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Monte Carlo Simulation of Energetic Electron Precipitation

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1 Extended Abstract

Precipitation of energetic particles into the Earth's atmosphere can significantly change the properties, dynamics, as well as the chemical composition of the upper and middle atmosphere [1]. The chemical changes induced by energetic particle precipitation (EPP) have implications for the production of atmospheric nitric oxides and reactive hydrogen oxides, which can lead to ozone loss in the stratosphere and mesosphere [1]. The resultant ionization collisions with neutral molecules are also responsible for sustaining the D-region ionospheric properties on the night side. To quantify the influence of precipitating electrons, the interaction of these electrons with the upper atmosphere has been studied using physics-based Monte Carlo simulations [2] and parameterization methods [3]. However, previous modeling studies were mainly dedicated to isotropically precipitating electrons and the pitch angle dependence of the particle-induced atmospheric effects is poorly understood. The effects of ionization production by bremsstrahlung photons, which are significant for relativistic precipitating electrons and particularly at low altitudes (<50 km) [4], have not been sufficiently studied.

Accurate modeling of electron precipitation is of crucial importance, especially for the estimation of its influence on the atmosphere using space-borne and ground-based observations. This represents a major goal of the present study. For this purpose, we employ Monte Carlo models in order to simulate the propagation of electrons, the transport of bremsstrahlung photons in the atmosphere, and the deposition of energy by those photons. In this study, monoenergetic electron beams are propagated into the upper atmosphere with discrete pitch angles. We focus on quantifying the energy deposition and ionization produced along the particle trajectory. By tracking the photons produced when precipitating electrons are deflected by nuclei in neutral molecules, we further investigate the secondary ionization effects induced by bremsstrahlung photons.

Using our Monte Carlo modeling approach, we find that electrons with higher pitch angles deposit energy at higher altitudes, and the altitude of peak deposition depends on pitch angle by a few kilometers. On the other hand, the transport of energy in the form of bremsstrahlung photons can create ionization at lower altitudes, as low as $\sim$20 km for 1 MeV precipitating electrons. Finally, we use our discrete simulations to create a lookup table forward model, enabling atmospheric effect calculation of any precipitating energy and pitch angle distributions using pre-calculated deposition profiles.

References

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