Simulation Study of CYGNSS Retrieval Algorithms for Wetland Extent

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CYGNSS (Cyclone Global Navigation Satellite System) is a constellation of 8 microsatellites that measure the reflections of GPS signals off of the Earth's surface. While CYGNSS's primary objective is to measure tropical ocean surface wind speed, recent measurements made from CYGNSS over land have shown the ability to resolve rivers, lakes, wetlands, and other inland water bodies, even under vegetation. This indicates that CYGNSS and future GNSS-R systems could be used to map the extent and depth of wetlands, fulfilling a crucial need for better observations of the global surface water distribution.

Over inland water, the reflections measured by CYGNSS occur from coherent rather than diffuse scattering, resulting in both high SNR and increased spatial resolution. Several approximations are traditionally made in this case. First, the spatial resolution of the reflection is assumed to be based on the first Fresnel zone and its along-track non-coherent integration (approximately 1km x 6km for typical CYGNSS bistatic geometries). Second, the reflected power is typically modeled using standard coherent scattering equations based on image theory. Third, CYGNSS will often encounter heterogenous scenes with mixtures of land and inland water in complex geometries. The strength of the reflected signals is often approximated as being proportional to the percentage of the first Fresnel zone area occupied by inland water. In this work, a simulation study is performed to evaluate the accuracy of these approximations and to quantify the performance of wetland extent retrieval algorithms based on them.

We present an accurate forward model for coherent reflections developed by extending the existing CYGNSS end-to-end simulator (E2ES) to incorporate a modified Helmholtz integral with Kirchhoff boundary conditions. This formulation leads to the well-known physical optics formulas and allows us to accurately produce simulated CYGNSS measurements over realistic heterogeneous wetland scenes with low Rayleigh parameters (mixed land and water over the scattering zone). Large scale simulation of CYGNSS measurements are performed over wetland areas of interest, and the accuracy of retrieval algorithms are quantified as the fidelity of the simulation is gradually increased. We find that scattering contributions from water outside the first Fresnel zone produce a significant impact on the strength of coherent reflections and the subsequent retrieval error. In heterogenous scenes, this complicates the otherwise simple modeling of coherent reflection magnitude using traditional image theory and percentage water. We present an analysis of these error sources in the context of a greater error budget, including vegetation, water depth, small scale roughness, and instrument calibration errors. Finally, we compare statistics and retrievals between simulated measurements and actual CYGNSS data.