2aAO1. Uncertainty of transmission loss due to small scale fluctuations of sound speed in two environments

J. P. Fabre* and Warren T. Wood

*Corresponding author's address: Acoustics 7180, Naval Research Laboratory, 1005 Balch Blvd, Stennis Space Center, MS 39529, jfabre@nrlssc.navy.mil

Seismic oceanography techniques reveal detection of small scale variations in sound speed not detectable via conventional oceanographic means, i.e. frequent XBT or CTD casts). Due to computational and practical limitations, such small scale spatial and temporal detail that exists in a real ocean environment is not typically included in acoustic ocean models. However, such measurements can provide insight to the small scale variability (uncertainty) that exists in the ocean but is not predicted by mesoscale ocean models. We show acoustic predictions made with the Range Dependent Acoustic Model (RAM) using measured seismic oceanography and CTD data at two locations in significantly different environments. Additionally, the CTD measurements are smoothed to a resolution comparable to that provided by a dynamic ocean model and acoustic predictions are computed. The Uncertainty Band (UBAND) algorithm [Zingarelli, R. A., "A mode-based technique for estimating uncertainty in range-averaged transmission loss results from underwater acoustic calculations" J. Acoust. Soc. Am. 124 (4), October 2008] is applied to the smoothed oceanographic data using estimates of sound speed uncertainty calculated from the high resolution measurements. We find reasonable estimates of uncertainty due to the small scale oceanography that is not characterized by mesoscale ocean models.

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INTRODUCTION

The technique of seismic oceanography (Holbrook 2003) relies on the near normal incidence reflectivity of temperature contrasts in the water column. In contrast to acoustic oceanography, the low frequency waves are coherently reflected by actual temperature contrasts, not scattered by ancillary material in the water column. Although the acoustic impedance of water depends on both sound speed and density, both of which depend on temperature and salinity, it is a much stronger function of temperature. Typically these contrasts are actually vertical gradients extending over several meters and therefore only efficiently reflect waves longer than a few meters. i.e. frequencies lower than about 250 Hz (Figure 1). Conventional seismic sources, such as air guns put out strong (>220 dB re 1microPa @1m) signals from about 20-250 Hz, and are thus well suited for this purpose. Water column reflections are quantitatively linked to temperature contrasts, and in some cases the temperature contrast can be inverted from the reflectivity data (Wood et al. 2008).

The similarity in lateral and vertical resolution (5-10m) makes seismic oceanography observations uniquely synoptic in nature. Features as small as 5-10 meters thick can be traced for many tens of kilometers, an impossible task using even the highest density CTD (conductivity, temperature, depth) or XBT (expendable bathythermograph) casts. Such features, effectively stringers of cold, density compensated water appear in seismic oceanography records acquired in the Adriatic Sea (Wood et al. 2010). The synoptic resolution allows us to very accurately model how these small features modify the acoustic propagation of higher frequency signals, and how they might affect estimates of uncertainty.

Acoustic uncertainty techniques have been developed to estimate uncertainty of transmission loss (TL) due to uncertainty of the waveguide through which the sound travels. Once such method is the Uncertainty Band (UBAND) algorithm (Zingarelli, 2008). UBAND applies mode summation techniques similar to that of acoustic range averaging (Harrison and Harrison, 1995), to compute an upper and lower estimate of TL, given estimates of mode uncertainty due to each source of environmental uncertainty.

Here we apply UBAND to TL predictions using climatological sound speed with sound speed uncertainty estimates provided by the seismic oceanography data.
ENVIRONMENT

In March of 2009 an array of two GI (generator Injector) was deployed along with a 1.2 km, 96 channel receiving array in the Adriatic Sea in the Gargano Peninsula and Bari Canyon areas. These data, along with coincident XBT data, provide the sound speed input for the acoustic model runs.

Climatological sound speed for the same track was obtained from the Generalized Digital Environmental Model (GDEM) (e.g. Carnes, 2009). Bathymetry taken during experiment was used with a generic sand sediment description to provide input to the acoustic model. Climatological sound speed from GDEM along a track in the Adriatic Sea for March is shown in Figure 2, the sound speed taken using XBTs during the exercise is shown in Figure 3 and the sound speed derived from the SO measurements along the same track is shown in Figure 4. The SO
measurements show quite a bit of structure that is not captured by the XBT data and is clearly not captured by climatology. Additionally, the climatology has significantly faster values of sound speed and does not capture the fast feature shown from ~20-25km in Figure 3 and Figure 4. An ocean model is not available for this time frame and area, but it is expected that ocean models would have consistent values, but not the detail provided by the SO and possibly that of the XBTs.

Figure 2. Climatological sound speed (m/s) versus range (km) and depth (m) along the experimental track for March.

Figure 3. Sound speed (m/s) versus range (km) and depth (m) from XBTs along track.
ESTIMATING UNCERTAINTY

The UBAND algorithm (Zingarelli, 2008) is based on Harrison and Harrison (1995), who noted that a range average of TL is very similar to a frequency average over the system band width, due to the mathematical similarity of the two techniques using sums over normal modes. Zingarelli (2008) extended the range averaging technique to calculate upper and lower boundaries on a TL prediction by estimating an uncertainty in the number of modes used in the mode sum. The uncertainty in the number of modes is based on the uncertainty in the environmental inputs. This technique has been shown (e.g. Zingarelli and Fabre, 2009) to be quite accurate for various applications.

RESULTS

Characterizing small scale ocean features, such as those captured by the seismic oceanography data, is crucial to understanding the ocean dynamics and acoustic propagation through the ocean. If available, this data can be used in model predictions to accurately estimate TL.

TL predictions are shown for the three environmental characterizations discussed above, for a shallow (20m) source (Figure 5), mid-water column (60m) source (Figure 6) and a deep (80 m) source (Figure 7). The shallow source cases all show some energy converging near the source depth, however the deeper energy differs significantly in structure and the XBT predictions show less energy near the surface from ~15km to the maximum range. A summary of the percentage of magnitude differences for the cases is given in Table 1. The mid-water column and deep cases also show structural differences, the XBT and SO cases show energy being redirected toward the bottom by the fast feature, this is evident by the higher energy (yellow) along the bottom in the upper right and lower left of Figure 6 and Figure 7, from a range of approximately 15km.

Figure 4. Sound speed versus range (km) and depth (m) and bathymetry (black) from seismic oceanography data.
Table 1. Percent of magnitude differences greater than 3dB.

<table>
<thead>
<tr>
<th></th>
<th>Shallow Source</th>
<th>Mid-Water Source</th>
<th>Deep Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>XBT vs Climatology</td>
<td>66</td>
<td>62</td>
<td>61</td>
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<tr>
<td>Seismic Oc. vs Climatology</td>
<td>43</td>
<td>54</td>
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<tr>
<td>Seismic Oc. vs XBT</td>
<td>51</td>
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Figure 5. Shallow source (20m) for three sound speed cases: climatology (upper left), XBT as measured during exercise (upper right), Seismic Oceanographic measurement as taken during exercise (lower left) and a single depth (50m) comparison, where the lines represent magnitude differences between climatology and the XBT (green), climatology and SO (blue) and XBT and SO (red).
Figure 6. Mid-water column source (60m) for three sound speed cases: climatology (upper left), XBT as measured during exercise (upper right), Seismic Oceanographic measurement as taken during exercise (lower left) and a single depth (50m) comparison, where the lines represent magnitude differences between climatology and the XBT (green), climatology and SO (blue) and XBT and SO (red).
While such small scale information may not be readily available to acoustic models, we can use the small scale information to estimate the uncertainty in a modeled or climatological environment, thus providing a more accurate estimates of TL with the available information.

Here, the UBAND algorithm is used to apply uncertainty information from the measurements described above to a climatological prediction. The sources of uncertainty required by UBAND are the sound source and receiver location uncertainty, bathymetric and bottom loss uncertainty, frequency band uncertainty and sound speed uncertainty. Standard values for all but the sound speed uncertainty are used for all cases. The sound speed uncertainty is estimated by computing the standard deviation of the sound speed collected using the seismic oceanographic techniques.

The transmission loss is then computed using the Range Dependent Acoustic Model (RAM) (Collins, 1989) with the climatological sound speed and bathymetry from the experiment. Figure 8 shows TL due to a unit continuous wave (CW) source at 20m depth, range 0, estimated at a depth of 20m. The black line is the RAM prediction of TL using climatological sound speed profiles, the uncertainty result, in blue, is the worst case and best case TL given the environmental uncertainties discussed above. The red line is the RAM TL prediction using the measured sound speed (as shown in the lower left pane of Figure 5). Similar results for the mid-water and deep source are shown in Figure 9 and Figure 10. From these results, it is evident that the best case TL prediction (RAM run with SO sound speed) generally lies between the uncertainty predictions. To quantify how well the UBAND algorithm estimates the uncertainty of the problem, we compute the percentage of values on the best case or
reference answer, that fall between the upper and lower uncertainty band. Table 2 shows a summary of these percentages. For one standard deviation, if approximately 70% of the points fall within the UBAND, then we consider the results to be valid. The results in Table 2 all show acceptable values.

Figure 8. TL versus range for a 20m source, 20m receiver predicted using climatology (black), TL uncertainty (blue) using climatology prediction with uncertainty from seismic oceanographic measurements and TL predicted using seismic oceanographic measurements (red).

Figure 9. TL versus range for a 60m source, 20m receiver predicted using climatology (black), TL uncertainty (blue) using climatology prediction with uncertainty from seismic oceanographic measurements and TL predicted using seismic oceanographic measurements (red).
Figure 10. TL versus range for a 80m source, 20m receiver predicted using climatology (black), TL uncertainty (blue) using climatology prediction with uncertainty from seismic oceanographic measurements and TL predicted using seismic oceanographic measurements (red).

Table 2. Percent of values inside the uncertainty band.

<table>
<thead>
<tr>
<th>Receiver Depth (m)</th>
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<th>Mid-Water Source</th>
<th>Deep Source</th>
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CONCLUSIONS

Small scale fluctuations in the ocean are common and can be measured using techniques such as seismic oceanography or high resolution expendable bathythermograph (XBT). Small fluctuations in the sound speed can impact acoustic transmission loss (TL) predictions, but are not generally available to acoustic models. We have shown that information regarding small scale oceanographic fluctuations can be applied via the UBAND uncertainty algorithm to TL calculated using a baseline acoustic prediction, made using sound speed from climatology or an ocean model.

ACKNOWLEDGEMENTS

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REFERENCES


