Ion Transport and Loss in the Earth's Quiet Ring Current

1. Data and Standard Model

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We have studied the transport and loss of ions in the Earth's quiet time ring current, comparing the standard radial diffusion model developed for the higher-energy radiation belt particles with measurements of the lower-energy ring current ions. We compiled a data set with full local time coverage from the quietest days seen by the AMPTE/CCE/CHEM instrument in near-equatorial orbit at $L=2$–9 R_E. This data set provides, for the first time, ionic composition information in an energy range that includes the bulk of the ring current energy density, 1–300 keV/e. Protons were found to dominate the quiet time energy density at all altitudes, peaking near $L\sim4$ at 60 keV cm^{-3}, with much smaller contributions from O^+(1–10%), He^+(1-5%), and He^{++}(<1%). The proton densities were azimuthally symmetric excepting a small dawn-dusk distortion caused by the cross-tail electric field, and a plasma sheet contribution for $L>6$ near midnight. Thus the standard radial diffusion model, which incorporates an outer source boundary at 7.5 R_E from the Earth, and diffuses ions earthward while undergoing charge exchange and Coulomb energy loss, should fit the data. We improved on previously used model loss processes by incorporating the latest atomic physics cross sections from the literature, updating the last survey done 15 years ago. We also included the effects of finite electron temperature on Coulomb drag. A χ^2 minimization procedure was used to fit the amplitudes of the standard electric radial diffusion coefficient, giving $D^E_{LL} = 5.8 \times 10^{-11}$ $R_E{}^2/s$. Yet the model was unable to fit the data (to within a factor of 10) over 50% of the energy and radial ranges of the data set, particularly at $L<4$ or $E<30$ keV. Assuming that the loss terms in the model are correct, the data can be inverted to extract a radial diffusion coefficient that had nearly constant amplitude from 2–7 R_E. This suggests that another transport mechanism is operating in the ring current region, which is strongest at smaller radial distances. We speculate that fluctuating ionospheric electric fields may be the source of this additional diffusion.

1. INTRODUCTION

The ring current (both steady state and storm time) plays a crucial role in the morphology and dynamics of the magnetosphere. The current carried by these trapped 1–300 keV ions significantly modifies the inner magnetospheric magnetic field [e.g., *Tsyganenko*, 1989; *Olson et al.*, 1979] and can be observed in ground based magnetograms where the departure from steady state is characterized by the *Dst* index [*Sugiura*, 1964]. Since the bulk of the energy density contained in all trapped particles (radiation belt particles included) lies in this energy range, there is a direct correlation between the ring current energy content and *Dst* [*Dessler and Parker*, 1965]. This ring current can also act as an energy source contributing to aurorae [e.g., *Kozyra et al.*, 1987] and to plasma instabilities and wave growth [e.g., *Cornwall*, 1966]. The ring current also can provide a way to image the magnetosphere through the energetic neutrals produced by charge exchange [e.g., *Williams*, 1990].

Since the earliest spacecraft flew detectors sensitive to fairly high energy (>1 MeV) ions [*Hess*, 1968], it was these trapped "radiation belt" particles that stimulated the early theoretical work on magnetospheric containment [e.g., *Northrop*, 1963]. While stable trapping on dipole field lines was easily understood, the access and radial transport of these ions was not. *Kellogg* [1959] first suggested some sort of radial diffusion process that conserved the first two adiabatic invariants while violating the third, although it was *Parker* [1960] who showed how a magnetic disturbance, a *Chapman and Ferraro* [1932] storm onset, could move particles from one stable dipole orbit to another and derived an appropriate diffusion equation. *Davis and Chang* [1962] argued that the correct approach was to use Fokker-Planck equation based on phase space densities. *Dunge* [1968] proved the equivalence of the two approaches. *Nakad and Mead* [1965] generalized the Parker mechanism to any magnetic disturbance of a more realistic magnetic field, deriving an L dependence for their magnetic diffusion coefficient. *Fälthamme* [1965] showed that for some particles, electric field disturbance caused more diffusion than purely magnetic ones, deriving an L dependence for the electric diffusion coefficient when independen of the fluctuation frequency. *Tverskoy* [1969] argued that Coulomb drag changed the spectrum of the distribution as it diffused. *Cornwall* [1971], recognizing that the primary loss mechanism for ion was charge exchange [*Dessler and Parker*, 1959; *Wentworth et al.*, 1959] wrote the diffusion equation in the form we use in this paper This standard model for radiation belt particle diffusion culminate in the exhaustive text by *Schulz and Lanzerotti* [1974] (hereafte SL) . Finally, *Spjeldvik* [1977] and *Spjeldvik and Fritz* [1978b] (hereafter SSF) applied the model to ring current ions and the "outer" radiation belt. Using satellite data for boundary conditions an numerically integrating Cornwall's equations, they could solve fo the distribution and compare with 100–1000 keV ion data throughout most of the trapping region. Our goal is to extend this analysi for the bulk of the ring current, 1–300 keV, over the entire region, 2.5–7.5 R_E.

The lower energy ring current structure depends not only o the magnetic field configuration, but on the particle drift orbit [*Roederer*, 1970], which in turn depend both on the electric fiel and particle pitch angle. This makes a global ring current mode more difficult to formulate than a high energy radiation belt model, [*Vette*, 1972], which remains unaffected by the electric field. Several investigators [*Lyons*, 1976; *Williams*, 1980; *Spjeldvik and Fritz* 1983] have analyzed and modeled Explorer 45 ring current dat from 1 to 1000 keV, but without composition information ove

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