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Operationally Relevant 4D Refractivity

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LONG-TERM GOALS

Investigate and develop engineering metrics that quantify how improvements to the Coupled Ocean Atmosphere Mesoscale Prediction system (COAMPS®) impact electromagnetic (EM) propagation predictions. Identify and correct limitations of NWP modeling capability to enable operationally relevant four dimensional littoral refractivity fields for radio frequency (RF) and sensor performance analysis.

OBJECTIVES

1) Design and test radio frequency engineering metrics that quantify the performance of advanced electromagnetic (EM) propagation codes, electronic warfare support measures (ESM) models and common data link (CDL) systems driven by numerical weather prediction (NWP) refractivity fields.

2) In collaboration with the NAVSEA EM engineering community, define operationally significant engineering-based performance metrics for ESM and CDL system designs.

3) Establish benchmark engineering performance metric values that quantify the current level of performance for NWP/EM code systems for radar, electronic warfare and communications.

4) Identify and target specific improvements to NWP models that will improve the performance metrics for NWP/EM code systems.

5) Exploit the comprehensive four dimensional surface layer, mixing layer and entrainment layer meteorological and multi-wavelength propagation data set from the Tropical Air-Sea Propagation Study (TAPS 2013).

6) Enhance the development of over sea and land surface layer/mixing layer blending in COAMPS by collaborating with TAPS 2013 numerical weather prediction teams from the UK Met Office, Environment Canada, Royal Australian Navy, and Meteo France.

APPROACH

Utilize the littoral non-standard radio frequency propagation environment by employing COAMPS® mesoscale numerical weather prediction techniques focused on resolving coastal marine atmospheric boundary layer (MABL) processes to provide an operationally relevant diagnostic and prognostic propagation information system. Combine COAMPS® NWP refractivity profiles with the operationally significant surface layer refractivity provided by the Navy Atmospheric Vertical Surface Layer Model (NAVSLaM). This capability coupled with a well-designed decision aid will lead to more well informed exploitation of non-standard propagation fields by Tactical Action Officers in order to re-deploy spectrum, sensor, communication and electronic warfare assets to avoid propagation liabilities and to take advantage of propagation enhancements. During FY11-13, COAMPS® technology has become a more widely accepted tool for RF system acquisition engineering, prototype RF system test support and forecast analysis of operational RF system anomalies and re-positioning of sensor assets. The AEGIS Ashore program has employed the technology to predict radar performance at Host Nation locations on land. The electronic warfare and communications acquisition communities have used the technology to evaluate engineering designs. The Common Data Link program will conduct testing off Wallops Island during the summer of 2013 and provide valuable engineering metric validation data. Lessons learned from the FY11-13 Operationally Relevant Four Dimensional Prognostic Refractivity Field effort have been used to design an FY14-16 research and development program that will combine COAMPS with surface layer models that will lead to a more quantitative prognostic radio frequency propagation capability to support fleet operational RF system performance forecasts.

WORK COMPLETED

Critical tasks completed include an extensive evaluation of the surface flux measurements from the jetty town and modeling systems used during the TAPS 2013 campaign. From the 20Hz sampling rates for sonic anemometer, temperature and fast response humidity sensors, covariances were computed to obtain sensible, latent and virtual buoyancy fluxs. Correlations between various combinations of measured data and model fields were investigated: The co-variance measured fluxes were compared to those given by Monin-Obukhov Similarity Theory (MOST) driven by bulk jetty data using the French PIRAM and NAVSLaM surface layer models. Second, a model intercomparison study was done to evaluate the fidelity of surface physics parameterizations schemes. The modeling components encompassed mesoscale prediction systems (UK-MetUM, Fr-AROME, NZ-RAMS) run in real-time for TAPS support and for retrospective hind casts, and the stand-alone MOST surface layer models (NAVSLaM, PIRAM, AU-SFC), which were driven by bulk surface values from jetty measurements. The flux values and surface scalar quantities were both considered in the obs-model and model-model comparisons.

The TAPS surface flux data are crucial for the development of methodologies to estimate surface layer structure from turbulent measurements, e.g. from TAPS kite sonde data. The methods explored use traditional MOST to construct the profiles but with an additional degree of freedom that controls the shape of the curve (Salamon et al. 2011). By varying the *ln* power, a family of possible surface layer curves are derived, and the rmse and bias statistics evaluated to yield a curve that best fits the kite

sonde data. The best fit profile data are manipulated to give a best fit obs-estimate for modified refractivity which then can be used to validate the surface layer structure predicted by the models.

The refractivity obs estimates aids our validation of model generated surface layer profiles, and the blended profiles (surface layer – COAMPS), that are designed to smoothly transition from surface layer to model predicted layers at an appropriately specified surface layer height (SLHT). Five techniques for determining the SLHT have been considered and the resulting blended modified refractivity evaluated against the obs estimate and using a baseline propagation metric. This metric leverages the Advanced Propagation Model (APM) to compare the impact of each profile blending method on RF propagation for the full seven days of the Wallops-2000 campaign. Trends were examined with respect to propagation space and outliers were inspected to isolate sources for differences. This step identified the range of propagation loss errors associated with the choice of blend height, which meteorological events are sensitive to the SLHT, and which methods are more robust.

RESULTS

Exploiting the TAPS campaign data with an international team of scientists has led to a manuscript submitted to the Bulletin of American Meteorology Society in which we highlight the comprehensive meteorological, surface flux, land/sea/air, and propagation datasets collected over the 12 day period, and the four member suite of mesoscale model forecasts that were run during the experiment. A selected set of variables are shown in Figure 1 comparing vertical profiles and surface time series to each model's forecast.

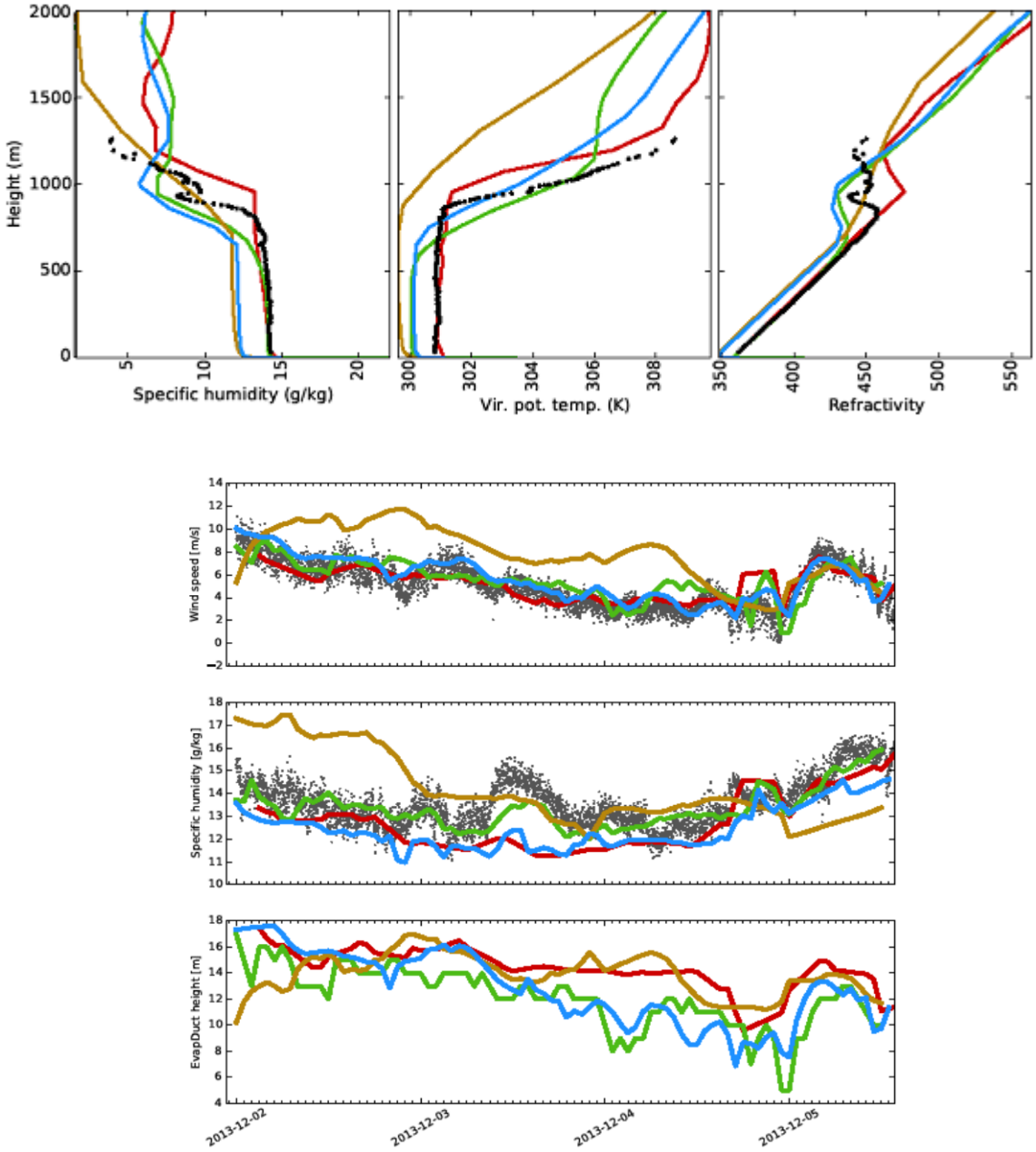

Figure 1: (a) Vertical profiles of specific humidity (g/kg), virtual potential temperature (K) and modified refractivity (M-units) from a radiosonde (black dots) launched at sea on 5 Dec 2013, and forecasts from each of the four NWP models: MetUM (4km grid, 1-hour fcst, red), COAMPS (1.67km grid, 1-hour fcst, green), AROME (2.5km grid, 7-hour fcst, blue) and RAMS (12km, 25-hour fcst, yellow); (b) time series at the Jetty of near surface wind speed (ms^{-1}), specific humidity (g/kg), and evaporation duct height (m) using the same line color/type convention as in (a).

The process of evaluating TAPS surface fluxes at the Jetty illuminated significant differences between the co-variance fluxes calculated from measured turbulence quantities and those given by MOST driven by measured bulk surface parameters. As shown in Figure 2, temporal trends in the fluxes are consistent throughout the 60 hour period; however, MOST fluxes have a large positive bias, upwards

of 100 Wm^{-2} for latent heat flux. The model predicted fluxes from COAMPS have similar magnitudes to MOST fluxes except near the start and end of the period. This ~100 Wm^{-2} discrepancy was traced to an error in COAMPS wind speed of 2-3 ms^{-1} at those times. It indicates high sensitivity of latent heat flux (LHF) to wind speed while the large biases between modeled and measured fluxes suggests that the method for de-trending the turbulence data and applying frequency response corrections requires further study. The source for this difference must be resolved before using those data to compute surface layer profile estimates.

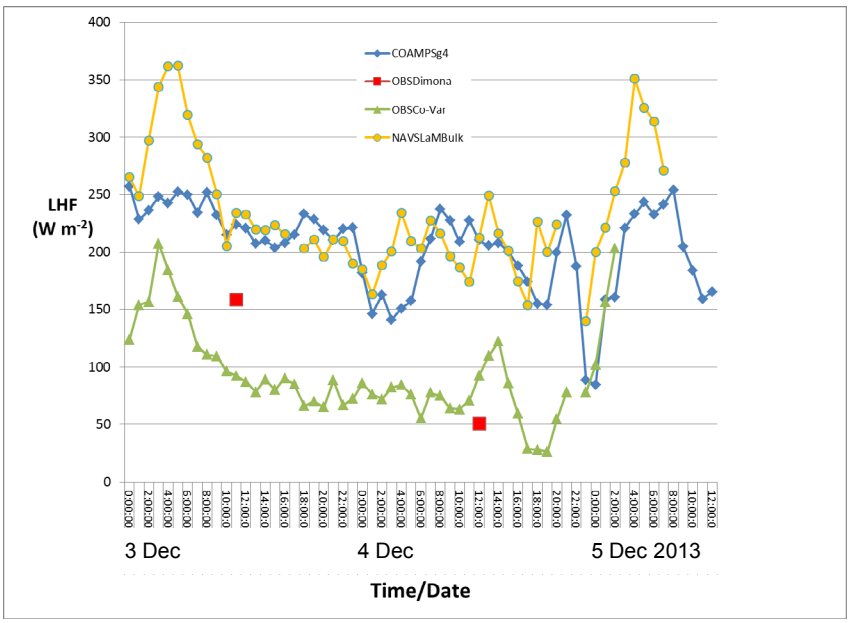

Figure 2: Time series of latent heat flux (W m^{-2}) at the Jetty computed from turbulence measurements (green), modeled by NAVSLaM using bulk measurements (yellow), and predicted by COAMPS 1.67km resolution grid.

Performing surface layer blending techniques on the model forecasts and translating the profiles into modified refractivity creates the necessary environmental forcing to run propagation codes and gauge the impact on RF propagation. This investigation was carried out on the seven day Wallops-2000 helicopter profiles and each of six profile types. Using an X-band radar at 15m, the resulting time-series of propagation loss, at a range of 27km and height of 3m, is shown in Figure 3.

The append method (without any blending) was found to be a clear outlier, while the other methods produced differences of typically less than 10dB. Deviations tended to be larger during high propagation loss periods in which there was no surface based ducting or the evaporation duct was well below the radar's signal and unable to affectively trap the energy. In these cases, the loss associated with either profile type is greater than the target detection threshold, and so the radar would be expected to perform poorly regardless of the blended profile used. Hence, we have identified environmental situations for which precise blending is important and those for which it is less so, and the range of propagation loss errors associated with profiles constructed using different blend heights.

IMPACT/APPLICATIONS

This research is an important component of the overall mesoscale modeling program at NRL, providing validation of and advancements to characterization of coastal marine boundary layers and air-sea interaction processes. The TAPS campaign has yielded a unique, comprehensive dataset with which to perform the model evaluation and identify sensitivities between prognostic state variables, surface forcing and the resultant impact on RF propagation. The development and verification of a 4-Dimensional refractivity cube using appropriate blending between the surface and marine atmospheric boundary layers is instrumental in the projects below that rely on an RF propagation prediction capability.

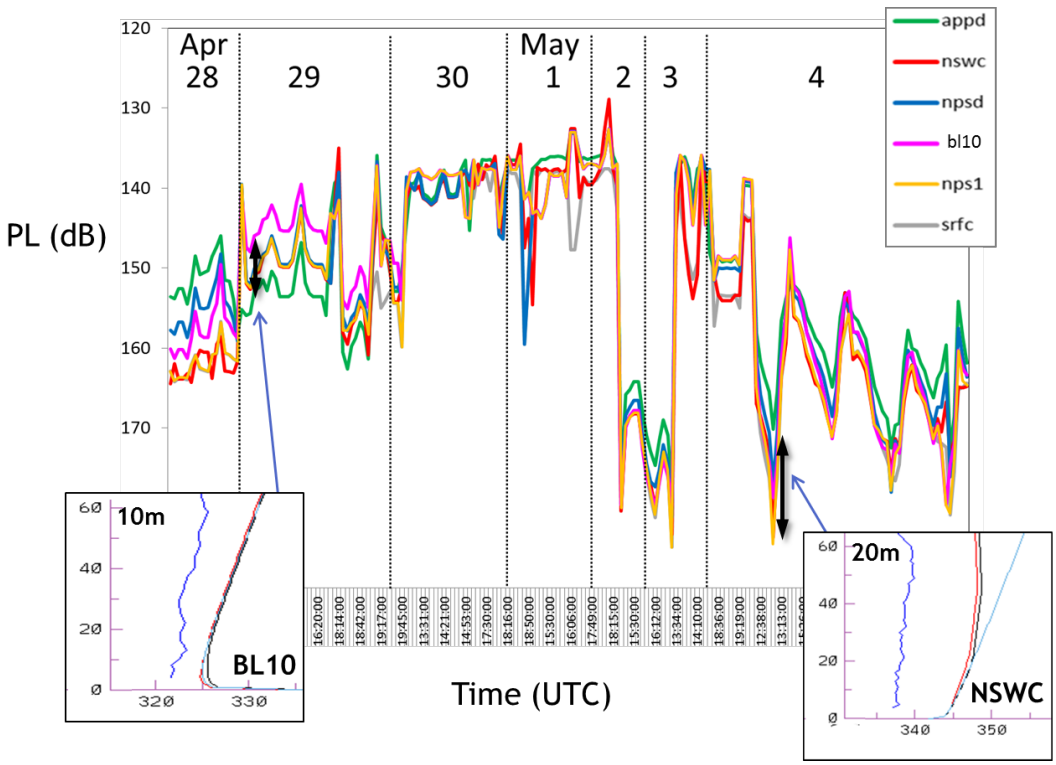

Figure 1: Time series of propagation loss (dB) of an X-band radar at 15m for the Wallops-2000 seven day campaign using environments specified by six blended (BLD) profile types: surface layer profile (SFC) alone (gray), COAMPS appended to SFC@10m (green), COAMPS blended with SFC@10m (pink), NPS fixed heights (yellow), NPS evap duct height (blue), and NSWC physics based (red). Two profile examples are shown for cases in which the prop loss differences were large, using Blend@10m on the left and NSWC on the right. Helicopter profiles (blue) are shown with COAMPS (red), SFC (cyan), and blended profiles (black).

RELATED PROJECTS

- RTP UAS
- RTP Refractivity Data Fusion
- NRL Base 6.2 BLEMP

- COAMPS-EM
- QUBE
- CASPER
- Enterprise Testbed
- Common Data Link
- Directed Energy Warfare
- Duel Band Radar
- Littoral Combat Ship
- Radar Data Collection
- AEGIS Operational Reach Back

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Organized and co-Chaired three IEEE Sessions:
IEEE APS/URSI International Symposium and the North American Radio Science Meeting, Vancouver, BC, Canada, 19-25 July 2015.

- Advances in Environmental Modeling for RF Propagation
- Atmospheric Effects on RF Propagation
- Measurements and Modeling from Recent Field Campaigns

Presentations:

IEEE APS/URSI International Symposium and the North American Radio Science Meeting, Vancouver, BC, Canada, 19-25 July 2015.

Flagg DD, Haack T, Doyle JD, Holt TR, Amerault CM, Geiszler D, Nachamkin J, Tyndall DP. 2015. "The Impact of Assimilation of Unmanned Aerial System Observations on Numerical Weather Prediction Modeling of Modified Refractivity and Electromagnetic Propagation".

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