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Navy Atmospheric Measurements for EM Propagation Modeling

Frederickson, Paul

Monterey, California. Naval Postgraduate School

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Project PI: Paul Frederickson, Research Associate, Dept. of Meteorology, GSEAS

Prepared for:
Topic Sponsor: Office of Naval Research
Research POC Name: Daniel Eleuterio
Research POC Contact Information: Daniel.eleuterio@navy.mil; 703-696-4303

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EXECUTIVE SUMMARY

Project Summary

The ultimate goal of this project has been to improve characterizations of the battlespace environment for operational U.S. Navy electromagnetic (EM) system performance prediction tools. New and past marine surface layer measurements have been used to test, validate and improve models for characterizing near-surface refractivity and the evaporation duct. The analyses performed during this project have led to demonstrated improvements in the performance of the NPS-developed Navy Atmospheric Vertical Surface Layer Model (NAVSLaM), which characterizes the evaporation duct for EM system prediction models, through the use of new dimensionless profile functions for both unstable and stable conditions. The improved performance was validated by systematic comparisons between NAVLSaM-modeled and measured propagation data (Frederickson 2017a and 2017b). The NPS Vertical Refractivity Profile Blending Algorithm (VRPBA) has also been improved as part of this project (Cherrett et al. 2016 and Frederickson et al. 2016) with capabilities to handle new environmental situations. Lastly, in collaboration with Jon Pozderac of the Ohio State University, the NAVSLaM model has been used to validate and improve the OSU X-band evaporation duct height estimation algorithm (Pozderac et al. 2017). In the month remaining before this project is completed, further analyses and validations will be performed with newly available experimental data from the Coupled Air Sea Processes and EM-ducting Research (CASPER) project. The modeling improvements resulting from this project will lead to more accurate EM system (radar, electronic attack, surveillance, communications, etc.) performance predictions for U.S. Navy warfighters.

Keywords: electromagnetic (EM) propagation, radar performance, evaporation duct, refractivity, Navy Atmospheric Vertical Surface Layer Model (NAVSLaM)

Background

Due to the persistence and critical impact of the oceanic evaporation duct on the propagation of radio waves, great effort has been made by U.S. Navy researchers over the past several decades to accurately model this refractivity feature in order to predict its impact on the performance of radars and other EM systems. The Navy Atmospheric Vertical Surface Layer Model (NAVSLaM), developed at NPS by this PI, is the U.S. Navy

standard evaporation duct model and, like many other models, it employs Monin-Obukhov similarity theory (MOST). MOST depends upon empirically-determined functions and physical assumptions that may not always be valid, therefore these functions and assumptions require extensive validation with actual experimental data.

The U.S. Navy is also increasingly relying upon numerical weather prediction (NWP) models, such as the Coupled Ocean-Atmospheric Mesoscale Prediction System (COAMPS), to characterize the refractivity environment for EM system performance predictions. It is currently not practicable for models such as COAMPS to have the required vertical resolution to characterize the evaporation duct with sufficient fidelity for EM propagation modeling purposes, nor is it clear that these mesoscale models have sufficient surface layer physics for this purpose. For these reasons, it is necessary to predict the evaporation duct using models such as NAVSLaM with input data from COAMPS, and then to realistically blend this near-surface refractivity profile onto the bottom of the COAMPS upper-air refractivity profile. NPS has developed the Vertical Refractivity Profile Blending Algorithm (VRPBA) with this goal in mind. An objective of this effort is to evaluate and compare different blending approaches using the combined marine surface layer measurements from multiple experiments.

Findings and Conclusions

The area with the most potential for improving the performance of evaporation duct models such as NAVSLaM is to incorporate improved dimensionless profile functions, especially for humidity and temperature, due to the model's high sensitivity to the form of these functions. Several different sets of empirical functions (i.e. Beljaars and Holtslag 1991, Grachev et al. 2000, Cheng and Brutsaert 2005, Grachev et al. 2007) have been evaluated, as well as modifications to these published forms. Comparisons were made between NAVSLaM-modeled data using the different profile functions and propagation data from the Roughness and Evaporation Duct (RED) Experiment conducted off Hawaii in 2001 and the Wallops 2000 Experiment. Based on these evaluations it is clear that the blended functions presented by Grachev et al. and used in the well-known Coupled Ocean-Atmosphere Response Experiment (COARE) model (Fairall et al. 1996), are not the best choices. The standard 'Kansas' type Businger-Dyer functions (Businger et al. 1971, Dyer 1974) with no blending clearly performed better than the blended Grachev et al. (2000) approaches in unstable conditions, as seen in Figure 1, with significantly lower mean and RMS differences between the modeled and measured data for NAVSLaM when using the Kansas functions. For stable conditions

(not shown here) the use of a modified form of the Grachev et al. (2007) profile functions in NAVSLaM performed better than the original published functions, or the Beljaars and Holtslag (1991) or Cheng and Brutsaert (2005) funcitons. These improved functions have been incorporated into NAVSLaM Version 1.2, which has recently been accepted as the U.S. Navy standard evaporation duct model in the Commander Navy Meteorology and Oceanography Command (CNMOC) Oceanic and Atmospheric Master Library (OAML).

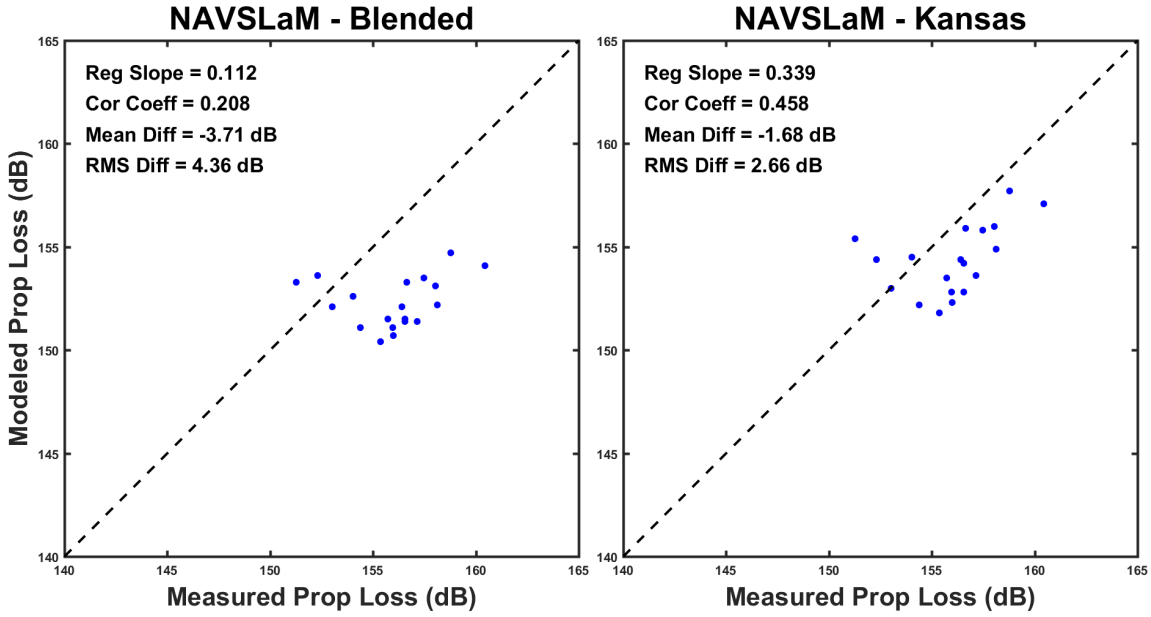

Figure 1. Scatter plot of modeled versus measured propagation loss in dB from the RED Experiment of 2001 with unstable conditions, for NAVSLaM using the Grachev et al. (2000) blended profile functions in the panel on the left, and the 'Kansas'-type functions of Dyer 1974 on the right.

The Vertical Refractivity Profile Blending Algorithm (VRPBA), developed by this PI, is currently used in operational U.S. Navy EM prediction systems. A study of data from the Wallops 2000 Experiment indicated that the blending algorithm should give more precedence to the COAMPS refractivity profiles in cases when COAMPS predicted a deep surface-based trapping layer. A parameter was introduced into the VRPBA to allow the user to set how much precedence to be given to NAVSLaM or to COAMPS, and recommended values for this parameter were established. Figure 2 shows an example in which COAMPS predicts a deep surface-based trapping layer, whereas the NAVSLaM refractivity profile computed from the lowest level COAMPS data predicts a much lower evaporation duct height (EDH). In such cases, blending with an EDH-based blending

interval produced a refractivity profile which is judged to depart too significantly from the COAMPS prediction, and thus a much lower blending interval was used to preserve the original COAMPS profile more, while importantly eliminating the sharp near-surface 'kink' at the lowest COAMPS model level.

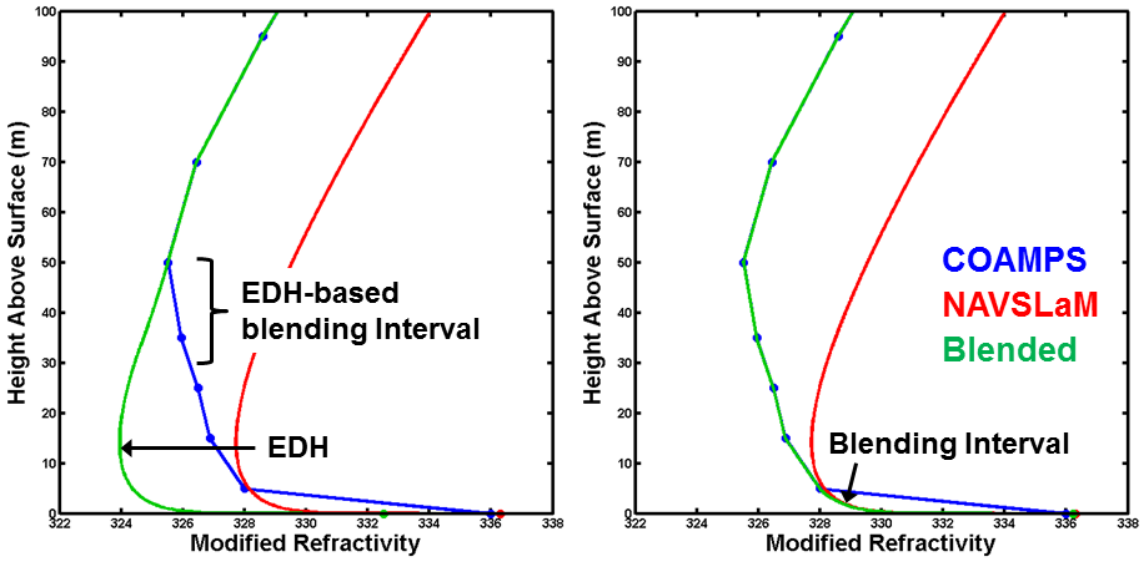

Figure 2. Examples of blended vertical modified refractivity profiles (green) produced from blending the COAMPS (blue) and NAVSLaM (red) predicted profiles. The new VRPBA produces blended profiles that more closely follow the original COAMPS profiles in situations when COAMPS predicts a much deeper surface-based trapping layer than indicated by NAVSLaM, as shown in the right panel.

In conclusion, the demonstrated improvements in the operational NAVSLaM and VRPBA models made possible through this study will lead to more accurate EM system performance predictions being provided to U.S. Navy warfighters, which will enable the warfighters to more effectively employ their sensors and weapons systems in the current or predicted environmental conditions.

Recommendations for Further Research

New data being collected as part of the ongoing Coupled Air Sea Processes and EM-ducting Research (CASPER) project, directed by Professor Qing Wang of the NPS Department of Meteorology, represent a promising source of experimental data for further model improvement and validation, which should be vigorously exploited. Further evaluations with this new data will continue over the month remaining in this project, and it is hoped further model improvements will result.

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