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Electron Precipitation in the Morning Sector of the Auroral Zone

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Auroral electron precipitation in the morning sector is assumed to be the result of an electromagnetic cyclotron instability of a particle distribution that evolves adiabatically as its constituent electrons drift eastward from a source near midnight. The adiabatic distribution is calculated by using Green's function in various magnetospheric field models, and the corresponding growth rates for whistler mode waves are calculated by the method of Kennel and Petschek (1966). The region of maximum calculated wave growth corresponds spatially and temporally to the region of maximum observed electron precipitation only when the magnetospheric electric field is included realistically in the model.

INTRODUCTION

The precipitation of energetic electrons in the earth's auroral zone is closely connected with the dynamics of the magnetospheric substorm. During a substorm (especially at the beginning of the expansion phase), plasma is thought to be transported from the tail into the inner magnetosphere. As a result the ring current strengthens, auroral arcs intensify and move in latitude, magnetic bay disturbances appear on ground magnetograms, and particles precipitate into the auroral zone atmosphere [e.g., *Akasofu*, 1968]. The injection of charged particles from the plasma sheet into the inner magnetosphere seems to energize such particles, as one would expect from conservation of the first two adiabatic invariants [*Sharber and Heikkila*, 1972]. Moreover, particles injected with large equatorial pitch angles may gain access to drift trajectories characteristic of trapped radiation, whereas particles injected with small equatorial pitch angles become lost in the atmosphere. The resulting distribution of pitch angles is unstable to wave generation, which in turn causes further particle precipitation into the atmosphere. Since electrons drift eastward from midnight, such precipitation should occur preferentially in the morning sector [*Pfitzer and Winckler*, 1969].

The precipitation of electrons as they drift into the morning sector is observationally well known. It has been seen by means of satellites, rockets, and balloons as well as by ground-based techniques. By measurements of cosmic noise absorption, *Brown* [1964] demonstrated that such electron precipitation has a repeating structure in time. Additional properties follow from the observation of X rays generated in the process of electron precipitation. Such morning sector precipitation commences earlier at high latitudes than at low latitudes [*Bewersdorff et al.*, 1966, 1968]. It is delayed in comparison with precipitation in the midnight sector of the auroral zone. Observations of the X rays [*Rosen and Winckler*, 1970; *Sletten et al.*, 1971] and also direct observations of the electrons on orbiting satellites [*Pfitzer and Winckler*, 1969; *Arnoldy and Chan*, 1969; *DeForest and McIlwain*, 1971; *Hoffman and Burch*, 1973] confirm that this delay corresponds to the time required for electrons to drift adiabatically from midnight into the morning sector. *Kremser et al.* [1973] have noted that characteristic variations of the electron energy spectrum support this model.

Theoretical interpretations of the morning sector precipitation of auroral zone electrons typically invoke the whistler mode instability described by *Kennel and Petschek* [1966]. *Brice and Lucas* [1971] have found some simple conditions for the interaction between energetic electrons and whistler waves in terms of the local density of cold plasma. *Lucas and Brice* [1973] have calculated growth rates for such waves in the midnight and the morning sector, using pitch angle distributions observed by *West et al.* [1973], and have determined that the morning sector distributions are the more strongly unstable. The purpose of the present work is to show how such pitch angle distributions emerge from a continuous source of energetic electrons located at midnight. As an indicator of precipitation the growth rate of low-frequency whistler mode waves is calculated in the manner described by *Kennel and Petschek* [1966] for the evolving model distribution of energetic electrons.

PARTICLE SOURCE

In the adiabatic theory of charged particle motion it is customary to specify three adiabatic invariants (proportional to the canonical action integrals J_i associated with gyration, bounce motion, and azimuthal drift, respectively) as constants of the motion. The conjugate phases φ_i ($i = 1, 2, 3$) advance respectively at rates $\varphi_i = 2\pi(\partial H/\partial J_i)$, where H is the single-particle Hamiltonian [e.g., *Schulz and Lanzerotti*, 1974]. In problems that involve the tracing of drift shells it is customary to average over the gyrophase φ_1 and the bounce phase φ_2. This average of the phase space density f (canonical distribution function) is denoted $\bar{f}$. Since the transformation to action angle variables is canonical [e.g., *Goldstein*, 1950], the function $\bar{f}$ must satisfy the equation

$$\partial \bar{f}/\partial t + \dot{\varphi}_3(\partial \bar{f}/\partial \varphi_3) = \bar{S} \qquad (1)$$

along the drift trajectory in the absence of invariant-violating processes. The bounce-averaged source term $\bar{S}$ introduces new particles into the adiabatically propagating distribution $\bar{f}$.

It is convenient to replace the drift phase φ_3 in (1) with the azimuthal coordinate φ at the equatorial intercept of the field line. The transformation from φ_3 to φ is exactly that described by *Schulz and Eviatar* [1969].

The field line label L is defined by the equation $L = \csc^2 \vartheta_a$, where ϑ_a is the particular magnetic colatitude ϑ at which the field line intersects the earth's surface. For the purpose of the present work the source term

$$\bar{S} = \oint \dot{\mathrm{f}} \cdot d\mathbf{s} \div \oint ds \qquad (2)$$

is modeled in terms of the function

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