the arc during the first half of the simulation; and (5) forced convection within the arc resembles convection due to particle heating alone, but particle heating contributed only ~ 25% of the net warming.

We analyzed the feedback between neutral atmospheric winds and the electrodynamics of a stable, discrete auroral arc (Lyons and Walterscheid, 1986). We solved simultaneously, as a function of time, the ionospheric current continuity equation and the equation for neutral gas acceleration by ion drag. Our results showed that, in general, the electric field in the ionosphere adjusts to neutral wind acceleration so as to maintain an approximately constant electric field in the frame of reference of the neutral. This keeps auroral field-aligned currents and electron acceleration approximately independent of time. We thus concluded that the neutral winds that develop as a result of the electrodynamical forcing associated with an arc do not significantly affect the intensity of the arc.

Our model has also been used to simulate the neutral response to an idealized representation of an intense, post-midnight, diffuse aurora. The results show the formation of an E-region "jet stream" within the aurora, with peak wind speeds > 700 m/s. We propose that this jet stream produces unstable Kelvin-Helmholtz waves, which can drive waves of converging Pedersen current along the poleward boundary of the preexisting diffuse aurora. The converging Pedersen current can drive upward field-aligned currents which are sufficiently intense to require significant field-aligned potential drops and thus form discrete auroras. We suggest that these currents, driven by the unstable neutral winds, form eastward propagating waves of aurora (omega bands) that are occasionally observed along the poleward boundary of post-midnight diffuse auroras. We also find neutral wind shears that develop in response to discrete auroral arcs to be unstable; however, we do not expect the resulting wind waves to drive significant auroral waves along discrete arcs.

8. The Neutral Wind "Flywheel"

Using published results from the NCAR thermospheric model we have evaluated ionospheric and field-aligned currents generated by the neutral wind flywheel which results from ion drag driven by magnetospheric convection. The neutral wind pattern over the summer polar cap can be driven by plasma convection to resemble the convection pattern. For a north-south component of the interplanetary magnetic field (B_z) directed southward, the wind speeds in the conducting E-region can become ~ 25% of the electric field drift speeds. If convection ceases, this neutral wind distribution can drive a significant polar cap current system for ~ 6 hours. The currents are reversed from those driven by the electric fields for southward B_z, and the Hall and field-aligned components of the current system resemble those observed during periods of northward B_z.

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