P2.1 Coastal Atmospheric Boundary Layer Impacts on Refractivity and EM Propagation

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1. Introduction

Sharp vertical gradients within atmospheric thermodynamic profiles in the boundary layer (BL) can create abrupt changes in the refractivity field, thereby impacting the propagation of electromagnetic (EM) waves. The ability of pronounced refractivity variations to produce 'anomalous propagation' of microwave energy was noticed very early after the advent of radar in the late 1930's (Battan 1973; Anderson *et al*. 2004).

This study uses the Naval Research Laboratory's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS™)[1] to investigate refractive structure (particularly at radio and microwave frequencies) during a field experiment at Wallops Island, VA (April-May 2000). Measurements taken by groups from DOD laboratories, universities, and elsewhere included low-elevation radar frequency pathloss, meteorological conditions (e.g., from buoys, rocketsondes, helicopter profiles), and radar clutter returns. An extensive description of the field campaign appears in TR-01/132 of the Naval Surface Weapons Division, Dahlgren Division. Further details concerning observations gathered during the field experiment were presented previously (Burk and Haack 2003).

The Tidewater Peninsula along which Wallops Island lies contains intricate topographic and land surface characteristics, as well as pronounced spatial SST variability including that of the offshore Gulf Stream, all contributing to complex BL structures (e.g., internal BL's; sea/land breezes; coastal jets). To explore the COAMPS fidelity in forecasting subtle BL and refractivity variations in this region, we nest COAMPS down to an inner grid mesh having 3 km spacing and utilize high vertical resolution in the first several hundred meters above the surface.

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2. Modeling Aspects

The COAMPS mesoscale model used in the present study is described in Hodur (1997). The model is nonhydrostatic and uses multiple nests having different horizontal resolution. It features a full suite of physical parameterizations, including a level 2.5 turbulence parameterization, long- and short-wave radiation, and cloud microphysics schemes. Surface fluxes and surface stress are computed from the Louis scheme. Data assimilation is accomplished using a multivariate optimal interpolation (MVOI) approach.

COAMPS has been used in several recent studies of coastal flows and refractivity in coastal regions and near islands (Burk and Thompson 2004; Haack and Burk 2001; Burk *et al.* 2003). The COAMPS model simulation for this study utilizes the grid structure shown in Fig 1a-b. Forty vertical levels are used for the model forecasts. Because our interest in this study is with very shallow, subtle features of the coastal refractivity profile, we strongly compress the model grid points near the surface. In the lowest 105 m the vertical grid spacing is 5, 15, 25, 35, 45, 55, 67.5, 85, and 105.

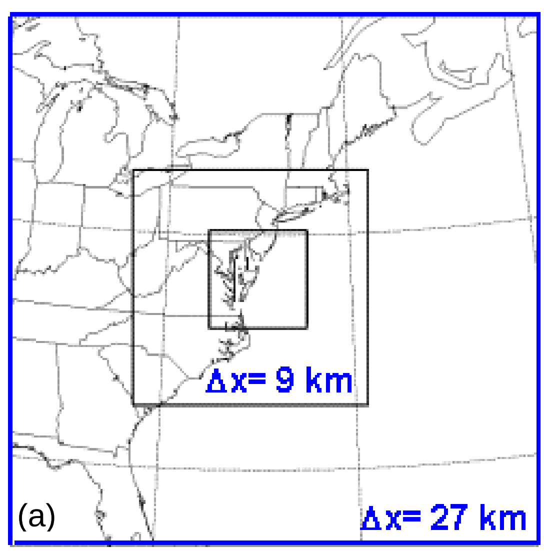

Fig. 1a. COAMPS nested grid structure.

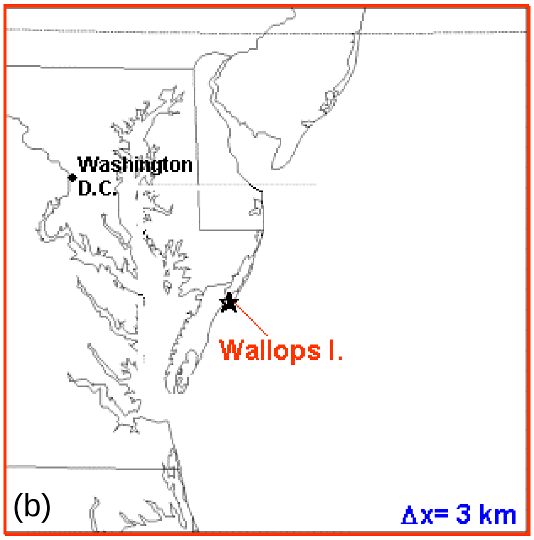

Fig. 1b. COAMPS innermost grid.

3. Diurnal Internal Boundary Layers & Sea/Land Breezes

Previously we presented COAMPS Wallops-2000 forecasts during times when synoptic fronts were located in the vicinity of the observational domain (Burk and Haack 2003). In this paper we focus on less active synoptic periods (e.g., 29 Apr 2000) when diurnal mesoscale circulations and internal boundary layers (IBL's) play a prominent role.

At 1200 UTC on 29 Apr 2000 a surface low is situated to the east of Wallops over the Gulf Stream and at 500 mb a trough axis extends roughly from New York state to the eastern coast of Florida. Flow at the surface at Wallops is generally from the NNE associated with the cyclone's northwest quadrant at this time. As the low moves to the NNE, the surface winds at Wallops back from NNE, to N, to NW through the remainder of the 29th. Thus, during the afternoon of the 29th, the prevailing synoptic flow near the surface is from the NW.

Advection of warm afternoon air from land across the cool Atlantic shelf water near Wallops produces a stable internal boundary layer (SIBL) in which the surface sensible heat flux is downward, while latent heat flux remains positive. Thus, this SIBL tends to cool and moisten with fetch, thereby increasing the modified refractivity, M, in this layer because the functional dependence of M on temperature and moisture is:

$$M = A/T(P + Be/T) + Cz/R,$$

where T, e, z, and P are conventional and A, B, and C are coefficients defined as A=77.6, B=4810, and C=10^6. Here T is in Kelvin, P in hPa, and z in meters. R is the mean Earth radius (m). Discussion of modified refractivity, M, and its utility in defining expected propagation characteristics (e.g., ducting, super-refraction, sub-refraction, etc.) may be found in standard radar meteorology texts (Battan, 1973). Layers where the vertical refractivity gradient, DM/Dz, is negative tend to trap EM rays launched at a low elevation angle. Conversely, layers in which DM/Dz is strongly positive are subrefractive; that is, EM rays initially launched parallel with the Earth's surface will tend to bend away from the Earth with distance in a subrefractive environment.

Figure 2 shows the COAMPS (3 km grid) forecast of near surface wind valid 3 pm Local Time (LT) on 29 Apr 2000 over the Wallops region. Complex mesoscale patterns in the wind field are evident, with an onshore sea breeze forming in the vicinity of Wallops Island while many other coastal areas are still experiencing offshore flow. Figure 3a-b displays a 3D model trajectory ending near Wallops (point 2) at a height of 5 m at 7pm LT on 29 Apr, having started at 640 m (point 1) at midnight LT on 28 Apr 2000. Although the surface wind at Wallops is from the SE at 7 pm LT, it is clear from this trajectory that the fetch from that direction is quite limited. The thermodynamic properties and refractivity of the sea breeze flow are strongly affected by this past history.

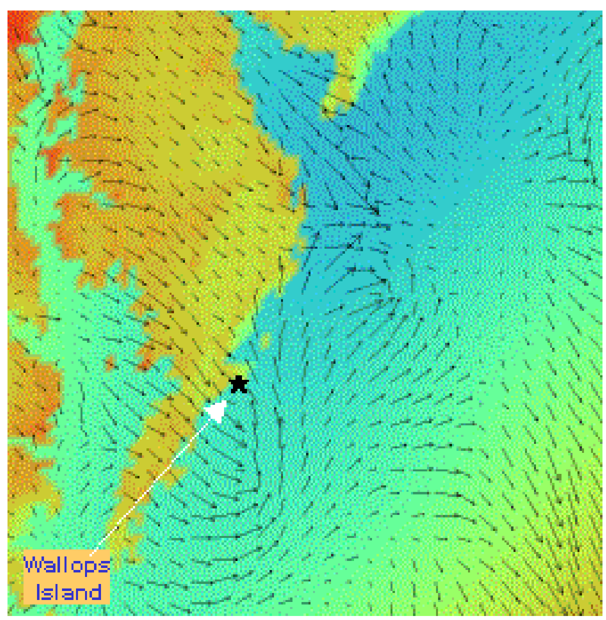

Fig. 2. COAMPS forecast near surface winds 2000 UTC 29 Apr 2000.

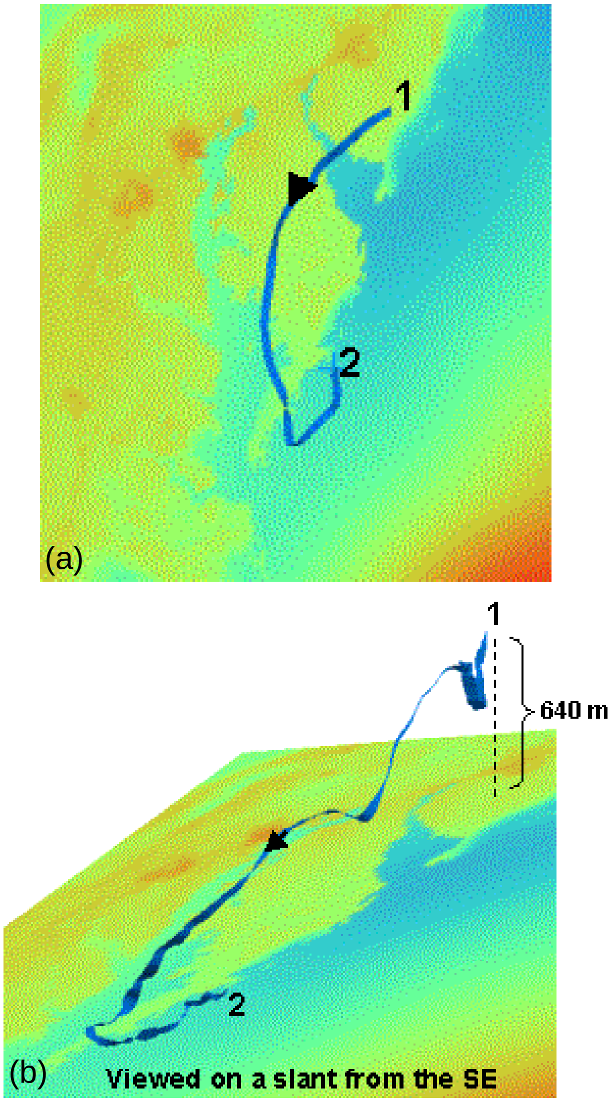

Fig. 3a, b. COAMPS forecast trajectory ending near Wallops I.

In the afternoon, shallow trapping layers [where DM/Dz < 0] develop in the SIBL's formed over coastal waters wherever the flow is offshore. Figure 4a depicts near surface streamlines; color-coded surface temperature; and white, cloud-like isosurfaces of trapping [i.e., inside the white isosurface, DM/Dz < 0] at 3 am LT on 29 Apr. The flow is northerly over most of the region, but with a low-pressure center on the grid's eastern boundary. The land (blue) is significantly colder than the SST at this hour and there are a few patches of elevated trapping that advect southward when this depiction is animated. Figure 4b shows that the situation has changed dramatically by 3pm LT. The land now is substantially warmer than the coastal waters (though not warmer than the Gulf Stream), and the flow has shifted to the NW. Apparent are the coastal trapping regions that have formed in the afternoon, particularly at locations where warm continental air is advected offshore over cooler Chesapeake Bay or Atlantic shelf waters and, thus, SIBL's have formed. The flow along the New Jersey coast is onshore in Fig. 4b and no trapping is present.

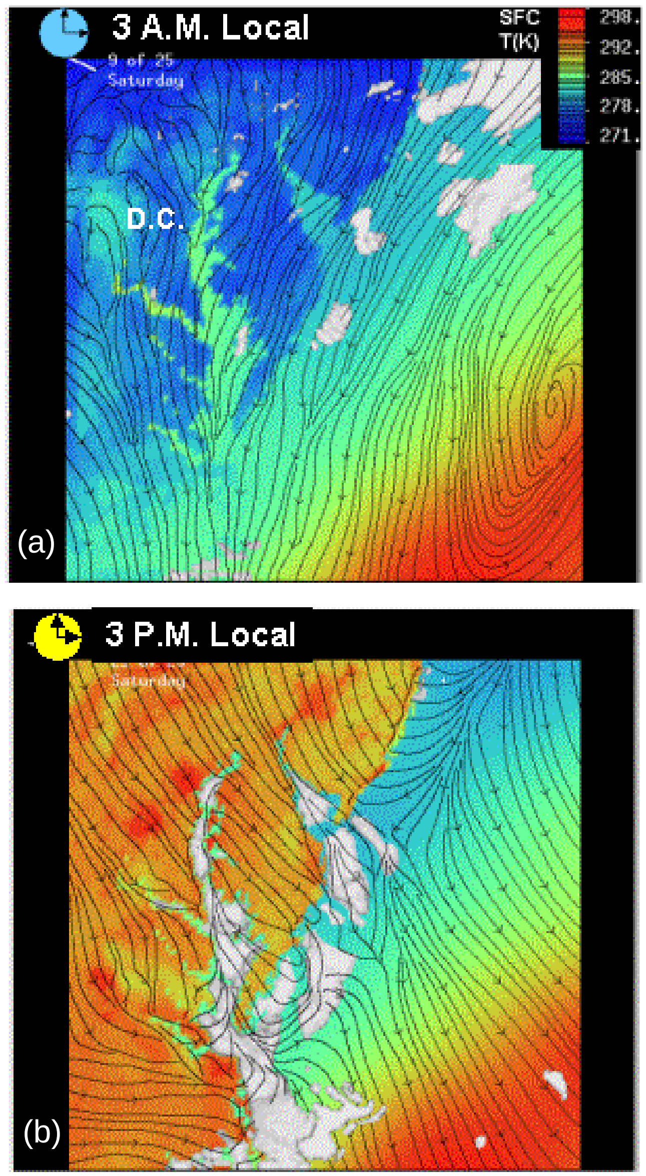

Fig. 4. 29 Apr 2000 near surface streamlines; surface temperature; and white isosurfaces of trapping [DM/Dz < 0] at 3 am (a), and 3 pm (b) LT.

4. COAMPS Wallops-2000 Reanalyses

In order to produce high-resolution mesoscale model fields for the Wallops-2000 field experiment (during which meteorological and propagation data were collected), a series of consecutive 12-h COAMPS data assimilation forecasts were produced for the period 1 Apr-13 May 2000. Hourly COAMPS forecast fields have been archived from this 1.5-month period and saved on the Master Environmental Library (MEL) database. This database will be available for wide usage in the EM propagation and modeling research community, and the fields used for a variety of purposes including: (1) ingest COAMPS refractivity fields into electromagnetic (EM) propagation codes and validate results with Wallops-2000 propagation data; (2) evaluate standard model surface data and model fluxes versus the Naval Postgraduate School (NPS) flux buoy observations; (3) conduct case studies on coastal phenomena impacting the EM propagation environment.

Figure 5 displays the hourly COAMPS forecast values (blue line) and the NPS buoy observations (red line) for this 1.5-month period [note that the buoy observations were unavailable early in the time period]. Shown are wind direction (degrees), wind speed (m s^{-1}), air temperature (K), and relative humidity (%). Wind direction values in Fig. 5 undergo abrupt directional transition for easterly flow by adding 360^0 to wind directions residing between 0^0 and 90^0.

It is evident that COAMPS does quite well in forecasting the temporal trends of these quantities, although there are significant forecast errors at times in each variable. RMS and bias statistics are shown in Fig. 5. Also shown are the evaporation duct height (EDH) statistics formed between the COAMPS forecast values and the values computed from the NPS EDH model using the buoy data directly. The EDH time series (not shown) indicate good agreement except during stably stratified periods where surface layer similarity tends to break down and often produces unrealistically large EDH values (note: this breakdown is a problem not only for the mesoscale model, but also for bulk EDH computations based upon observed data).

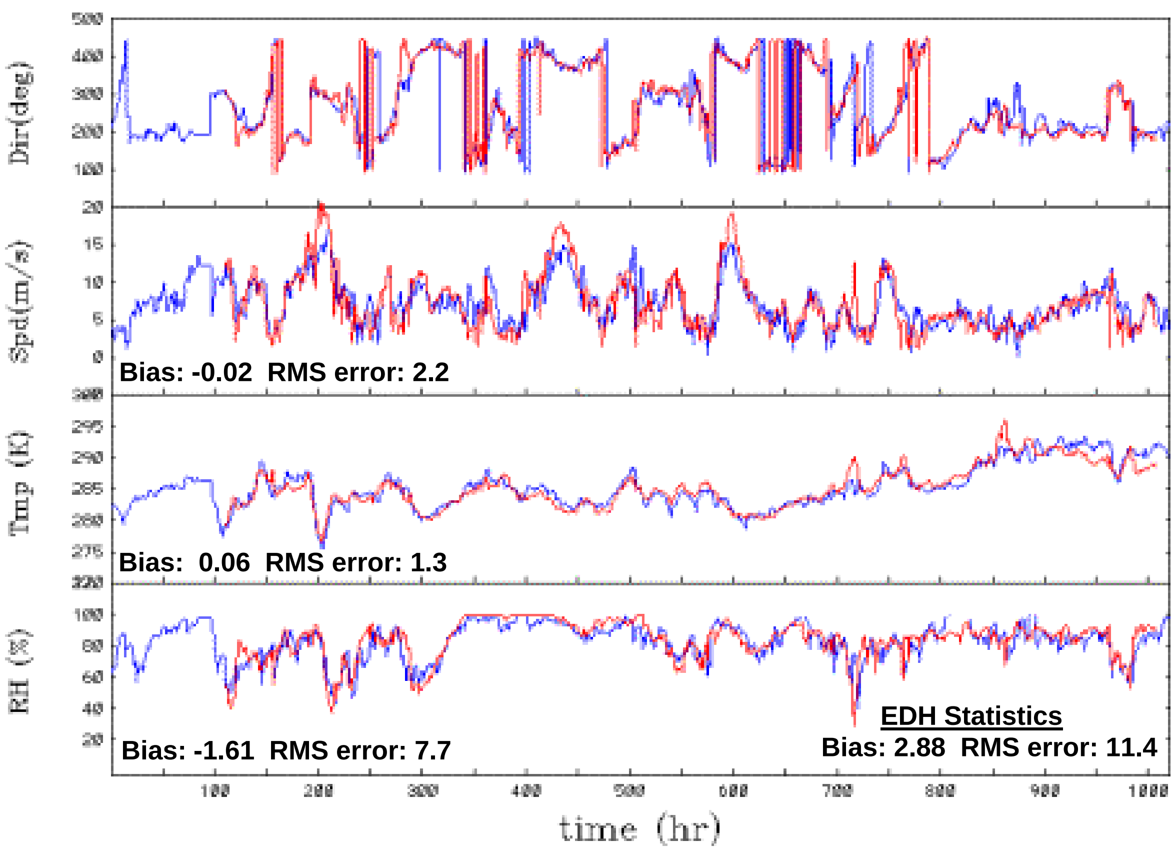

Fig. 5 Hourly COAMPS forecast (blue line) and NPS buoy observations (red line) for 1 Apr – 13 May 2000.

5. Concluding Remarks

We have now used this Wallops-2000 data and COAMPS to document case studies of the impact of major synoptic features (e.g. fronts) on the refractivity field [Burk and Haack, 2003a,b] and, in this paper, the impact of IBL's and the sea/land breeze on refractivity. However, there is much yet to be learned from this rich data set, including whether COAMPS forecasts possess sufficient fidelity to routinely warrant their ingest by EM propagation codes. And, if not, what are the major hurdles yet to be overcome in order to attain this goal. Additionally, along with colleagues, we are continuing to use COAMPS for EM propagation studies in other geographical regions, including along the California coast, the Sea of Japan, and the Arabian Gulf.

ACKNOWLEDGMENTS

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