

# **Near-Surface Atmosphere and Surface Wave Influences on Rf/EO Propagation over the Sea**

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## **LONG-TERM GOALS**

The long-term goal of the Naval Postgraduate School's research effort as part of the Roughness and Evaporation Duct (RED) Experiment is to obtain a more complete understanding and improve parameterizations of atmospheric and surface wave effects on radio-frequency (Rf) and electro-optical (EO) propagation near the ocean surface, and ultimately to enable Navy warfighters to operationally assess and predict environmental effects on weapons/sensor systems in order to gain a tactical advantage over any adversary through knowledge superiority.

## **OBJECTIVES**

The initial objective of NPS participation in the RED Experiment was to obtain high quality atmospheric and wave data required to directly address the experimental science issues, which are: 1) To determine the effect of surface roughness on near-surface refractivity profiles and, consequently, on Rf/EO propagation; and 2) To evaluate and validate new surface roughness and near-surface profile and aerosol distribution parameterizations. The ultimate objective of this effort is to evaluate the application of existing Monin-Obukhov surface layer scaling formulations over the wavy ocean surface under a wide variety of conditions and where necessary to develop modified scaling functions for near-surface profiles and turbulence quantities and parameterizations to describe their effects on Rf/EO propagation.

## **APPROACH**

The approach used to meet the goals and objectives of this effort was to: first, deploy the NPS 'flux' buoy instrumented with at the mid-point of the RED EO path and obtain the necessary meteorological and wave data concurrently with the EM/EO propagation data obtained by K. Anderson (SPAWAR Systems Center, San Diego); second, to perform analyses and interpretations on the combined meteorological/propagation data sets to examine the effects of atmospheric and surface wave properties on optical and microwave propagation characteristics and find relationships between the various properties studied; and third, quantify these relationships and develop new physically-based parameterizations to enable the modeling and prediction of atmospheric effects on propagation. Specifically, the directly measured air-sea fluxes and atmospheric profiles will be compared to mean meteorological and wave quantities in order to determine under which conditions Monin-Obukhov similarity theory must be modified over the ocean, and to develop new physically-based parameterizations. Collaborations with scientists from other research institutions, such as K. Anderson, S. Doss-Hammel (SSC-SD), C. Friehe (UCI), L. Forand, D. Dion (DREV), A. deJong and G. deLeeuw (TNO), continue to be critical to this effort.

# Report Documentation Page

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## **WORK COMPLETED**

High-quality meteorological and surface wave data were successfully obtained by NPS during the RED Experiment from the NPS flux buoy and from an instrumented research vessel, the R/V *Wailoa*. The location of the NPS flux buoy at the mid-point of the EO propagation path and the *Wailoa* boat tracks along both the Rf and EO paths are shown in Figure 1 in relation to other RED Experiment assets. The buoy data consists of mean and turbulent meteorological parameters (including temperature and humidity profiles and directly-measured values of  $C_T^2$  and air-sea fluxes) and one-dimensional and directional spectral wave information. Near-surface refractivity profile data were obtained from a small boat using kite-borne radiosondes, as well as standard up/down radiosonde profiles from balloons. A time series of the mean meteorological data obtained from the flux buoy, a summary of the kite-sonde profile data, and the collection periods for the RED microwave and optical propagation data are shown in Figure 2.

A preliminary processing of the NPS data has been completed, and the documented buoy data set has already been provided to collaborating RED Experiment researchers. Both the NPS buoy and kite data sets have been merged with the SPAWAR Systems Center, San Diego (SSC-SD) propagation data and analyses and interpretations regarding air-sea interaction effects on Rf/EO propagation have been conducted on these combined data sets. Propagation loss predictions have been obtained using the Advanced Propagation Model (APM) with NPS buoy data as input, and these data have been compared with the SSC-SD propagation measurements. These analyses have resulted in the completion of five conference presentations with extended papers for the American Meteorological Society's 12<sup>th</sup> Conference on the Interaction of the Sea and Atmosphere in February 2003 and also an NPS masters theses (see publications listed below) up to this date. Additional papers are planned and in preparation to present RED results.

## **RESULTS**

It was found that the near-surface profiles of temperature and humidity (and hence modified refractivity) measured on the NPS buoy and from the kite-sondes often disagreed with predictions based on traditional Monin-Obukhov similarity theory. These scalar gradients tended to be less steep just above the surface in most cases, indicating that ocean waves induce significant mixing in the lower part of the surface layer, which decreases the scalar gradients from predictions based on the traditional 'Kansas'-type functions that were determined over land. These wave-induced influences on the modified refractivity profile appear to contribute to the observed discrepancy between measured microwave propagation loss and APM-predicted loss based on the mean NPS buoy data, especially in X- and Ku-band, which exhibit much lower loss than predicted.

## **IMPACT/APPLICATIONS**

The successful achievement of the goals of this ongoing research project will greatly improve current understanding of ocean wave effects on near-surface atmospheric properties and the reflectivity and scattering of Rf waves, which in turn will lead to an improved ability to predict IR and microwave propagation. The RED Experiment results are currently being applied to verify and improve the NPS evaporation duct model, which is used in many DoD research and operational applications.

## TRANSITIONS

The modified and improved bulk model parameterizations expected to result from this research effort will be utilized for many different applications of importance to the Navy warfighter, especially radar and IR propagation assessment and prediction models and tactical decision aids (TDAs) and coupled air-ocean prediction models.

## RELATED PROJECTS

This research effort is closely related to other projects being conducted by NPS in the field of atmospheric effects on Rf/EO propagation. NPS has been and continues to be a participant in propagation studies conducted by the Naval Surface Warfare Center, Dahlgren Division off Wallops Island ('98, '00 and proposed for '03), and radar signature studies conducted by NSWC, Crane Division off Dam Neck, Virginia, in '02, with additional tests planned. We are currently working jointly with SPAWAR (PMW-155) on the development of an integrated model for Rf propagation.

## PUBLICATIONS

Anderson, K. D., P. A. Frederickson, and E. Terrill, 2003: Air-sea interaction effects on microwave propagation over the sea during the Rough Evaporation Duct (RED) Experiment. Preprints, *12<sup>th</sup> Conf. on Interaction of the Sea and Atmosphere*, Long Beach, CA, Am. Met. Soc., 9-13 February 2003.

Davidson, K. L., P. S. Guest, D. L. Mabey, P. A. Frederickson, and K. D. Anderson, 2003: The use of kite observations to study air-sea interaction-controlled atmospheric surface layer profiles during the RED Experiment. Preprints, *12<sup>th</sup> Conf. on Interaction of the Sea and Atmosphere*, Long Beach, CA, Am. Met. Soc., 9-13 February 2003.

Doss-Hammel, S., D. Tsintikidis, P. Frederickson, and K. Davidson, 2003: Near-surface scintillation in the marine atmospheric layer during the RED field campaign. Preprints, *12<sup>th</sup> Conf. on Interaction of the Sea and Atmosphere*, Long Beach, CA, Am. Met. Soc., 9-13 February 2003.

Frederickson, P. A., K. L. Davidson, K. D. Anderson, S. Doss-Hammel, and D. Tsintikidis, 2003: Air-Sea Interaction Processes Observed from Buoy and Propagation Measurements during the RED Experiment. Preprints, *12<sup>th</sup> Conf. on Interaction of the Sea and Atmosphere*, Long Beach, CA, Am. Met. Soc., 9-13 February 2003.

Mabey, Deborah L., 2002: Variability of Refractivity in the Surface Layer: RED Buoy/Kite Profiles. Naval Postgraduate School M.S. Thesis, June 2002, 45 pp.

Tsintikidis, D., S. Doss-Hammel, P. Frederickson, and K. Davidson, 2003: Infrared Propagation in the Marine Atmospheric Surface Layer: Extinction and Refraction. Preprints, *12<sup>th</sup> Conf. on Interaction of the Sea and Atmosphere*, Long Beach, CA, Am. Met. Soc., 9-13 February 2003.

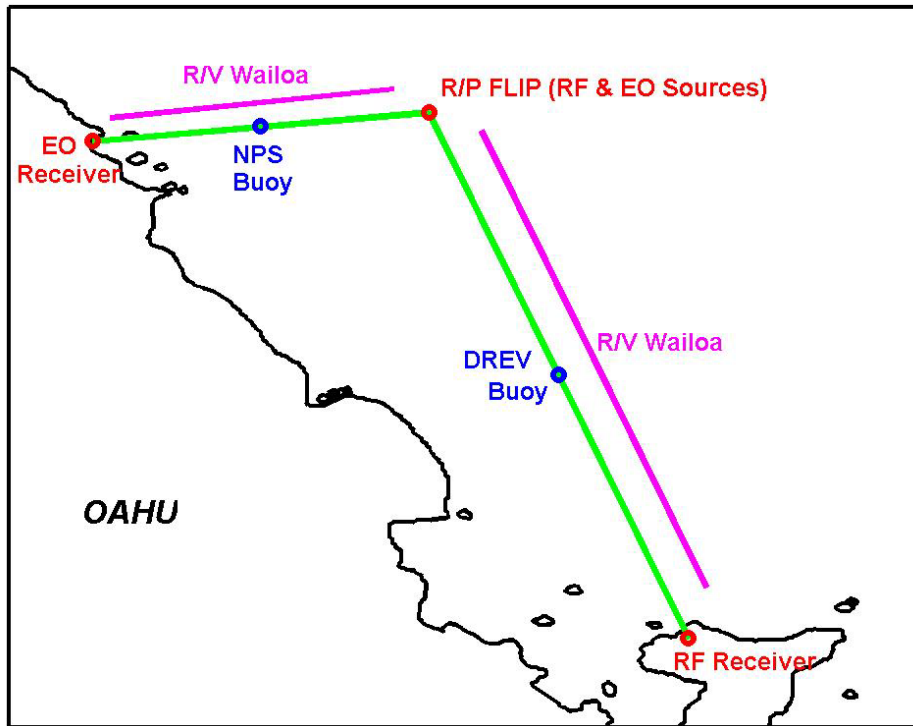


Figure 1. Map of the RED Experiment setup off Oahu

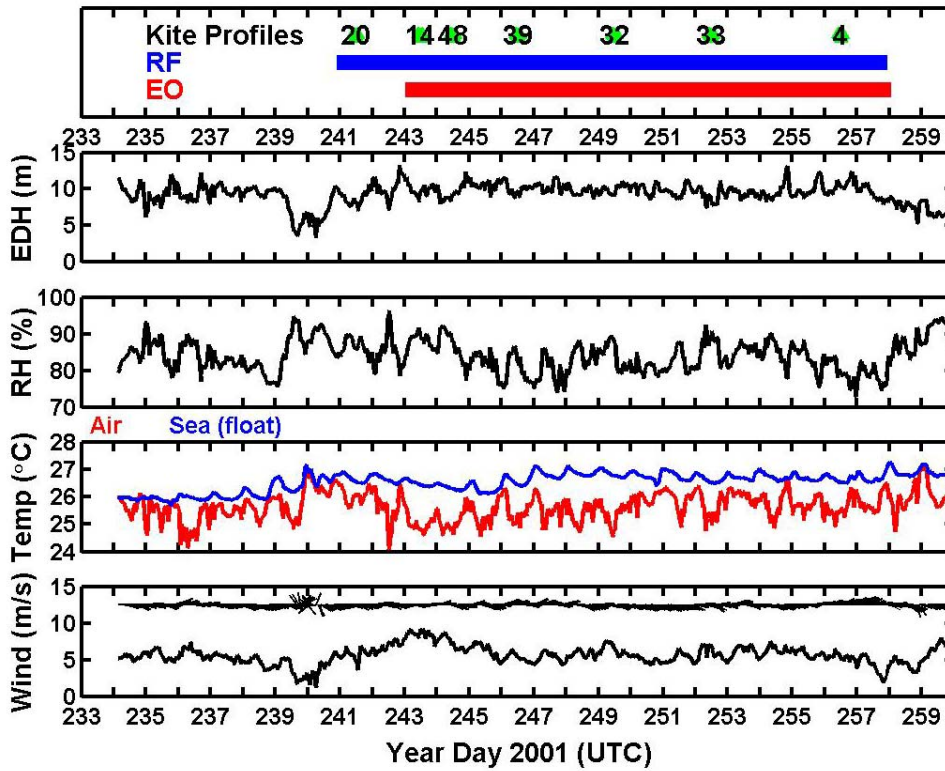


Figure 2. Time series showing mean NPS flux buoy measurements in relation to kite profile and RF and EO propagation data coverage. The top panel indicates the number of kite profiles obtained on different days and shows the times when Rf and EO data were obtained. (Note: EDH is the evaporation duct height).