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Three papers that were supported by NAGW-1625 were published during the past two years, and a fourth has been accepted for publication in the Journal of Geophysical Research. The following sections describe the principal results contained in each of these studies. Copies of each reprint and of the preprint are attached.

Mapping and Energization in the Magnetotail. 1. Magnetospheric Boundaries, R. L. Kaufmann, D. J. Larson, P. Beidl, and C. Lu, *J. Geophys. Res.*, *98*, 9307-9320, 1993.

This project involved mapping structures from the equatorial plane to the ionosphere. Magnetospheric boundaries, electric fields, electric equipotentials, and regions characterized by distinct magnetotail ion orbits all were projected along magnetic field lines. The *Tsyganenko* [1989] or T89 magnetosphere model was used. We found several problems with this model. The flanks are not adequately represented. The equatorial geocentric solar magnetospheric magnetic field B_{zo} drops abruptly near $|y| = 25\ R_E$. All field lines beyond $|x| = 10$ to $15\ R_E$ with positive B_{zo} map to the Earth in the $Kp \geq 1$ versions of T89. We therefore did not base any of our conclusions on such regions. The midnight region of the $Kp = 0$ model also was avoided because B_{zo} is unrealistically small.

One conclusion was that all the realistic field lines that passed within $3\ R_E$ of the magnetopause mapped to the day side ionosphere. Night side field lines that are associated with the principal current diversion process mapped to portions of the plasma sheet that are well separated from the flowing solar plasma. We generated maps of the projection of the well-known magnetospheric regions to the ionosphere.

The plasma sheet then was divided into regions according to the class of orbit that is followed by energetic ions and electrons. The most important non-guiding-center regions are described below. Boundaries between the orbital regions were projected to the ionosphere. Regions populated by ions on simple resonant orbits formed east-west bands separated by approximately 100 km. We concluded that it may be possible to use low and middle altitude satellite data to identify field lines on which ions have resonances in the equatorial plane. The important property of resonant orbits is that ions pass through the equatorial current sheet with almost no change in pitch angle. The pitch angle changes are so small that the loss cone is not filled when ions in a several-hundred-eV band pass through the equatorial current sheet. We therefore predict that very narrow energy band loss cone structures may be seen in downgoing ion fluxes. If such structures can be measured, it will be possible to determine the equatorial factor $B_{zo}(L/B_{xo})^{1/2}$, where B_{zo} is the equatorial field, B_{xo} is the earthward field component just outside the current sheet, and L is the current sheet thickness.

Mapping and Energization in the Magnetotail. 2. Particle Acceleration, R. L. Kaufmann, D. J. Larson, and C. Lu, *J. Geophys. Res.*, *98*, 9321-9333, 1993.

If accurate models of both the **B** and **E** fields were known, then it would be possible to calculate the rate at which charged particles gain energy everywhere in the magnetosphere. Through Ampere's law, $\nabla \times \mathbf{B} = \mu_o \mathbf{j}$ for steady-state conditions. As a result, a complete knowledge of **B** is equivalent to a complete knowledge of the distribution of steady electric currents throughout the magnetosphere. Since particles are energized at the rate $\mathbf{j} \cdot \mathbf{E}$, a good electric field model also is required to calculate the volume energization rate. An **E**-field model that is as reliable as the T89 **B**-field model is not available. We therefore projected one of the *Heppner and Maynard* [1987] ionospheric electric field models to the plasma sheet in order to calculate energization rates. We concluded that the resulting combined model is not sufficiently accurate to provide a reliable estimate of the volume energization rate throughout the plasma sheet. However, energization rates integrated through the thickness of the plasma sheet and average energization rates per R_E of tail length could be obtained. We concluded that approximately 15% - 20% of the energy that constantly is being transferred from electromagnetic fields to magnetotail particles must be diverted to the ionosphere in order to support the steady night side auroral zone processes.

The role of electric currents in particle energization was emphasized in this paper. It was noted that the cross-tail components of **j** and **E** provide the dominant contribution to $\mathbf{j} \cdot \mathbf{E}$ in the tail. Ions carry most of this cross-tail current, and therefore it is primarily ions that are accelerated in the plasma sheet. Birkeland currents are responsible for diversion of energy to the ionosphere. Since most of the Birkeland current is carried by electrons, it is primarily electrons that are accelerated along field lines. In regions in which the Birkeland current carriers have very little kinetic energy, the field-aligned energy flux is carried by electromagnetic fields. The magnitude of this parallel Poynting flux is controlled by Birkeland currents. If there is a parallel electric field somewhere along a magnetic field line, then electromagnetic energy is transferred to particle kinetic energy at this point. If no substantial $E_{\parallel}$ region exists, then the Poynting flux travels all the way down to and is dissipated as joule heat within the ionosphere. The total parallel energy flux therefore is determined by the equatorial **E** and **B** fields, while the form in which energy arrives at the ionospheric end of a field line is determined by the parallel potential drop.

A final topic considered briefly in this paper was acceleration by induced electric fields. The most important conclusions were that induced electric fields extend throughout the tail, and that they tend to produce drift of plasma toward any localized current disruption region.

Cross-Tail Current: Resonant Orbits, R. L. Kaufmann and C. Lu, *J. Geophys. Res.*, *98*, 15,447-15,465, 1993.

Most studies of nonadiabatic ions have been based on one-dimensional (1-D) magnetic field models. The modified (through the addition of a constant B_{zo}) *Harris* [1962] field is one such model that we and a number of others have used [*Chen*, 1992]. Ion orbits are traced in three dimensions, but the field model is one-dimensional because **B** depends only upon z in geocentric solar magnetospheric coordinates. The technique we use to generate a self-consistent modified Harris current sheet involves tracing groups of 1000 ions each. The particles are randomly selected from one of several parent populations. The particle groups used in this paper were dominated by resonant orbits. Resonant trajectories look very simple. The resonances are distinguished using the κ parameter, which was introduced by *Büchner and Zelenyi* [1986]. Guiding center motion is characterized by $\kappa > 1.5$. Orbits become chaotic when κ decreases to 0.8. A very small change in the injection pitch or phase angle produces a major change in the appearance of a chaotic ion orbit. When κ decreases to 0.53, the first resonance is reached. Almost all $\kappa = 0.53$ particles follow very simple orbits, regardless of their injection pitch and phase angles. Ions appear to bounce off the current sheet with almost no net change in pitch angle at this first resonance. As κ continues to decrease, one alternately observes bands dominated by resonant and then by chaotic orbits. At $\kappa < B_{zo}/B_{xo}$ the orbits become insensitive to further changes in the κ parameter. These nonresonant orbits were originally studied by *Speiser* [1965].

While tracing the groups of 1000 randomly selected ions, we keep track of the particle number density and cross-tail current density generated. We then search for groups of ions which carry the current distribution $j_y(z)$ that is needed to produce the magnetic field in which their orbits were traced. We end up with distribution functions of ions and electrons throughout the current sheet. From this, fluid parameters such as the particle density, pressure, temperature, and the electric current are calculated.

We originally thought the usual one-dimensional models would be sufficient for an initial study of ionosphere-magnetosphere coupling. The hope was that we could generate a series of one-dimensional models, with each representing a small portion of the plasma sheet. We then could map each of these models down to find the associated ionospheric latitude and longitude. In this way, an extended region of the plasma sheet could be mapped to the auroral ionosphere. One of the principal conclusions of our paper is that this procedure is inadequate. We do end up with a self-consistent current sheet. However, we find that gradients of magnetic fields and plasma parameters in both the x and z directions are required to construct a current sheet that is sufficiently similar to the Earth's inner magnetotail. The two features of the observed plasma sheet we were unable to model with one-dimensional current sheets involved particle density and pitch angle dependence. We needed a substantial number of particles that are trapped within the current sheet in order to produce the required $j_y(z)$ or to satisfy force balance. There is no net drift of such particles in one-dimensional models while there is in two- and three-dimensional models. We found a density of 1 ion cm^{-3} was needed to carry the necessary $j_y(z)$. The observed density is approximately 0.4 cm^{-3}. We also found an excessively large $T_{\|}/T_{\perp}$ ratio is needed at the edge of the current sheet. This large ratio was required to produce force balance. In contrast, ions are observed to be nearly isotropic in the current sheet, though anisotropies are present in the plasma sheet boundary layer (PSBL). We concluded that no one-dimensional model can adequately represent the inner or middle magnetotail.

Cross-Tail Current, Field-Aligned Current, and B_y, R. L. Kaufmann, C. Lu, and D. J. Larson, to be published, *J. Geophys. Res.*, 1994.

This work examines effects of a cross-tail component of the magnetic field. A constant B_y was added to the one-dimensional model, just as a constant B_z is added to create the usual modified Harris field. The addition of B_y had a strong effect near half the ion resonances, and produced little change near the other half of the resonances. Near the odd resonances, which are the ones which are strongly influenced by B_y, we found that the characteristic resonance structure disappears when B_{yo} exceeds several tenths of one nanotesla. As a result, we concluded that only the even resonances could be identified by a low-altitude ion detector.

Another result from this work involves Birkeland current generation. Resonant particles were found to be much more efficient at carrying cross-tail current in the current sheet than are chaotic particles. However, any given ion can move between resonant and chaotic orbit regions as it drifts across the tail. Continuity therefore requires the ion density to vary in the cross-tail direction. Electrons follow guiding center orbits, and have a relatively uniform cross-tail drift velocity throughout this region. The result is a tendency to produce charge imbalance in the current sheet, and therefore to drive Birkeland currents.

We have not been able to investigate the generation of Birkeland currents in any detail with our one-dimensional models. We therefore have recently been developing sets of two dimensional models. We believe that these should be adequate to study the Birkeland current generation and ionospheric coupling problems, and plan to extend our work in this direction.

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Students Supported by NAGW-1625

Chen Lu, received Ph. D. in December, 1993. Thesis title: Study of Cross-Tail Current Carriers in the Magnetotail.

Douglas Larson, expected to graduate during 1994. Working on two-dimensional tail models.

John Kontodinas, new graduate student.