Near-surface Measurements In Support of Electromagnetic Wave Propagation Study

Qing Wang
Meteorology Department, Naval Postgraduate School
Monterey, CA 93943
Phone: (831) 656-7716, Fax: (831) 656-3061 email: qwang@nps.edu

Award # N0001414WX20090

LONG-TERM GOAL

The long-term goal of this project is to improve environmental prediction for electromagnetic wave propagation forecast.

OBJECTIVES

The objectives of this project are 1) to characterize atmospheric conditions resulting in nonstandard EM propagation in the atmospheric boundary layer during Trident Warrior 2013 field campaign; 2) to support NPS ongoing research on numerical simulations of EM propagation using AREPS and COAMPS.

APPROACH

Basic approaches of the project involves measurements of the NPS Marine-Air-Sea Flux (MASFlux) buoy during Trident Warrior 2013 (TW13) field campaign and analyses of the measurements to reveal the interplay between surface fluxes, surface layer mean profiles, surface waves, and upper ocean temperature. This analyses will be aided by other measurements from TW13 including rawinsonde profiles and measurements from other platforms.

The TW13 data is used to initialize/evaluate COAMPS and COAMPS single column model simulations in an effort to improve predictions of the near surface thermodynamic profiles as input to EM propagation modeling.

Qing Wang is responsible for the overall project and part of the TW13 data analyses. NPS Ph. D student, LCDR Corey Cherrett, made more in-depth data analyses. Mr. Dick Lind was responsible for buoy preparation and field deployment.

WORK COMPLETED

1. Final quality control of the NPS TW13 measurements was completed. Data products in NETCDF format was distributed to TW13 participants and collaborators.
2. Evaluation of COAMPS TW13 simulations using TW13 datasets.
3. Test of COAMPS single column simulation (SCM) for TW13 cases using idealized forcing based on COAMPS results.

RESULTS

**COAMPS evaluation using TW13 sounding data:** We assessed the performance of the 3D COAMPS simulation for the TW13 cases by comparing the 50 atmospheric soundings collected during the field campaign with coincident profiles from the 3-D COAMPS simulations. For this purpose, we use COAMPS forecast results between 6 and 12 hours after initialization for our validation assessment since atmospheric models normally demonstrate an initial adjustment period and the forecast was updated every 12 hours. Figure 1 shows the comparison between COAMPS and the soundings for horizontal wind components, potential temperature, specific humidity, and modified refractivity. The modified refractivity was repeated in Figure 1f using line plots so that data from a single sounding can be nominally identified. By examining all observed sounding profiles, we found that the variability between soundings was normally seen below 2 km altitude. The observation-COAMPS comparison was thus made separately for below and above 2 km. In general, the scatterplots show a good comparison with most data points scattered about the 1:1 line. There were clearly more data points in the lower levels which is a result of higher vertical resolution of CAOMPS at lower atmosphere. Table 1 summarizes the statistics of the comparison with the exception that the statistics for the higher levels are limited to data between 2 and 5 km only. COAMPS shows a cold bias by about a half degree at all levels below 5 km. Specific humidity has nearly no predicted bias (-0.06 g kg\(^{-1}\)) below 2 km and a ~0.84 g kg\(^{-1}\) moist bias aloft. However, individual forecasts may have large errors as seen in the large standard deviation of \(q\) difference in Table 1.

Comparisons of the modified refraction, \(M\), show very different behavior for the lower and upper atmosphere. Below 2 km, the COAMPS predicted \(M\) has a small bias of 0.24 M-unit compared to 4.6 M-unit above 2 km. The upper atmosphere forecast error is less scattered compared to the lower levels. Figure 1f suggests that the predicted \(M\) error in the lower levels may vary significantly in its gradient as the \(M\) forecast error can be very different between adjacent vertical levels. This is not the case for the higher atmosphere where the \(M\) gradient is likely to have small errors although the forecast \(M\) profiles have large bias.

**Ducting layers from COAMPS and Soundings:** The objective of this COAMPS evaluation effort is to examine how well COAMPS represents the refractive features in the atmosphere, which requires an evaluation of the gradient of the \(M\) profile from COAMPS. Figure 2 shows an example \(M\) profile derived from a sounding from July 14th at 17:50Z with significant ducting layers indicated by the horizontal lines. These ducting layers were identified based on the \(M\) gradients for each ducting type. In doing so, we have ignored duct layers thinner than 50 m to eliminate spurious duct layers as a result of small scale variability. This particular sounding showed three significant elevated ducts. We apply this same technique to all COAMPS profiles corresponding to TW13 profiles. The ducting layers from all profiles are shown in Figure 3. Here, ducting layers from rawinsondes and COAMPS are in blue and red, respectively. The asterisks indicate the height of the local maximum of \(M\) or the trapping layer base and top and bottom of each bar show the ducting layer top and bottom, respectively. The plus marks on the left show the vertical grid levels of COAMPS model as a reference since the upper and lower limits of the ducts from COAMPS can only be identified at a grid point. More ducting layers were identified from the sounding profiles above 1500 m, but they were rarely represented by
COAMPS and they become less tactically relevant. Consequently, we only show the lower atmosphere below 1500 m for these comparisons.

Figure 3a shows that nearly every sounding has a fairly complex multiple elevated duct profile. COAMPS on the other hand typically only indicates a single elevated duct in any given profile although COAMPS does occasionally indicate an elevated duct in conjunction with a surface or surface based duct. To a very rough approximation, it appears that on July 14th and 15th, COAMPS indicates mostly elevated ducts between about 300 and 1000 m and surface, surface based, or low level elevated ducts for the remainder of the period. This tends to also be the pattern for the measured soundings.

A direct comparison of the ducting layers from the observed sounding profiles and COAMPS profile is inherently misleading because COAMPS coarse vertical resolution prevented the presence of any ducting layers thinner than the two adjacent vertical grids. Figure 3b shows the same comparison of ducting layers except that the observed ducting layer were identified based on profiles interpolated onto the COAMPS 60 vertical level grid. Resampling the sounding profiles at COAMPS vertical grids smoothed out the original profiles significantly, resulting in much smaller number of ducting layers compared to the original sounding. In some cases, such as the few soundings on July 14, resampling at coarser resolution has completely removed the presence of any ducts. This was especially true at the elevated duct levels where COAMPS grid level spacing was on the order of 80 m and this reinforces that the 60 level COAMPS grid is inadequate to preserve or represent many of ducting features in the atmosphere.

The comparison of interpolated sounding and COAMPS provides another view at the COAMPS performance in capturing the ducting. Overall, during July 14th and 15th both model and sounding indicate elevated ducting features. During the 16th and 17th surface and surface based ducts are represented. However, COAMPS fails to capture the combined elevated and surface based duct profiles prevalent on July 17th. We also showed that the vertical resolution can change how the layers are identified. The average duct depth in the sounding was 51.9 m without interpolation onto the COAMPS grids, 72 m after interpolation, and the COAMPS model average duct depth was 80 m.

Although many of the ducting features are represented in the COAMPS simulations, the gradient strength, ducting height, and ducting depth appears to be very poorly represented with difference ranging 100 to 1000 m in ducting layer height. It is worth noting, though, that the proximity to the coastline leads to complicated layering structure in the lower atmosphere due to horizontal and differential advections. The TW13 cases present substantial challenges for COAMPS to characterize the ducting layers. This is also likely the reason for significant variability in the observation among individual sounding profiles.

**SST from COAMPS:** Sea surface temperature is also compared between COAMPS and ship observation during TW13. The COAMPS SST output was hourly since COAMPS simulations were made in coupled mode. SST observations (courtesy of Luc Lenain of SCRIPPS) on the bow were determined to be most reliable since it measured the undisturbed surface in front of the ship and was continuous. The comparison scatterplot is shown in Figure 4 and the corresponding statistics are shown in Table 2. The coastal locations (•) tended to be cooler and more variable with more error than the offshore locations (o). The colors indicate data points on different days. Overall COAMPS tended to have a warm bias in the cooler coastal waters by almost 0.5 K. Also, the absolute error was over 0.8
K in coastal waters and more than 0.4 K in offshore waters. Since the SST is a key variable in surface flux parameterization, these discrepancies in SST may induce errors in other model output.

**COAMPS single column simulation:** Single column simulation of the July 14 case was made using idealized forcing based on COAMPS 3-D model results and 200 levels in the vertical with many levels near the surface and in the boundary layer. The three-hour forecast is plotted and compared to the coincident COAMPS results and the synoptic sounding. The COAMPS model had evolved to roughly match the synoptic sounding especially above the inversion level, a suggestion that COAMPS is representing well the large scale effects. The effect of subsidence is clear in that the inversion level has been pushed downward to a new level at about 620 m for the SCM and about 750 m for COAMPS. Neither had subsided enough to match the sounding inversion level and there may be several reasons that contribute to that discrepancy. The COAMPS result at SCM initialization may have higher inversion and weaker subsidence. Also, the sounding representativeness may be questionable because of the local variability expected in the coastal regime. The inversion gradient of potential temperature is approximately the same for SCM, COAMPS, and the sounding although the depth of the inversion is slightly over estimated by both the SCM and COAMPS. The specific humidity gradient at the inversion is slightly stronger for COAMPS and appears to match the sounding. The residual layer remains fairly neutral for the SCM but the COAMPS shows some positive potential temperature slope with height. Also, the COAMPS specific humidity shows a bulge in moisture just below the inversion that is not present in the SCM or the sounding profile. However, there is a spike in moisture at the corresponding sounding level above the inversion. It seems that COAMPS may have captured a real moist advection but at a lower level below the inversion. Regardless, these inversion and residual layer differences between COAMPS and SCM are due to the absence of differential vertical velocity and horizontal advection forcing used in SCM.

The M profile shows an elevated duct corresponding to the temperature inversion temperature and the associated humidity gradients. Nearer the surface, the 17:50Z sounding shows an inversion at about 120 m and what appears to be a shallow mixed layer below. In the model runs, the surface and boundary layer has destabilized in both the COAMPS and SCM. The SCM in fact matches the boundary layer top in both height and gradient of potential temperature. COAMPS matches the height of the mixed layer depth the following hour (not shown). This delay in COAMPS is likely due to the COAMPS SST starting at 15Z at 298 K and gradually warmed up until 18Z whereas the SCM SST was set to 295.5 K and was persistent throughout the three hour simulation. In other words, the acceleration in the SCM to match the representation of the mixed layer is due to warmer persistent surface forcing. In addition, shear generated turbulence at and below the inversion is likely another reason reason that the SCM may have mixed the layer faster and deeper than the COAMPS. The presence of the wind shear is evident in the increase in wind speed across the inversion. COAMPS shows much weaker gradient in wind speed across this inversion. The sounding actually shows a low level jet at the inversion and COAMPS resembles that jet in the next hour (not shown). Therefore the larger shear in the SCM combined with the destabilizing boundary layer may have initiated turbulence earlier than COAMPS due to the surface forcing and shear. The remainder of the profile evolves primarily as a result of the prescribed forcing (i.e., advection and subsidence). Specific humidity appears to have maintained too much moisture in the surface mixed layer for both COAMPS and SCM, especially in COAMPS. This again is likely a result of mixing down drier air. As such, the M profile gradient indicates a surface-based duct for COAMPS, but an elevated duct for the SCM. The sounding indicates a weaker elevated duct.
IMPACT/APPLICATIONS

The Navy’s operational mesoscale forecast model, COAMPS, is evaluated using measurements from TW13 with the focus of its capability in characterizing ducting layers for EM propagation. These results can be used to guide future use of COAMPS in operational environments.
Figure 1. Comparison of coincident COAMPS forecast profile and rawinsonde measurements for 50 sounding during TW13. Each panel shows the comparison for below and above 2 km altitude separately. a) u wind, b) v wind, c) potential temperature, d) specific humidity, e) modified refractivity and f) same as in e), except using line plots to show data from the same sounding profile.
Table 1. Statistics of COAMPS forecast error in comparison with sounding profiles. Here forecast errors are defined as $\Delta \varphi = \varphi_{\text{COAMPS}} - \varphi_{\text{obs}}$.

<table>
<thead>
<tr>
<th>Variables</th>
<th>theta (K)</th>
<th>$q$ (g kg$^{-1}$)</th>
<th>$M$ (M unit)</th>
<th>$U$ (m s$^{-1}$)</th>
<th>$V$ (m s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;2 km</td>
<td>2 - 5 km</td>
<td>&lt;2 km</td>
<td>2 - 5 km</td>
<td>&lt;2 km</td>
</tr>
<tr>
<td>Mean</td>
<td>-0.52</td>
<td>-0.44</td>
<td>-0.06</td>
<td>0.84</td>
<td>0.24</td>
</tr>
<tr>
<td>Std</td>
<td>0.9</td>
<td>0.8</td>
<td>2.1</td>
<td>1.7</td>
<td>13.4</td>
</tr>
<tr>
<td>Absolute Error</td>
<td>0.85</td>
<td>0.74</td>
<td>1.62</td>
<td>1.49</td>
<td>10.4</td>
</tr>
</tbody>
</table>

Figure 2. An example of ducting layers defined from a sounding profile obtained on July 14 sounding at 17:50Z. The horizontal lines of the same color indicate the top and bottom of each propagation ducts.
Figure 3. Comparison of resolved ducts at coincident time and place between sounding (blue) and COAMPS forecast (red) for a) actual measured sounding layers and b) sounding data interpolated onto COAMPS vertical levels. The error bars indicate the duct top and bottom and the asterisks indicate the trapping layer base. The plus marks on the left are COAMPS vertical levels for reference.
Figure 4. Comparison of COAMPS and ship observed SST during TW13. The star markers indicate near-shore and the circle markers indicate off-shore points. Red is data from July 14\textsuperscript{th}, green is July 17\textsuperscript{th}, and blue indicates the other days.

Table 2. Statistics of SST difference between COAMPS and ship observation for TW13.

<table>
<thead>
<tr>
<th>Date</th>
<th>All TW13 days</th>
<th>7/14/2013</th>
<th>7/17/2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Coastal</td>
<td>Offshore</td>
<td>Coastal</td>
</tr>
<tr>
<td>Mean</td>
<td>0.47</td>
<td>-0.01</td>
<td>0.06</td>
</tr>
<tr>
<td>Std</td>
<td>1.02</td>
<td>0.62</td>
<td>0.5</td>
</tr>
<tr>
<td>Absolute Error</td>
<td>0.82</td>
<td>0.42</td>
<td>0.42</td>
</tr>
</tbody>
</table>
Figure 5. An example of SCM results for idealized forcing in comparison with COAMPS 3D results and rawinsonde sounding at SCM initialization and SCM 3-hour forecast for a) and b) potential temperature, c) and d) specific humidity, and e) and f) modified refractivity. The blue line represents the sounding recorded at 1750Z on July 14th. The pink symbol on the surface is the COAMPS SST while the SCM SST was fixed at 299.5K.