Real-time Estimation of Ionospheric Parameters from VLF Atmospherics Using Machine-Learned Models

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Lightning discharges generate wideband radio signals (sferics) and their features can be used to determine properties of the generating discharge. Ionospheric reflections of the lightning strike, known as skywaves, are also present in the sferics, and they provide information on the ionospheric region around the reflection point. Different methods have been successfully employed for extracting D-region ionospheric height, h', and steepness, β, from sferics using lightning propagation models, and first suggested for VLF (30-300 kHz) sferics by S. A. Cummer in 1998 (Radio Sci. , 33, 6, 1781-1792). Thus it is clear that the sferics themselves contain enough information for the estimation of ionospheric parameters when the source location is known. While previous methods have used costly and complex propagation models, we estimate the ionospheric parameters via machine-learned models.

In order to establish the feasibility of extracting ionospheric parameters from VLF sferics using a machine-learned model, we simulate the propagation of hundreds of cloud-to-ground flashes using a finite-difference time-domain (FDTD) model of RF propagation, and measure the simulated sferics observed between 100 km and 700 km from the source. Each simulation draws from a random distribution of input variables corresponding to nominal parameters of the lightning discharge, the atmosphere and the ionosphere, which include the true values of h' and β. Using supervised machine learning with the truth information, we can train a model to output an estimate of h' and β from the input sferic data and source location. We choose to employ a neural network classification scheme for obtaining a probabilistic model of the estimated parameter, given the categorical nature of the sferic patterns and given our previous experience with sferic machine learning. The output of the trained model is thus a discrete two-dimensional PDF in h' and β space.