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On the influence of the initial pitch angle distribution on relativistic electron beam dynamics

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Abstract. Simulations of the evolution of a relativistic electron beam injected into the Earth's magnetosphere are examined. It is found that the lifetime of beam particles strongly depends on the initial pitch angle distribution and that lifetimes similar to those found for the radiation belts are obtained for nearly equatorially mirroring injections. It is concluded that the results of our previous study on beam propagation [*Khazanov et al.*, 1999], which only considered upper ionospheric injections, are consistent with other relativistic electron studies and should be regarded as an examination of the loss cone edge population, whether naturally occurring or artificially injected into near-Earth space.

Khazanov et al. [1999] discussed simulations of relativistic electron beam injections into the inner magnetosphere and the associated flux intensities and lifetimes of these particles in the geomagnetic trap. The calculated lifetimes lead to reductions in the total particle count of the order of tens of percent by 1 day after injection. It has been commented to the authors that these timescales are far shorter than particle lifetimes for naturally occurring relativistic electrons [see *Lyons et al.*, 1972; *Spjeldvik and Rothwell*, 1985; *Abel and Thorne*, 1998; *Albert*, 1999] or those from rocket-based nuclear detonations [e.g., *Walt*, 1964; *Walt and Newkirk*, 1966; *Stassinopoulos and Verzariu*, 1971], where lifetimes are of the order of days at a minimum and are usually weeks, months, or even years. This difference is because of the initial distribution of the beam simulations given by *Khazanov et al.* [1999] compared with the distributions examined in these other studies.

The simulations of *Khazanov et al.* [1999] are all for ionospheric injection of the electron beam. As a result, the initial equatorial pitch angle distribution has a 1°-2° width that borders the loss cone. For example, the trapped part of the beam injected at the altitude 700 km in the pitch angle range between 60° and 90° at L=2 occupies pitch angles of 17.5°-19.6° in the equatorial plane. This range is even smaller for larger L shells [*Khazanov et al.*, 1999]. The entire beam mirrors in the upper atmosphere, where losses from coulomb collisions dominate the scattering process. In spite of the fact that the bounce-averaged wave diffusion coefficient drops off at small equatorial pitch angles, the inclusion of collisional scattering and loss significantly reduces the lifetime of the beam particles compared with the standard radiation belt lifetime calculation, where wave scattering is more essential.

To illustrate this, several new simulations were conducted using the model of *Khazanov et al.* [1999]. Figure 1 shows the total particle count for three simulations with the initial injection on an L=3 field line: (1) an isotropic injection at the equator; (2) an injection limited to the pitch angle range of 80°-90° at the equator; and (3) an injection limited to the pitch angle range of 9°-10° at the equator (the case from *Khazanov et al.* [1999]). As can be seen, the timescales for beam particle loss are vastly dissimilar when different parts of the trapped zone are filled, and essentially no particle loss occurs in the anisotropic equatorial injection (case 2). The combination of two factors makes the ionospheric injections have much faster losses (as a percentage of total particle number) than the magnetospheric injection of cases 1 and 2. These two factors are a narrow injection region and its proximity to the loss cone.

Figure 2 clarifies the role of these factors by showing the evolution of the equatorial pitch angle distribution for case 2. These distributions are integrated over energy and local time to remove the changes in intensity due to the different drift speeds around the Earth (and therefore show the total scattering rate). Without the energy and local time integrations, the intensity would vary dramatically depending on the chosen location of the presented distribution (see *Khazanov et al.* [1999] for further explanation). As can be seen, no particles are anywhere near the loss cone, even after 10 days, and thus the particles from such a beam injection would linger in the

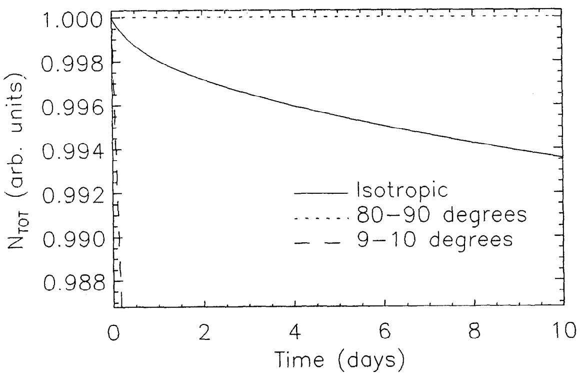

Figure 1. Total beam content results for various injection configurations at L=3, normalized to their initial beam contents. The solid curve is for isotropic injection at the equatorial plane, the dotted curve is for injection only in the 80°-90° pitch angle range at the equatorial plane, and the dashed curve is for injection from the upper ionosphere (9°-10° pitch angle range at the equatorial plane).

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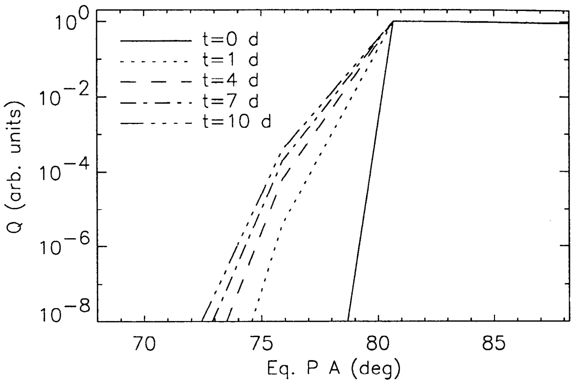

Figure 2. Time development of the pitch angle distribution for relativistic beam injection in the 80°-90° pitch angle range at the equatorial plane, showing the slow propagation of the particles through the trapped zone.

magnetosphere for timescales similar to those for the radiation belts. Note that there is a slight decrease in the distribution function within the 80°-90° range, but this deviation from the unity cannot be seen on this scale.

Therefore the results of *Khazanov et al.* [1999] are consistent with the results from other inner magnetospheric relativistic electron studies and complement the previous studies by focusing on the narrow range of pitch angles nearest the loss cone. In fact, relativistic beam injections and the simulation of such experiments can be used as controlled tracer experiments to investigate the natural radiation environment. The model is well adapted to the analyses of the radiation belt fine structure evolution and the dynamics of various regions of velocity space.

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