Tomographic Reconstruction of Simulated Two-Dimensional Propagation Data

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The forward propagation equation (FPE) has been used extensively for simulating ionospheric propagation data. However, for most applications the structured region has been replaced by an equivalent phase screen. This allows fully three-dimensional simulations under strong-scatter conditions, but it does not capture detail with sufficient fidelity to support tomographic reconstruction. The problem is compounded by the fact that field-aligned structure extends to altitudes approaching 1000 km. To meaningfully populate a data space with representative structure over the full range of scale sizes is challenging in its own right, but a two-dimensional slice captures the essential attributes of propagation through highly extended structure. Tomographic reconstruction makes use of multiple propagation paths that intersect a common ionospheric volume. A modified form of the FPE reproduces data from a receiver at the ground intercept of the ray from the source. The nominal propagation angle is local reference. While most simulations have concentrated on realizations of a single receiver, varying the propagation direction is equivalent to reception by a displaced receiver. With care to manage the phase relations, one can generate data representative of multiple widely separated receivers. Moreover, because the FPE contains additive differential diffraction and structure components, the diffraction term can be bypassed to generate the path integration that forms the basis of tomographic reconstruction schemes.

Tomographic reconstruction has its own limitations imposed by the highly ill-conditioned model equations that relate path-integrated measurements to in-situ structure. For the purpose of illustration a two-dimensional Fourier decomposition of the structure was used to derive the model equations. The spectral decomposition relates directly to the interpretation of path-integrated stochastic structure. The sparse coverage of the spectral decomposition provides a graphic illustration of why the ill-conditioning occurs. A range of examples are presented that illustrate the effects of refraction and scintillation. It is noteworthy that the scintillation for typical equatorial spread F conditions is near fully developed at the exit plane of the structured region. Even so, scintillation that is not severe enough to destroy phase reconstruction is effectively noise that can be managed by the implicit filtering necessary for ill-conditioned model reconstruction. Distortion of large-scale features by refraction and the stochastic nature of ESF is a subject of study that relates to the practical and intrinsic limitations of ionospheric tomography. The two-dimensional simulations provide an ideal test bed for exploration.