Final Report
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Transport of Energetic Ions in the Ring Current During Geomagnetic Storms

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Abstract

In the final year (plus no-cost extentions) of this grant, we have:

- Used the particle tracing code to perform a systematic study of the expected energy spectra over the full range of local times in the ring current using a variety of electric and magnetic field models.
- Shown that the Weimer electric field is uperior to the Volland-Stern electric field in reproducing the observed energy spectra on the AMPTE CCE spacecraft.
- Redone our analysis of the pitch angle spectra of energetic ions during storms in the magnetosphere, using a larger data set, and a more reliable classification technique.

Introduction

This report will outline the conclusions of our work on energetic ions in the ring current under NASA grant NAG5-4695 . This grant had two major goals. One was to characterize the pitch angle distributions of the major ion species during geomagnetic storms. Second goal was to develop a particle tracing code which allows the input of realistic magnetic and electric fields, and to use this code to understand the energy spectra and pitch angle distributions observed during geomagnetic storms. Our ongoing efforts have resulted in 4 contributed talks and 1 invited talks since the beginning of this grant. Two papers have been published in the Journal of Geophysical (JGR) research, and one is about to be submitted, also to JGR.

Final Accomplishments

Statistical Study of Ring Current Pitch Angle Distributions

During the first year of this grant, we performed a study of the pitch angle distributions of the ion species H^+, He^{++}, and O^+ during the main phase of geomagnetic storms as a function of energy, L-value, and local time. The pitch angle distributions were first classified as either “isotropic”, “normal”, “butterfly”, “head-and-shoulders” or “field-aligned.” Those which were classified as either “normal” or “isotropic” were then fit to a $\sin^n$ distribution. The data set used included all major storms during the first two years of the AMPTE/CCE mission. Although this lead to some results, it was also clear that the statistical data set was not big enough. Therefore, during the final year of this grant, we extended the study to include all major storms during the complete AMPTE/CCE mission. In addition, we sorted both by pitch angle distribution and by time since the beginning of the storm. The results were:

- For protons, the low energies (~2 keV) were predominantly field aligned on the nightside, but normal or isotropic on the dayside. At medium energies (20-100 keV) there was a mixture of normal and butterfly, and at high energies (150 keV) the distributions were predominantly normal. As the storm progresses, there are fewer butterfly pitch angle distributions at medium energies, but more at low energies.
- The $\sin^n$ fit showed that the "normal" distributions were more anisotropic in the pre-noon sector and at lower L-shells. The higher energies were also more anisotropic.
- The O^+ ions had a much higher percentage of butterfly and field-aligned distributions. These became less frequent later in the storm. The He^{++} distributions were consistent with proton distributions.The statistics in general were poor for He+, but the distributions were mainly isotropic and normal.

The dayside results were qualitatively consistent with those expected from drift and loss in a non-dipole field. Ions on longer drift paths or closed drift paths were more anisotropic, and the butterfly distributions tended to correlate with drift path transition energies and drift-shell splitting. The field-aligned and butterfly O^+ on the nightside is most likely an indication of injection from the ionosphere.

This project is now complete, and will be submitted to the Journal of Geophysical Research.

Development of Particle Tracing Code

One of the major goals of this study was to trace particle trajectories in realistic magnetic and electric fields. Most previous modeling of ring current trajectories has been done using dipolar magnetic fields, and simple electric fields such as the Volland-Stern model. Ion drifts in these fields will not produce the butterfly and head-and-shoulder distributions that are commonly observed. Because the code to do the full particle trajectory (rather than bounce and drift-center averaged trajectory) in the Tsyganenko magnetic field already existed, we decided to just add the appropriate electric field model to do the ring current particle tracing. Although this is obviously computationally intensive, it allows us to move smoothly into regions where large gyroradius effects become important and the assumptions of adiabadicity start to break down. To this end, we have worked on adding a realistic electric field to the existing code.

Writing the software necessary to calculate the electric field for particle tracing turned out to be more time-consuming than anticipated. The general approach for calculating the electric field for a given point is as follows. First, field lines must be traced from points surrounding the desired coordinate to the surface where the potential is defined. In the case of the Weimer model this is the northern hemisphere. Conversely, the Volland-Stern model potential is defined in the equatorial plane. Second, the potential at each end of these field lines is used to calculate the divergence (E(x,y,z)=-Div(Phi)). The results give a value of the electric field at the desired point. This fieldline-to-field method involved writing fieldline tracing subroutines capable of targeting the desired potential surface as well as properly computing numerical derivatives to calculate the electric field.

It was first thought that implementing this procedure would be all that was needed for the particle tracing. However, repeatedly calling the fieldline-to-field procedure while integrating the equations of motion proved to be too slow on a workstation. It was then decided to pre-calculate the electric field values on a grid and then interpolate them as needed. The new interpolation scheme required writing a grid generating application that would use the previously developed fieldline-to-field procedure. Additionally, the particle tracing application had to be updated to allow for reading the pre-computed values from multiple files and performing the interpolation. This code was completed under this grant, and is now a useful tool for other applications requiring magnetospheric particle tracing.

Initial results from the particle trajectory model are published in Larson and Kaufmann, 1996.

Comparing trajectories with observed particle distributions

The final project for the grant was to use the new particle tracing code to test a variety of models of the magnetic and electric field models in the magnetosphere. This was done by computing the drift trajectories of ions over a range of energies (2-300 keV) at 1 hour local time intervals at one L-value, L=4.5, for two initial pitch angles, 89 degrees, and 10 degrees. This is the most comprehensive test ever done of how the different models effect the drift trajectories.

To test the models against observations, we used AMPTE/CCE data to give us initial energy spectra on the nightside. We then calculated the charge exchange loss along the calculated drift trajectories for the ion species H+, O+, He+, and He++. By applying these losses to the initial spectra, we were able to generate predicted spectra at each of the local times. These were then compared with energy spectra observed by the AMPTE/CHEM instrument for geomagetic storms in which the spacecraft was at the right local times.

The results showed that the correct choice of electric field was critical in reproducing the observed spectrum, and the Weimer electric field was significantly better than the Volland-Stern electric field. The Weimer field both reproducted the energy of the minimum in the spectrum, and the depth (loss) of the minimum. Both electric field models showed a higher different transition energy from eastward to westward drift paths for 10 degree angle than for 89 degree pitch angle. This difference can lead to the butterfly pitch angle distributions observed during storm times.

This work was published in Kistler and Larson, 2000.

Publications

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Presentations

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