R. B. Sheldon and J. D. Gaffey, Jr.

University of Maryland, College Park, Maryland

We use a fast, efficient method to trace charged particles through realistic magnetospheric electric and magnetic fields, greatly reducing computer simulation times. The method works for particles having arbitrary charge, energy, or pitch angle but which conserve the first two adiabatic invariants. We also apply an efficient method of classifying drift orbits, which greatly simplifies the task of identifying the last closed drift path or other drift boundaries. Finally, we calculate the time-independent evolution of the bounce-averaged phase space density along convective drift orbits. With these three tools, convective evolution of the particle distribution from the tail can now be described quantitatively, an essential step in understanding the production of unstable distributions in the magnetosphere. One can also categorize topologically different drift orbits, which is necessary to understand the unique particle signatures of the convecting plasma such as Alfvén layers and the plasmapause. These signatures can then be used to extract the electric and magnetic fields or to test the validity of the model fields. The method is particularly appropriate for particles in the energy range 0.01<E<100 keV, which are influenced by both electric and magnetic fields, and for time periods without invariant destroying waves.

1 INTRODUCTION

A major problem hindering the data modeling efforts to describe particle motion in the magnetosphere has been the highly computer intensive algorithms needed. Particle convection in a realistic magnetosphere has generally been analyzed with a numerical method that integrates the forces acting on the particle with time, essentially a Lagrangian approach, [e.g., *Ejiri et al.,* 1978]. These techniques can analyze a few (< 1000) particles for a few (< 10) hours, but are not efficient enough (even for fast computers) to follow the evolution of an entire phase space distribution over long time periods. A Hamiltonian energy conservation approach can produce a more efficient, and therefore more powerful algorithm for tracing the entire time evolution of the phase space distribution. Although the method has been known since the early days of magnetospheric research, [e.g., *Roederer,* 1970], it has generally been applied only to the equatorially trapped, 90° pitch angle particles. *Taylor and Hones* [1965] show how non-equatorial pitch angles can be analyzed, *McIlwain* [1974] showed how global fields can be extracted from geosynchronous satellite data with the method and *Whipple* [1978] developed a coordinate transformation that greatly simplifies both tasks.

A second problem, even when particle trajectories are given, is classifying the types of drift orbits and identifying the boundaries between classes. For a simple dipole magnetic field and a Volland-Stern [*Volland,* 1973, *Stern,* 1973] electric field, analytic expressions can be derived that, for example, specify the stagnation point of the plasmapause. It was this identification that permitted *Maynard and Chen* [1975] to calculate a K_p dependent electric field from particle signatures. A more realistic magnetosphere, however, does not lend itself to analytic expressions, making the boundaries much harder to identify and correlate with data. We show that not only does the conservation of energy method calculate trajectories rapidly, it also provides a very efficient classification scheme that can automate the search for topological boundaries.

The third problem arises from the wide gap between analytic, fluid MHD theories and the models which trace discrete particle trajectories. Without the relevant distribution function, one cannot calculate growth rates and wave-particle interactions self-consistently. Two common, but computationally intensive methods for estimating the distribution function either used vast numbers of particles to construct the moments numerically, or extrapolated distributions from a select subset of particle energies. An alternative fluid approach [e.g., *Northrop and Teller,* 1960] calculates the bounce averaged phase space density along the drift trajectories, which opens up the data to the powerful tools of global MHD analysis. The fluid description can be extended to include the effects of diffusion and loss and even time-dependence. Thus one can begin to create quantitative models of the entire convecting plasma without being restricted to discontinuities at topological boundaries.

We develop three tools that address each of these problems, and demonstrate them by displaying the effect of pitch angle on convecting ion trajectories in realistic magnetic and electric fields, which, to our knowledge, has not been done before.

2 THEORY

The first two tools are carefully described by Whipple, so we give a brief summary of the Hamiltonian method and classification scheme. If a charged particle conserves the first two adiabatic invariants, it also conserves energy, since the first invariant, $\mu = E_\perp/B$ is proportional to the perpendicular kinetic energy (K.E.), and the second invari-

Paper number 93GL00835
0094-8534/93/93GL-00835$03.00