# Effects of Out-of-Plane Terrain Slopes on Tropospheric Radar Propagation – Theory and Modeling

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Numerical simulation of long-distance tropospheric radar propagation is usually performed by marching the propagating field forward from the source to the receiver using either Fourier transform or finite difference techniques. The equation governing the field is a one-way parabolic wave equation subject to the terrain boundary condition in addition to an absorption condition, which is enforced on the boundaries of the numerical domain to prevent reflection artifacts.

In order to facilitate efficient propagation calculations over long distances (hundreds of kilometers), several approximations of the original problem have been proposed. An important approximation among these is the assumption that the lateral terrain variations along the great circle connecting the transmitter and the receiver are negligible. This approximation effectively reduces the original vector 3D problem into a scalar, efficiently solvable 2D problem. The latter problem is then transformed from the original spherical geometry to a Cartesian geometry via the appropriate conformal map and solved via one of the aforementioned marching techniques. It is obvious that such an approximation amounts to ignoring the effects of the lateral (cross-range) terrain slopes on the propagating field. These effects, which include depolarization, lateral diffraction and shadowing, may become prominent for steep cross-range terrain slopes.

In this paper we describe a 3D vector propagation model (VEMPE) that was developed to investigate the effects of lateral terrain variations on radar coverage. In this model, the parabolic wave equations governing the three Cartesian components of the vector electric (magnetic) field, and the terrain boundary condition, which couples these field components, are discretized using the finite-difference method. Close to the terrain, the coupled system of equations is solved using an efficient sparse-matrix bi-conjugate gradient method. Away from the terrain, the field components are independent and the solution is carried out via the alternating direction implicit method (ADI). Perfectly matched layers are used to prevent reflection artifacts from numerical boundaries.

We conclude by describing a common approach for generating quasi-3D results using a 2D propagation code. This approach propagates several 2D fields to create vertical slices that sample the 3D environment. Slices emanate radially from the source position, and each slice's 2D source field represents a different cut through the 3D source distribution. In our implementation, azimuthal separation between slices and 2D-propagation range/altitude calculation increments are selected to make the quasi-3D solution grid as coincident as possible with the VEMPE solution grid.