Coastal Atmospheric Effects on Microwave Refractivity

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Introduction: Sharp vertical gradients within thermodynamic profiles in the atmospheric boundary layer (BL) create abrupt changes in refractivity, thereby impacting electromagnetic (EM) wave propagation. This study uses NRL's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS™) to investigate refractive structure during a field experiment[1] conducted at Wallops Island, VA. Measurements include low-elevation radar frequency pathloss, meteorological conditions (e.g., from buoys, rocketsondes, helicopter profiles), and radar clutter returns.

EM propagation codes are useful for naval operations and decision-making; when supplied with accurate refractivity fields, they produce radar coverage diagrams. The fidelity of COAMPS™ refractivity analyses/forecasts, and their usefulness as input to microwave propagation codes, is evaluated here in a complex littoral setting.

Internal BLs and Refractive Effects: The Delmarva Peninsula along which Wallops Island lies is relatively flat but contains an intricate coastline, and the surrounding waters have pronounced spatial sea surface temperature (SST) variability. These factors contribute to complex BL structures (e.g., internal BLs, sea/land breezes).

Advection of warm, dry afternoon air from land across the cool Atlantic shelf water near Wallops produces a stable internal BL (SIBL) wherein surface sensible heat flux is downward, while latent heat flux remains upward. This SIBL tends to cool and moisten with fetch, thereby increasing the modified refractivity. The refractivity is represented by $M = A/T(P + Be/T) + Cz/R$, where T, e, z, and P are temperature, vapor pressure, height, and pressure, respectively, while A, B, and C are constant coefficients. Layers where the vertical refractivity gradient dM/dz is negative tend to trap, or duct, microwave energy launched at a low elevation angle. Conversely, layers in which dM/dz is strongly positive are subrefractive, and initially horizontal rays bend away from the Earth, yielding shortened radar detection ranges. If shown to be sufficiently accurate and reliable, analyses/forecasts of these effects on propagation can have clear value to many aspects of naval operations (e.g., ship self defense and Special Operations).

Case Study Results: Figure 4(a) depicts near-surface streamlines, surface temperature, and white, cloud-like isosurfaces of trapping ($dM/dz < 0$) at 3 a.m. local time (LT) on April 29, 2000. The land (blue) is significantly colder than the SST at this hour. The wind is northerly over most of the region, although a low-pressure center lies near the grid's eastern boundary. On the backside of the low-pressure center, dry subsiding air creates patchy, elevated trapping regions throughout the night.

With daytime heating, the situation changes dramatically. Figure 4(b) shows that by 3 p.m. LT, the land is substantially warmer than the coastal waters and the flow has shifted to the NW. Shallow, near-surface trapping layers develop in the SIBLs formed over coastal waters where the afternoon flow is offshore. No trapping is present in the onshore flow along the New Jersey coast. A 24-h-long trajectory descends from 1.3 km at point 1 to a height of 5 m near Wallops, being drawn onshore by the sea breeze. Dry air is advected along such parcel trajectories, altering the near-surface refractivity profile and making simple 2-D sea/land breeze concepts of limited value in this region.

Figures 5(a,b) and 6(a,b) illustrate the diurnal changes in coastal BL vertical structure that alter refractivity and EM propagation conditions. The vertical cross section angles across the model grid from the NW to SE (intersecting Wallops) and extends from the surface to 850 m. Surface temperature is displayed in the foreground, while the vertical section shows contours of potential temperature along with shaded specific humidity (Figs. 5(a), 6(a)) or wind vectors and dM/dz (Figs. 5(b), 6(b)).

At 10 a.m. LT, Fig. 5(a) shows a fairly homogenous BL capped by a strong inversion and dry air aloft. Elevated trapping is present in Fig. 5(b) associated with the gradients at the top of the nocturnal BL. By 3 p.m. LT, a deep, warm, well-mixed BL has formed over land with a very shallow, stable BL over water (Fig. 6(a)). Dry air intrusion just offshore of Wallops results from advection of the type indicated by the trajectory in Fig. 4(b). The resultant strong vertical moisture gradients contribute to the shallow, surface-based duct that is seen in Fig. 6(b). A region of subrefraction, where moist BL air over land is advected aloft into dryer layers over the Atlantic, tops this trap-

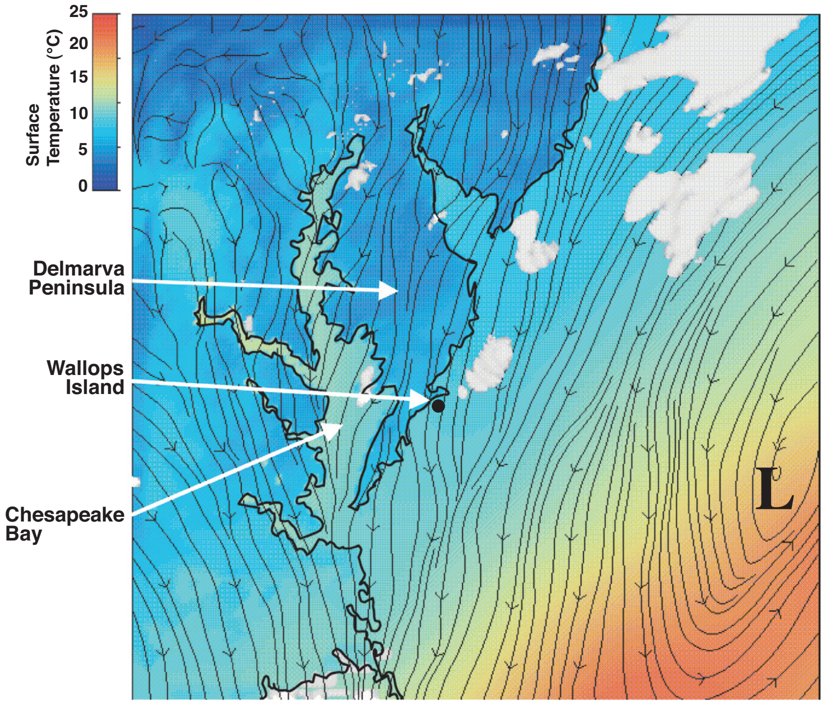

FIGURE 4(a)
COAMPS™ forecast valid 3 a.m. LT April 29, 2000 of color shaded surface temperture (°C), near surface streamlines, and white isosurface where *dM/dz* < 0 (e.g., microwave trapping regions).

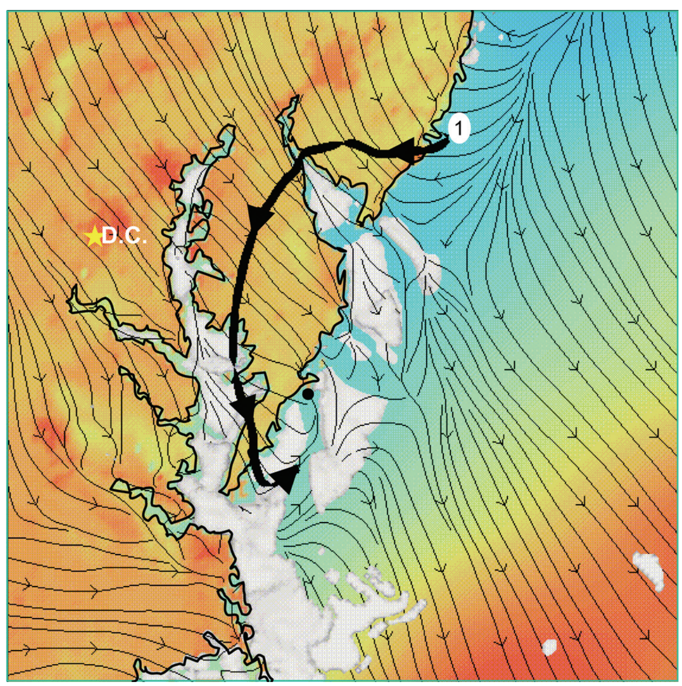

FIGURE 4(b)
As in (a), except at 3 p.m. LT. Also shown is a 24-h-long parcel trajectory beginning at point 1 (at 1.3 km) and ending at Wallops Island at 7 p.m. LT (at 5 m).

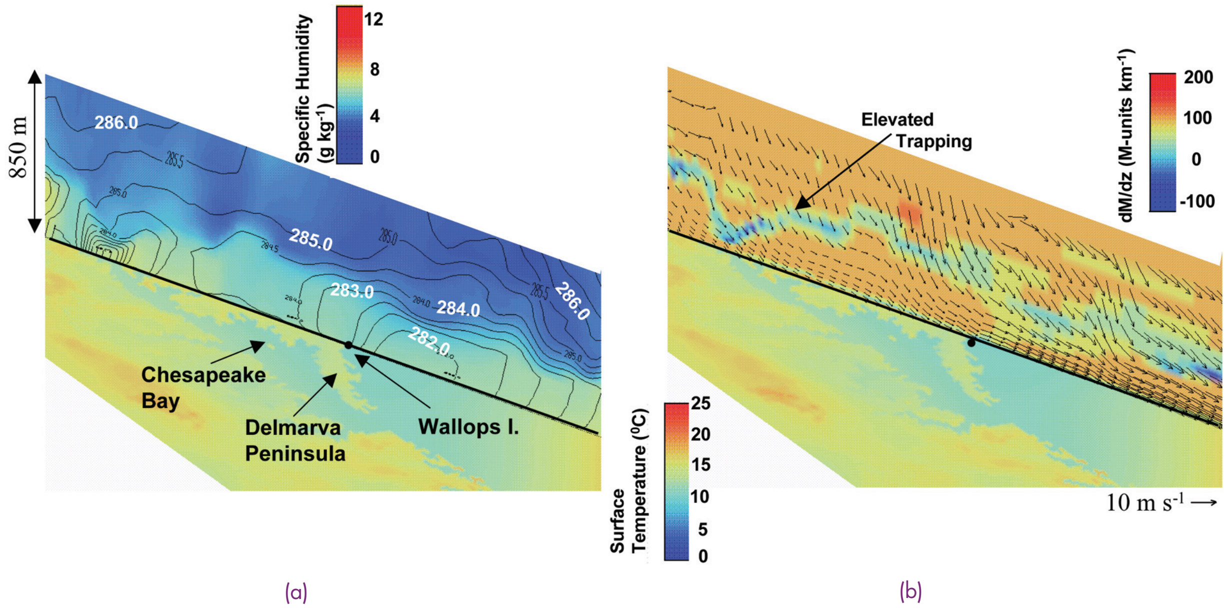

FIGURE 5
COAMPS™ forecast valid 10 a.m. LT April 29, 2000 of surface temperature (°C) in the foreground. Cross sections of (a) color shaded specific humidity and potential temperature contours (K), and (b) wind vectors in the plane of the cross section and color shaded *dM/dz*. Blue regions indicate EM trapping, while dark red is subrefractive.

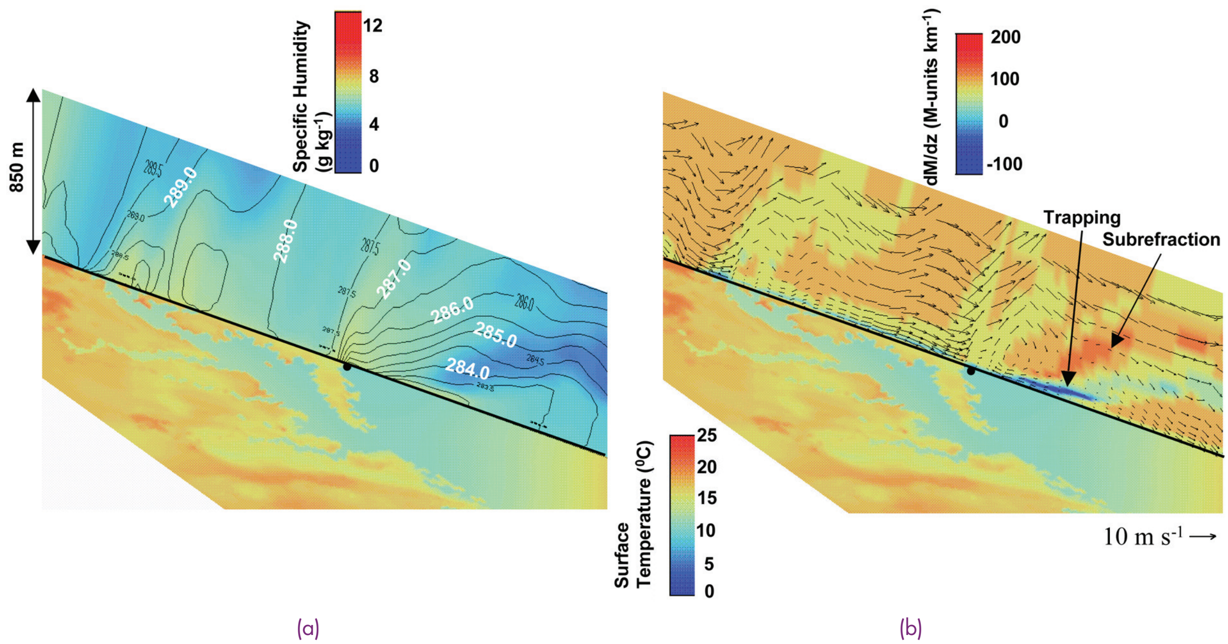

FIGURE 6
As in Fig. 5 except 3 p.m. LT.

ping layer. Flow reversal associated with the sea breeze is evident in a thin layer over water.

Summary: High-resolution analyses/ forecasts of refractivity and EM propagation conditions for use in Naval operations are rigorously evaluated using extensive data sets that include both meteorological conditions and EM propagation measurements.[2] COAMPS™ hourly forecast fields have been archived for the 1.5-month period of the Wallops experiment and have been saved on the Master Environmental Library (MEL) database. RMS errors for this period formed between Naval Postgraduate School buoy measurements and COAMPS™ forecast values of wind speed, temperature, and relative humidity are 2.2 ms^{-1}, 1.3 °C, and 7.7%, respectively. This unique model and observational database are now available for wide usage in the EM propagation and atmospheric modeling research communities.

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References

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[2] S.D.Burk, T. Haack, L.T. Rogers, and L.J. Wagner, "Island Wake Dynamics and Wake Influence on the Evaporation Duct and Radar Propagation," *J. Appl. Meteor.* **42**, 349-367 (2003).