Secondary effects of lightning-induced electron precipitation: chemical effects, optical emissions, and X-rays

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Lightning-induced electron precipitation (LEP) is a well-known phenomenon that couples tropospheric lightning to the upper atmosphere, ionosphere, magnetosphere, and radiation belts. The electromagnetic pulse (EMP) from an intense lightning discharge propagates through the ionosphere and converts to a whistler-mode wave propagating in the inner magnetosphere. There the whistler interacts with radiation belt electrons through cyclotron resonance, causing energy and pitch-angle scattering; electrons whose pitch angles are pushed into the loss cone will precipitate in the upper atmosphere in their subsequent bounce.

In the upper atmosphere, LEP creates new ionization, which is then detected as an electron density disturbance, persisting for tens of seconds at D-region altitudes. This electron density disturbance has been detected and spatially-resolved in the past two decades using subionospheric VLF remote sensing.

Precipitation of energetic electrons in the upper atmosphere also produces chemical effects, optical emissions, and X-ray emissions. All of these are known effects of radiation belt precipitation, but have not been considered in previous studies of LEP. In this work, we present model simulations of LEP in which we calculate the expected chemical, optical, and X-ray signatures. We use the Electron Precipitation Monte Carlo (EPMC) model framework to conduct these calculations, which includes X-ray generation and propagation tools.

The optical signature of LEP was previously considered in Marshall et al [2011], who predicted very weak, ∼1 Rayleigh signatures on the ground. An experimental effort to detect these signatures did not find clear signals from LEP. Calculations of X-ray fluxes are conducted to predict signatures at balloon altitudes (35 km) and LEO spacecraft altitudes (∼400 km), where future missions may detect these X-rays. Finally, we use the Sodankylä Ion and Neutral Chemistry (SIC) model to compute chemical effects in the atmosphere, including production of odd nitrogen and odd hydrogen and the destruction of ozone in the mesosphere. We find that LEP produces a measurable chemical signature but likely does not produce long-lasting effects.