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Modeling and inversion of narrowband VLF signals through EPP-perturbed ionospheres

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1 Extended Abstract

The *D*-region ionosphere is an important interaction region between the neutral atmosphere and ionospheric plasma above. It also responds to a variety of external factors including lightning and energetic particle precipitation (EPP) from the radiation belts. Low electron density in the *D*-region has made remote sensing by ionosonde, incoherent scatter radar, and GNSS radio occultation difficult below 90 km. Fortunately, VLF radio waves are naturally guided between earth's surface and the *D*-region ionosphere. High power VLF transmitters designed for naval communication energize the waveguide almost continuously and can be received from thousands of kilometers away. The discrete modes propagated by the waveguide are a function of the effective reflection height of the guide, which is in turn a function of the conductivity profile of the ionosphere.

For decades, various research groups have monitored the amplitude and phase of VLF transmitter signals to infer the state of the *D*-region ionosphere [1, 2]. The multi-megameter long propagation paths mean the parameters being estimated are path averages over large portions of the globe. Recent efforts have employed more sophisticated estimation techniques to combine multiple path measurements simultaneously and infer spatially varying ionosphere parameters [3, 4, 5]. In almost all nonlinear inversion techniques, it is necessary to use a forward model to determine what VLF amplitude and phase would be observed through a known ionosphere. We have constructed a new waveguide mode theory propagation model with a more robust mode solver than that built in to LWPC, the de facto standard for modeling VLF propagation in the earth-ionosphere waveguide, or its predecessors. The new mode finder does not require transforming the physical equations to avoid poles in the complex plane and does not interpolate the ionospheric reflection coefficients. The much simpler code base follows modern programming standards so additional capabilities can be more easily added. Validation of this new code against LWPC and FDTD VLF propagation codes is presented. Additionally, using the new propagation model we have simulated a large number of typical and perturbed ionospheres to train an artificial neural network for the *D*-region inversion problem with a network of VLF receivers. We are particularly interested in estimating ionospheres that have been perturbed by precipitation of energetic particles from the radiation belt. Precipitation patches in the *D*-region may have fairly sharp boundaries and electron density profiles that do not fit the typical Wait and Spies exponential parameterization very well [6, 7]. We present progress on spatially estimating the perturbed ionosphere profiles using an artificial neural network.

References

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