Global Sensitivity of Radar Wave Propagation Power to Environmental Variables for a Parabolic Equation Numerical Simulation in Maritime Regions

Nathan E. Lentini and Erin E. Hackett
School of Coastal and Marine Systems Science, Coastal Carolina University, Conway, SC

Numerous environmental factors impact radio wave propagation in the marine atmospheric boundary layer (MABL) through effects such as scattering and refraction. Furthermore, environmental parameters can interact with each other to either compound or reduce the impact of each individual parameter. Thus, in order to properly assess the sensitivity of radar wave propagation power to environmental variables a global sensitivity approach is needed. In this study, we examine the global sensitivity of propagation power to a number of environmental variables using a parabolic equation (PE) numerical simulation for maritime regions. The sensitivity analysis is performed using the Extended Fourier Amplitude Sensitivity Test, which is a global variance-based method that can account for multi-degree interaction effects. The method is ideal for complex nonlinear models and permits computation of both leading order and total order sensitivity for each parameter. The study examines 16 environmental parameters, 8 sea state and 8 atmospheric, that are used to generate inputs for the Variable Terrain Radiowave Parabolic Equation (VTRPE) numerical simulation. This model uses a split-step rotated Green's function parabolic wave equation solution to the scalar wave equation for transverse field components derived from Maxwell's equations. The simulation accounts for effects of refraction (including ducting) as well as variable boundary conditions on water surfaces, such as wind seas, swell, and variable dielectric properties. Vertical profiles of atmospheric refractivity, which are assumed homogenous in range for this study, are generated using a simplified refractivity model that depends on the 8 atmospheric parameters and can generate linear refractivity profiles as well as evaporation, surface, and elevated ducts, including any combination of these ducts. Sea state parameters can be grouped into 3 general categories: surface dielectric properties, directionality, and surface roughness. Atmospheric parameters can be grouped into 4 general categories: evaporation layer, mixed layer, inversion layer, and upper layer parameters. We examine results in the context of these parameter groupings.

The sensitivity analysis is carried out for three radar frequencies (3, 9, and 15 GHz) and for both horizontal and vertical polarizations because the relative importance of environmental parameters can change with radar frequency and polarization. In addition, sensitivity is computed both over the entire MABL domain (defined here as 1000 m in altitude and 60 km in range) as well as regionally in order to capture variations in sensitivity within this domain. Results show that interaction effects are significant as there are often large discrepancies between leading-order and total-order sensitivity, where the latter includes interaction effects. Over the entire domain, parameter sensitivity varies more with frequency than polarization, and, as expected, the atmospheric parameters are more important than ocean surface parameters. Ocean surface roughness and dielectric properties are most important at the higher radar frequencies, while at lower frequencies sea directionality is most important. For the atmosphere, overall, the mixed layer parameters are most significant; however, the relative importance of different parameters varies with location within the domain. In summary, these results provide insight to help determine which parameters are the most important for assessing and modeling a radar system's performance at a given frequency and spatial coverage.