

High altitude radiation belt particles from either natural or man-made origin have a significant impact on the satellite environment. An important loss mechanism for these particles is their interaction with very low frequency (VLF) electromagnetic waves. Wave energy at these frequencies is naturally resonant with high-energy radiation belt particles and, through nonlinear wave-particle interactions causing pitch angle scattering, can cause their precipitation and loss into the atmosphere. Predicting the upward propagation of very low frequency radio waves through the ionosphere to radiation belt altitudes is thus an important element of understanding radiation belt dynamics. Recent analysis of high altitude satellite measurements of VLF transmitter signals has shown that measured field amplitudes are consistently 20 dB lower than predictions from a simplified model. There thus appears to be a significant discrepancy between satellite measurements and model predictions, and this discrepancy has a major impact on previous calculations of radiation belt lifetimes.

Using a unique existing dataset of simultaneous high altitude and ground-level VLF field measurements of broadband lightning signals we probed many different facets of the missing VLF power. This dataset comes from two sources. On one hand we have data coming from the Lightning Bolt rocket experiment, which flew in 2000. On the other hand we have ground-based broadband VLF measurements performed at Duke University during the flight. We present an empirical model based on this analysis which shows how VLF attenuation varies with frequency and altitude. To validate the model, we extensively simulated the VLF power and field distribution in the vicinity of ground-based VLF transmitters and compared the predictions to the two sets of measurements. The simulations were performed with our custom made finite-difference-time-domain code capable to model in detail the propagation of electromagnetic waves produced by ground-based sources through ionosphere hundreds of kilometers away from the transmitter.