

# Range-Dependent Propagation Measurements in a Stable Boundary Layer

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**Abstract**—Stable atmospheric conditions are of great interest in radio propagation research. The Radar and Electromagnetic Ducting in Stable Atmosphere over Water campaign is a multi-university research initiative which seeks to observe and improve understanding of stable conditions and the effect on radiowave propagation. Among various other systems, we obtain range-dependent measurement of propagation loss in a stable environment and compare to simulated results. Our initial findings encourage further investigation.

## I. INTRODUCTION

Refractive conditions of the air, which are directly influenced by meteorological conditions, can have significant effects radio propagation along the horizon. The vertical profile of the refractive index in the boundary layer is well predicted by Monin-Obukhov Similarity Theory (MOST) [1] for unstable and neutral conditions. However, MOST fails to accurately predict the profile under stable atmospheric conditions [2]. In the Spring of 2024, the Radar and Electromagnetic Ducting in Stable Atmosphere over Water (REDSAW) campaign, funded by the office of Naval research (ONR), focused on electromagnetic (EM) and meteorological measurements of the stable boundary layer over the Salton Sea [3]. Our team, along with groups from other universities and companies, deployed numerous EM measurement systems. We successfully refurbished and redeployed the Lower Atmospheric Propagation Ultra-Wide Band (LATPROP-UWB) system [4] for propagation loss measurements from 2 to 40 GHz. We establish three EM links with this system; a 2–40 GHz shore-to-shore link, a C-Band aircraft-to-shore link and a 2–18 GHz ship-to-shore link. The shore-to-shore link is designed for precise propagation loss measurements between fixed points whereas the aircraft-to-shore and ship-to-shore links capture measurements of various points via mobile transmitters at the cost of precision and UWB capabilities.

For a system with a fixed-position receiver, a mobile transmitter allows observation of the propagation phenomenon along one or more spatial dimensions, granting more information than a fixed-position transmitter. During the Coastal Land-Air-Sea Interactions (CLASI) campaign [5], we deployed our phased array receiver alongside various EM and meteorological equipment [6]. The primary measurement mode of the system was via three narrowband transmitters mounted on fixed-position buoys separated in range from the fixed-position receiver system at the shore. Supplemental to these measurements, the Naval Postgraduate School (NPS) personnel operated a Twin Otter aircraft with an onboard narrowband

transmitter and flew straight and level over the buoys toward the receiver array. We compare the measurements to simulated results modeled via a parabolic wave equation (PWE) method [7] on Fig. 1. On the day of this measurement, the environment conditions were unstable and there is agreement between measurement and simulation. One of our goals during the REDSAW campaign is to repeat the range-dependent measurements using various systems to better characterize the stable boundary layer.

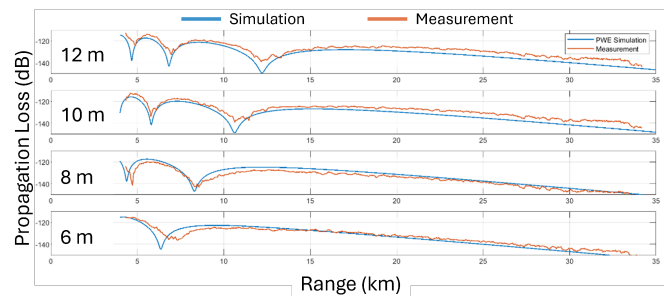


Fig. 1. Propagation loss measurements by the four element, vertical, coherent array during CLASI in Monterey, 2021 (red) compared to simulated propagation loss measurements (blue).

## II. THE SHIP-TO-SHORE SYSTEM

For the ship-to-shore system, which is the focus of this work, we utilize the receiver end of the LATPROP-UWB system with the antenna mounted 12 m above the sea surface as shown in Fig. 2. The transmit end features a 2–18 GHz signal generator installed on a remotely controlled, mobile vessel, the JetYak, operated by NPS personnel. As shown in Fig. 2, the JetYak features various meteorological sensors with a pair of transmitting antennas mounted 2.1 m above the water surface. The JetYak cruises along the EM line as shown in the middle of Fig. 2. The fore and aft transmitting antennas are switched via RF switch accordingly to emit in the direction of the receiver system. The antennas are chosen for their 2–18 GHz performance and wide main beams to reduce the effects of the JetYak motion due to rough sea conditions.

## III. COMPARISON OF SIMULATED AND MEASURED RESULTS

We select the JetYak cruise on May-21 for this work. We simulate the EM propagation using the PWE, modeling the ship-to-shore system configuration. At the same time the

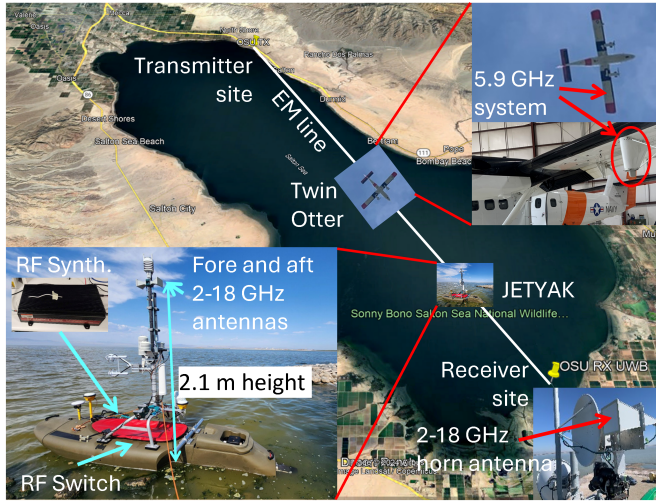


Fig. 2. The deployment locations of various systems during REDSAW (middle). The transmitter end of the ship-to-shore system onboard the JetYak (bottom-left), the transmitting end of the aircraft-to-shore system onboard the Twin Otter (top-right) and the LATPROP-UWB receive antennas used as the receiver end for all systems (bottom-right).

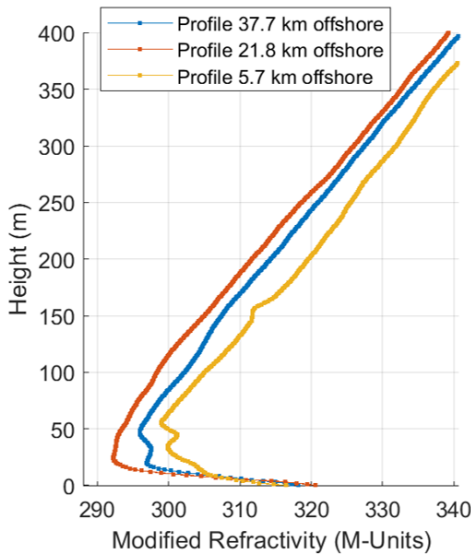


Fig. 3. Refractive profiles measured on 2024-05-21 via dropsondes. Credit to the Naval Postgraduate School and Hank Owen.

JetYak was in operation, the Twin-Otter aircraft measured vertical refractivity profiles via dropsondes and are shown on Fig. 3. We use these profiles as the range-dependent refractive environment in the PWE model. We select three of the fifteen frequencies measured and compare the measured and simulated results in Fig. 4. Notice similar trends in the behaviors over range. Some differences in the results may indicate incomplete characterization of the stable boundary layer in the model, but further analysis is needed. This preliminary result encourages further investigation of the measurements by range-dependent systems during REDSAW.

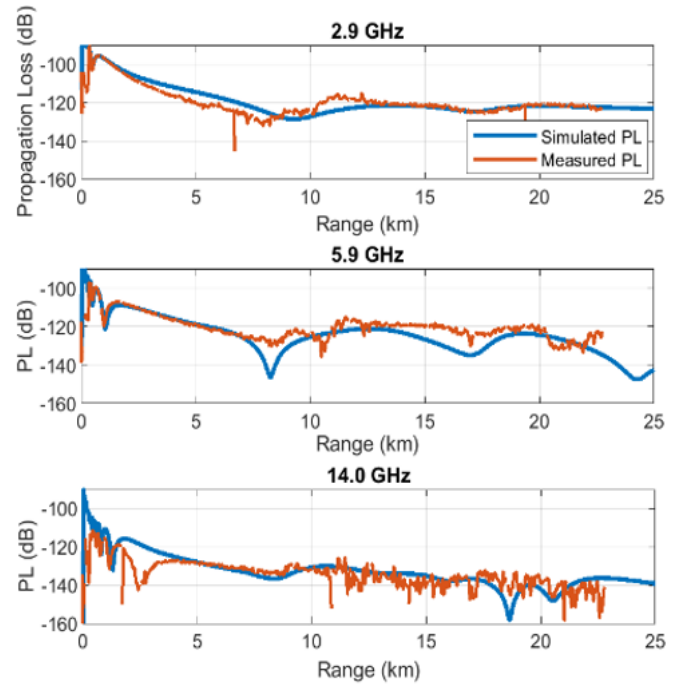


Fig. 4. Measured and simulated results from the ship-to-shore system on 2024-05-21.

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