Scaling Near-surface Atmospheric and Surface Wave Influences On Radar Propagation Over the Sea

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LONG-TERM GOALS

To improve models for describing near-horizon radar propagation by proper specification of the near-surface atmosphere refractivity gradients and wind influenced surface roughness.

OBJECTIVES

To evaluate Monin-Obukhov surface-layer scaling for describing near surface gradients of refractivity and on characterizing the surface roughness for radar backscatter and propagation within evaporation ducting.

APPROACH

The overall approach is to perform special joint analyses/interpretations on environmental measurements from buoys and vessels and near-shore radar data obtained during a coordinated EM propagation experiment conducted off Wallops Island, Virginia, in March-April 1998. Participants in the experiment were the Naval Surface Warfare Center, Dahlgren Division (NSWC-DD), SPAWAR Systems Center-San Diego (SSC-SD), the Johns Hopkins University, Applied Physics Laboratory (JHU/APL) and the Naval Postgraduate School (NPS). The defining feature of this experiment was the coordinated measurement of the marine surface layer environment and surface wave field, together with radar field strength (NSWC-DD) and backscatter inversion (SPANDAR, SSC-SD).

Approach: Formation of merged data set

There will be a formation of a data set for analysis/interpretation that consists of the atmospheric and radar data sets. The merged in situ data set will be used to document environmental conditions and to evaluate surface-layer scaling for the description of radar propagation. It will be based on both mean surface layer and wave measurements (from buoys and ships) and turbulence and near-surface profile measurements (from the instrumented vessel *Chessie* and the catamaran).

Approach: Estimating surface-layer refraction conditions

The near-surface refractivity profile is most frequently described in terms of the evaporation duct height. Existing Monin-Obukhov (MO) surface-layer scaling provides general empirical expressions

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for near-surface gradients (d*X*/d*z*) in terms of velocity, temperature, humidity, and buoyancy scaling parameters (u_*, T_*, q_*, g/T). This enables the evaporation duct height to be estimated from single-level measurements of mean quantities using bulk methods. The NPS bulk model will be used to estimate evaporation duct heights for all data sets. The scaling parameters u_* and T_* estimated from the *Chessie* NPS sonic anemometer measurements will be analyzed to evaluate and verify the MO-based bulk model for the near-shore region in the presence of swell.

Approach: Characterizing atmospheric forcing and wave descriptions for clutter

This is particularly important for interpreting the SSC-San Diego obtained SPANDAR data. The wind stress is the mechanical forcing by the wind on the ocean surface. As such, the turbulence-controlled wind stress is an intermediate link between the atmosphere and the ocean for interpreting radar-measured features. Interpretations will be based on spatial patterns within the SPANDAR fields and combined near-surface refractivity gradient and temporal/spatial wind stress estimated from ship and buoy in situ data. The relation between radar clutter and the wind stress and measured roughness elements may depend on swell. The swell dominated regime is not understood relative to influence of momentum flux on surface backscatter. The NPS wave-rider buoy provided two-dimensional wave statistics for wind waves and swell. These two-dimensional descriptions of surface waves will be merged with the wind stress scaled capillary waves for interpretations.

WORK COMPLETED

The combined collection of in situ environmental and remote (radar) data occurred off Wallops Island, Virginia, from 4 March to 3 April 1998. Table 1 is a summary of the Wallops '98 combined atmospheric and ocean surface data set. The measurements obtained by NPS are denoted by bold **X**'s in this table.

NPS has completed the merging of the environmental measurements from all platforms (NPS buoys, NSWC-DD buoy and *Sealion*, JHU/APL *Chessie* and catamaran) into one combined data set available for analyses/interpretation by all experiment participants. The merged data set is useful not only because it facilitates inter-comparisons and joint analyses, but also because data 'gaps' from individual platforms are usually filled in with data from other available platforms. This data set includes evaporation duct height and scaling parameter estimates (u_*, T_*, q_*) for all measurement platforms computed using the NPS bulk model.

The merged data set provided by NPS is currently being used by NSWC-DD and SSC-SD for combined analysis with other data sources. NSWC-DD (Michael Young) has merged the environmental data with helicopter-measured refractivity profiles and radar propagation data and is currently leading a collaborative effort to investigate temporal and spatial variations in refractivity conditions in the littoral zone. SSC-SD (Ted Rogers) has compared the NPS bulk evaporation duct height estimates with inferred refractivity from clutter (RFC) duct heights using SPANDAR radar data, with promising results.

The Wallops '98 experiment has provided an excellent opportunity to test and validate the NPS bulk evaporation duct model. This model has been provided to NSWC-DD (Michael Young) and is currently being used to compare refractivity profiles from the bulk model with helicopter measurements. The NPS evaporation duct algorithm is also being incorporated into a meso-scale forecast model (COAMPS) by The Pennsylvania State University, Applied Research Laboratory (Stephen Fast) to study propagation variations over a larger spatial and temporal time scale.

Inertial-dissipation wind speed and temperature scaling parameters (u_* and T_*) have been computed from the NPS sonic anemometer data obtained on the *Chessie*. A sample time series of *Chessie* data from 2 April 1998 presented in Fig. 1 shows good agreement between bulk estimates and inertial-dissipation measurements of u_*, indicating that the bulk model is performing adequately in the coastal environment off Wallops Island.

Table 1. Wallops '98 Atmospheric Boundary Layer Merged Data Set

Platform Type/ Platform	**Buoys**			**Vessels**	
	NPS Mean Met	NPS 2-D wave	NSWC-DD Endeco	JHU/APL *Chessie*	NSWC-DD *Sealion*
Mean Atmospheric					
Vector Wind	**X**		X	X	X
Air Temperature	**X**		X	X	X
Humidity	**X**		X	X	X
Atmospheric Pressure	**X**		X	X	X
Turbulent Atmospheric					
Wind				**X**^{1}	
Temperature				**X**^{1}	
Atmospheric Profiles					
Near-surface (T,RH)				X^{2}	
Mixed-layer (T,RH,P)				X^{3}	
Surface Properties					
SST interfacial (IR)	**X**			X^{2}	
SST bulk (thermistor)	**X**		X		X
2-D wave/swell		**X**	X		

[1] NPS sonic
[2] JHU/APL catamaran

RESULTS

Merged time series data from the NPS met and wave buoys over the 4 March to 3 April 1998 period are presented in Figure 2. These results show the wide range of stratification conditions encountered during the experiment. Evaporation duct height estimates from the NPS bulk model are shown in the top panel. Focus days based on activities by the NSWC-DD, JHU/APL and SSC-SD groups are identified by color-coded marks in the top panel. The radar periods of interest are for daytime hours of these days. Adequate environmental data exists for most focus days from at least one measurement platform.

Measured temperature profiles from the *Chessie* and the catamaran have been compared with bulk model predictions based on MO scaling. These comparisons indicate that the near-surface scalar profiles predicted by traditional MO theory may over-estimate the profile steepness over ocean swell under stable stratification. A likely cause of this observation is that waves induce additional mixing in the stable surface layer, leading to smaller vertical scalar profiles.

IMPACT/APPLICATIONS

The potential future impact is for understanding the influence of waves on the overlying scalar profiles and applications include improved prediction of near-horizon radar propagation conditions.

TRANSITIONS

These results are being used to improve operational models now used in the fleet. The NPS bulk evaporation duct model is currently being incorporated into the MORIAH data acquisition and analysis system to provide real-time information on EM propagation conditions.

RELATED PROJECTS

The ONR Electro-Optical Processes and Coastal Environment is a closely related projects because it also requires improved models of near-surface gradients, affecting optical wavelengths.

PUBLICATIONS

Frederickson, P. A., K. L. Davidson, C. R. Zeisse, and C. S. Bendall, "Estimating the Refractive Index Structure Parameter (C_n^2) Over the Ocean Using Bulk Methods." Accepted by *Journal of Applied Meteorology*, September 1999.

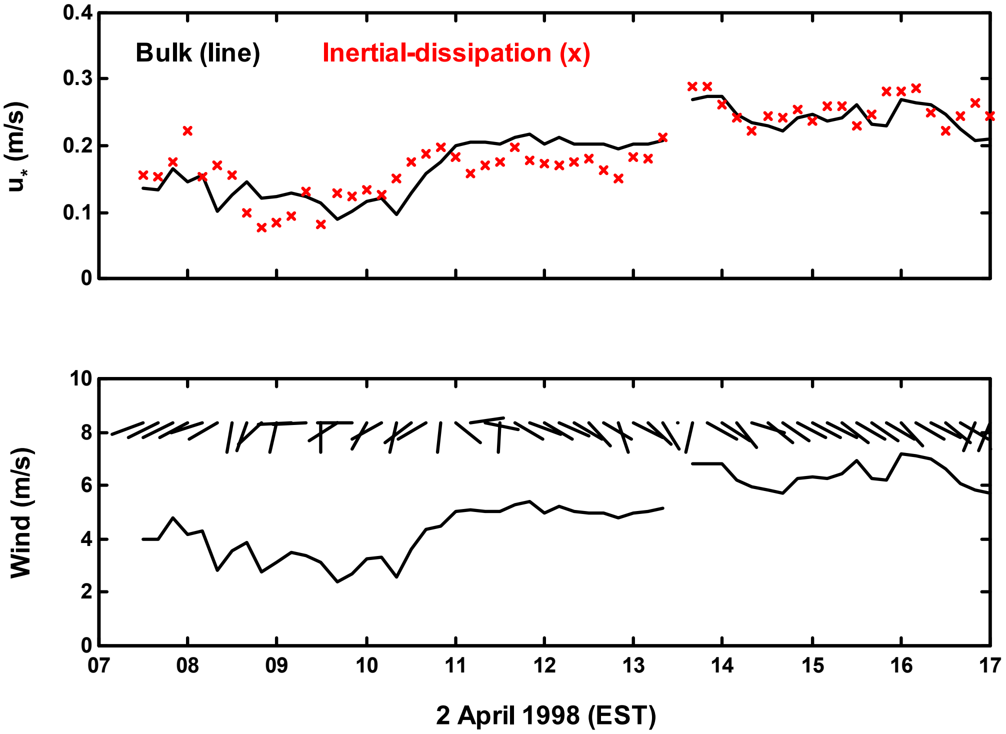

Figure 1. Time series of Chessie data for 2 April 1998. Top panel: bulk u_* estimates indicated by solid line, inertial-dissipation u_* values from NPS sonic anemometer indicated by red x's. Bottom panel: wind speed indicated by solid line, wind direction indicated by barbs.

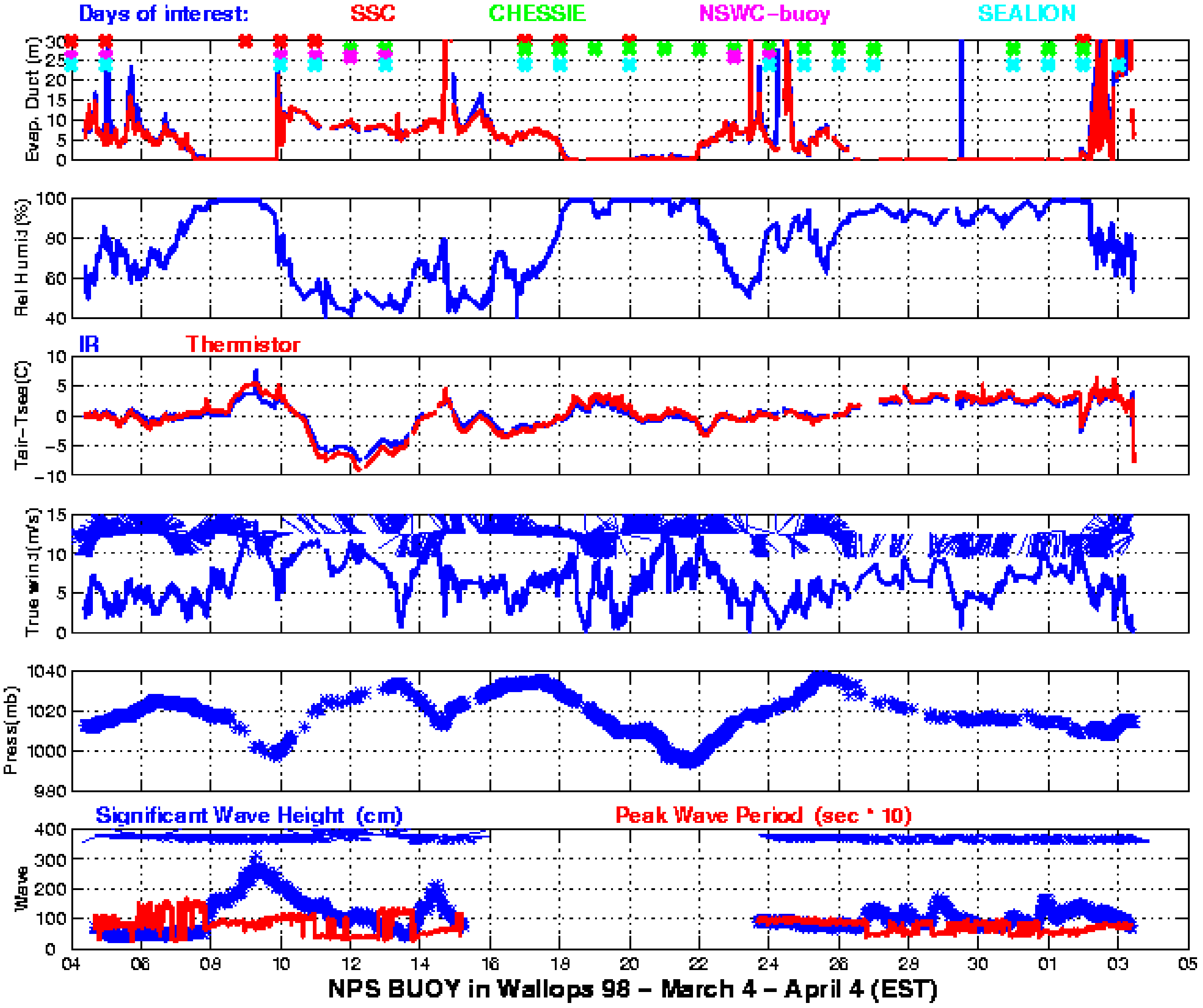

Figure 2. Time series from NPS Wallops '98 mean meteorology and wave buoy measurements and calculated evaporation duct heights. Color coded symbols in top panel indicate days of