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Final Technical Report on NASA Grant
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The project period extended from June 1989 to November 1991. During this period, I both collaborated on a number of projects, and worked on a number of individual problems of my own initiative.

I have collaborated with colleagues at the Geophysical Institute in the analysis of the results of metal vapor injection experiments in space. This involved developing a code that computes expected images of the neutral and ionized vapor cloud, given velocity distribution of injected neutrals, magnetic field direction and ionization rate. In particular in a collaborative effort with Wescott et al., the code was used to infer the ionization rate of strontium in a shaped charge injection event. In another example, version of the code was used by Tom Hallinan and his student to analyze color TV camera coverage of Heppner's shaped charge injection experiments at Churchill for anomalous ionization.

The same type of coding has been used to compute synthetic images of the ring current and plasma sheet in the scattered sunlight of the 835 A line of ionized oxygen. I made the program available to a graduate student, Dante Garrido, who extended the code to include effects of Doppler broadening and Doppler shift due to finite temperature and plasma flow. The objective of this project is to evaluate the feasibility of global imaging of the magnetosphere.

A number of years ago, I developed an electromagnetic particle code to model reconnection processes. This code was made available to a graduate student, D.-Q. Ding. I collaborated with Mr. Ding to modify the boundary conditions suitable for investigating driven reconnection.

A major project of my own initiative was the development of a multispecies fluid code to model the ejection of plasma from the polar cap and cusp ionosphere. The high-latitude ionosphere appears to be the major source of plasma populating the plasma sheet. The objective was to understand the ejection and transport process from the polar ionosphere to the plasma sheet. In particular, it was hoped the model would help us understand the ejection of $O^+$ plasma. An innovative feature of the code was that the simulation domain consisted of a moving magnetic flux tube that extended from the 100 km level in the ionosphere to the equatorial plane. The inertial forces, including the centrifugal force, associated with a moving flux tube were incorporated into the momentum equation The mass conservation and entropy transport equations also had time-dependent scale factors. The results showed the escape of hydrogen plasma when a dayside flux tube opened out into the polar cap. The centrifugal force doubled the escape velocity. However, the code was unable to account for the escape of $O^+$, unless there were some extraordinary process to heat the $O^+$ plasma to the point it had a scale height comparable to that of the $H^+$.

Another major project has been an investigation of the process responsible for the Birkeland currents associated with the aurora. For east-west aligned auroral arcs, these currents circulate in the meridian plane. These currents cannot be accounted for by diversion of the dawn-to-dusk plasma sheet currents. A 2½-D electromagnetic particle code was used to simulate the plasma sheet and surrounding lobe region. The simulation showed the generation of

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current circulation extending upward and downward from the plasma sheet to the plasma boundaries. The currents are a consequence of the differential motion between ions and electrons due the the partial demagnetization of the ions in the region of high line field curvature. There are two necessary conditions for this process to occur: (1) the presence of a convection electric field and (2) the continued supply of plasma on lobe field lines. These two conditions are met at the beginning of the substorm expansive phase. The transit time of ions between the polar ionosphere and the plasma sheet is consistent with the duration of the substorm growth phase. The simulation results suggest that the substorm expansive phase may coincide with the impact of ionospheric plasma from the cusp and polar cap onto the plasma sheet.

The simulation described above provided a possible explanation of the Birekland currents. However, as the simulations showed little indication of a field-aligned potential drop, they did little to answer the question of how auroral electrons are accelerated. Many theories of auroral acceleration require the presence of a field-aligned potential drop. However, most attempts to model a field-aligned potential drop have considered such a potential structure in isolation and usually in a setting of a constant magnetic field. A new attempt was made to model a current-carrying magnetic flux tube on a more global scale using an implicit electrostatic code. A flux tube in the magnetosphere was simulated by assuming the two ends to be populated by a dense, cold, gravitationally bound plasma representing the ionosphere. The center of the domain contained a hot, magnetically trapped population, with a thermal energy considerably in excess of the gravitational potential energy. A current was driven by applying a potential difference between the two ends of the simulation domain. The model showed entirely different evolutions, depending on the ratio of the potential difference to the trapped particle energy. When the potential difference is <u>greater</u> than the thermal energy, all of the potential drop becomes concentrated in a single double layer that forms just above the ionosphere on the cathode end of the simulation domain. All of the electron acceleration is in the upward direction and concentrated in this region. Current limitation is by electron inertia in a region of density minimum that forms at the double layer. This result is at extreme variance with the observed fact that auroral electrons are accelerated downward on the anode end. When the potential is <u>less</u> than the energy of the trapped ions, no double layer forms. Instead, the potential drop is spread across the region extending from the equatorial plane to the ionosphere at the anode end. The current is limited by the magnetic mirror force on the trapped particles. Also, the plasma density decreases in the region above the ionosphere on the anode end. This is consistent with the observed density depletion above the ionosphere on auroral magnetic field lines. The general conclusion is that potential differences along auroral field lines do not exceed the energies of trapped particles and that some mechanism additional to any field-aligned potential drop is needed to explain auroral electron acceleration.

The primary methodology during the grant period has been the use of micro or meso-scale simulations to address specific questions concerning magnetospheric processes related to the aurora and substorm morphology. This approach, while useful in providing some answers, has its limitations. Many of the problems relating to the magnetosphere are inherently global and and kinetic. Effort during the last year of the grant period has increasingly focused on development of a global-scale hybrid code to model the entire, coupled magnetosheath-magnetosphere-ionosphere system. In particular, numerical procedures for curvilinear coordinate generation and exactly conservative differencing schemes for hybrid codes in curvilinear coordinates have been developed. The new computer algorithms and the massively parallel computer architectures now make this global code a feasible proposition. The Grand Challenges, HPCC program holds the promise of providing sufficient resources to carry out his ambitious program. We have entered into a consortium to develop such a code. Support provided by this project has played an important role in laying the groundwork for the eventual development of a global-scale code to model and forecast magnetospheric weather.

List of Publications Supported by NAGW 1787

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