Electromagnetic Ducting Research and Applications as part of CASPER

Teddy R. Holt
Naval Research Laboratory
Monterey, CA 93943-5502
phone: (831) 656-4740 fax: (831) 656-4769 email: teddy.holt@nrlmry.navy.mil
Award Number: N0001415WX01553

LONG-TERM GOALS

The long-term goal is to conduct research on numerical simulation and prediction of air-land-wave-sea coupled processes in the littoral environment, with a particular emphasis on the impact on electromagnetic refractivity and tropospheric scatter as part of the Coupled Air-Sea Processes and Electromagnetic Ducting Research (CASPER) field project. This effort will support pre-field study scientific objectives and plans development, at-sea mission real-time planning, as well as the data analysis, quality control, assimilation and synthesis of in situ and remotely-sensed ocean and atmospheric environmental conditions.

The CASPER project is sponsored by the Office of Navy Research (ONR) 2014 Multi-disciplinary University Research Initiative (MURI) to address overarching knowledge gaps related to electromagnetic (EM) wave propagation in coastal Marine Atmospheric Boundary Layers (MABL). The objective, as described in the Science and Experiment Plan (Wang et al. 2015), is to “fully characterize the MABL as an EM propagation environment. The emphases will be on spatial heterogeneities and surface wave/swell effects, both of which contravene underlying assumptions of Monin-Obukhov Similarity Theory (MOST) used in coupled environmental forecast models and evaporative duct models. Furthermore, coastal variability in the elevated trapping layer atop the MABL presents a challenge to forecast models and also causes practical issues in trapping layer interpolation in EM prediction models. These issues are the target of investigation of CASPER.”

OBJECTIVES

The CASPER field exercises aim to be the most comprehensive suite of measurements of co-located atmospheric, oceanographic, air-sea flux and propagation data that has been collected since Wallops-2000. The Marine Meteorology Division at the Naval Research Laboratory (NRL MMD) proposes to use this immense dataset to (i) investigate the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS\textsuperscript{®}) ability to capture the mesoscale and boundary layer gradient structures in the surface layer as well as the land and marine boundary layers across the coastal environment and to (ii) evaluate how the propagation of electromagnetic signals within and above the MABL are affected by COAMPS prognosis of the refractive environment. The model predictions will be analyzed with the measured propagation data to determine the level of fidelity in radar detection range estimates. From

\textsuperscript{1} COAMPS is a registered trademark of the Naval Research Laboratory.
the range, bearing and temporal dependencies in the propagation data, an evaluation of spatial patterns
in sensor performance will be conducted and used to validate COAMPS sensor performance surfaces
generated across COAMPS high resolution grids.

**APPROACH**

There are two main components to the technical approach: (i) real-time modeling support, and (ii)
post-time modeling analysis. For the first component, the real-time modeling support includes pre-
field study scientific objectives and plans development, field study model forecasts, at-sea mission
real-time planning, and data archiving. For the pre-field study scientific objectives and plans
development, NRL MMD will provide a dedicated COAMPS-OS web page (air-ocean-wave) with
displays of 2-D Maps, additional EM/ducting fields, meteograms, customized cross-sections,
soundings, and hourly AREPS (Advanced Refractive Effects Prediction System) GRIB-2 data. Model
products will be available for daily forecast discussion/mission planning (in collaboration with the
Naval Postgraduate School, NPS). NRL MMD will also provide archival of all model binary data. For
the second component, the post-time model analysis will focus on a) COAMPS model validation
efforts for the surface layer, sea surface (temperature, currents, and waves), vertical structure (both
spatial and temporal) for meteorology and refractivity/ducting, turbulence and fluxes, and profile
blending; b) propagation analysis along the primary ship-track for vertical refractivity structures,
ducting layers, and propagation path loss for all deployed sensors; and c) grid-wide analysis for
maximum detection range for three target types as well as for all deployed sensors.

An integral component to the data analysis effort is the data collection needs. As part of the CASPER
field program, NRL MMD would require both meteorological and radar data. For meteorological data,
the following requirements are desired: (i) 4-hourly radiosonde profiles (including at night) at the
Duck, NC pier and over water, near-surface to 1.5 km; (ii) observations (coincident with radiosonde
location and time) of high quality sea surface temperature (SST) measurements, bulk surface
measurements, photographs of the horizon, and log records of clouds, visibility, winds, and seas; (iii)
at least one buoy location with continuous (10-min) data of surface sensible, latent heat fluxes and
wind stress, continuous bulk surface data, and SST (~0.2 m depth); (iv) range-dependent vertical
structure (aircraft saw tooth pattern) of meteorological data, turbulence/turbulent kinetic energy (TKE)
measurements, and fluxes. For radar data, it is desired to have data coincident with ship/radiodonde
data for detection ranges, clutter data, and ship-to-shore propagation loss (range versus height).

**WORK COMPLETED**

NRL MMD participated in the CASPER Pilot experiment conducted off the west coast of the US from
20 April-4 May 2015. NRL MMD provided real-time COAMPS-OS modeling support and
collaborated with NPS to provide high-resolution air-ocean-wave forecasts for mission planning and
execution. Figure 1 shows a summary of the COAMPS setup for modeling support provided for the
CASPER Pilot experiment. In preparation for the CASPER EAST field program in October 2015,
NRL MMD has participated in planning meetings and teleconferences. NRL MMD has setup
COAMPS-OS to provide real-time air-ocean-wave modeling support (available from a dedicated web
site). Figures 2 and 3 show the proposed modeling setup for the CASPER EAST field program. NRL
MMD has also coordinated with NRL-Stennis to provide WaveWatch III (WW3) forcing for SWAN
simulations and made several model improvements in the urban and land surface model (LSM) linkage
with the coupled air-ocean model that have shown to be important for regions that are more heavily
urbanized, such as the East Coast of the US.
RESULTS

The primary technical results for this COAMPS-OS modeling and analysis project are those gleaned from the CASPER Pilot experiment. Figure 4 shows an example of the types of COAMPS-OS related output from the Pilot Experiment. Based on the results from the Pilot experiment, and the subsequent planning discussions for the CASPER EAST field project, NRL MMD was able to provide customized improvements to the COAMPS-OS model setup and product suite to better aid the forecast team in providing both mission planning information as well as real-time forecasts. Specifically these improvements include: (i) higher horizontal resolution (2-km) atmospheric grid; (ii) tailored meteorological and ducting products along the ship track; (iii) coordinated propagation loss/radar measurements with ship/radiosonde observations; and (iv) need for real-time SST. These improvements are evident in the new setup (as shown in Figures 2 and 3), as well as the desired data needs discussed in the approach section.

IMPACT/APPLICATIONS

There are significant impacts and implications of the proposed COAMPS-OS modeling and refractivity/ducting study. Improved three-dimensional on-scene environmental assessments with high-resolution numerical modeling will significantly impact Area Access/Anti-Denial (A2AD) and warfare mission planning and execution. The analysis of model predictions in conjunction with measured propagation data to evaluate spatial patterns in sensor performance for validation of high-resolution COAMPS radar detection range estimates aligns closely with Navy S&T goals for information dominance in the battlespace environment.

RELATED PROJECTS

This project is related to the “Improved EM tactical applications through UAS-enhanced high-resolution mesoscale data assimilation and modeling” project via the implications for EM and coastal modeling applications. It is also related to related 6.2 projects within PE 0602435N that focus on the development of the atmospheric components (QC, analysis, initialization, and forecast model) of COAMPS. Developments in model post-processing software concerning the diagnosis and analysis of fields relevant to EM propagation prediction generated for this work are also currently in use by the SPAWAR-funded “Validation of tactical-scale EM propagation: COAMPS:EM” project and will likely also extend to the NRL-BASE funded “Boundary Layer Characterization for EM Propagation Predictions” project. This synergy of tool development among projects involving EM propagation serves to harmonize and expedite products for research and operational use.

REFERENCES

Figure 1. COAMPS-OS model setup in support of the CASPER Pilot Experiment (April 2015).

Figure 2. COAMPS-OS proposed model setup for the CASPER EAST experiment (October 2015).
Figure 3. Zoom depiction of proposed COAMPS-OS inner-nest (2-km) and ship track cross-sections for the CASPER EAST experiment.

Figure 4. Sample COAMPS-OS related output for the CASPER Pilot experiment.