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Forward Propagation Modeling of High Frequency Waves through a Structured Ionosphere with Magnetic Field Effects

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High frequency (HF) sky-wave systems used for over-the-horizon-radar (OTHR), communication, and signal geolocation must contend with ionospheric structuring, which affects propagation and can adversely impact the primary mission of these sensors. Ionospheric structuring results from a variety of geophysical mechanisms that operate at low-, mid-, and high-latitudes and manifest as sporadic-E, traveling ionospheric disturbances (TIDs), mid-latitude spread-F, equatorial plasma bubbles, auroral arcs, and polar cap patches. Propagation modeling at HF wavelengths is traditionally performed via numerical ray-tracing, but the results become difficult to interpret when ionospheric structure creates highly multi-modal propagation [1]. Full wave techniques offer the advantage of providing the electric and magnetic fields throughout the region. The improved spatial context is useful as HF waves often interact with irregularities over very long distances (hundreds or thousands of km). In addition, full wave techniques accommodate diffraction effects which ray-trace models neglect. Diffraction causes scintillation of the HF signals when Fresnel-scale sized irregularities are encountered along the propagation path. While a full treatment of Maxwell's equations via finite-difference time domain (FDTD) methods is possible, at least in principle, the computational requirements for solving large-scale HF propagation problems of practical interest remain prohibitive. Previous forward propagation modeling techniques, such as parabolic wave equation (PWE) methods, provide an efficient solution to large-scale problems, but have been under-utilized for ionospheric applications partly because of their inability to model the effects of an external magnetic field. The Earth's magnetic field causes significant polarization effects at HF wavelengths that must be modeled to assess the performance of modern polarization-aware HF systems.

In this paper, we describe a recently developed forward propagation method for modeling the interaction of vector waves through a structured ionosphere in the presence of an external magnetic field (Rino and Carrano, accepted JASTP, 2021). Interaction of the waves with a perfectly conducting curved earth surface is implemented using the method of images. The ordinary (O) and extraordinary (X) propagation modes are extracted from the full wave solution (vector electric field) post-facto. Traces of intensity peaks in the extracted O and X mode solutions are compared with the results of rays traced with the magnetoionoic Hamiltonian ray-tracing engine PHaRLAP [2]. In this paper, we demonstrate application of the vector forward propagation equation (VFPE) method for modeling the propagation of HF waves though both quiescent and structured ionospheric states. In a companion paper at this meeting [3], we describe a configuration space model for generating stochastic realizations of structure representative of magnetic field-aligned irregularities. In a future work, we will use the VFPE to model HF propagation through these field-aligned structures to understand their effects on signal characteristics including intensity, delay, arrival angle, and polarization.

References

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[3] Rino, C., C. Carrano, and K. Groves (2021), "Configuration space ionospheric models", *2020 XXXIVrd General Assembly and Scientific Symposium of the International Union of Radio Science*, Rome, Italy, 2021, Rome, Italy, 28 August - 4 September 2021.