Efficient Acoustic Uncertainty Estimation for Transmission Loss Calculations

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LONG-TERM GOALS

The overall long-term goal for this project is to enhance the Navy's predictive capabilities in uncertain ocean environments. This project is a collaboration with Dr. Robert Zingarelli at the Naval Research Laboratory - Stennis Space Center (NRL-SSC). At the time of this project's proposal, the long-term goal was the integration of the existing field-shifting algorithm [1,2] with uBand, the Navy's transmission loss (TL) uncertainty prediction program. However, for the uncertain variables of greatest interest to NRL-SSC, alternative reciprocity-based or calculation-statistics-based techniques are likely to provide more accurate results with greater computational efficiently than the field-shifting approach. At present, the long-term goal for this project is to produce techniques and algorithms that improve the performance of uBand for predicting TL uncertainty in underwater environments of interest to the US Navy, specifically when the source depth is uncertain.

OBJECTIVES

The current objectives of this project are: a) develop and optimize a statistical technique using field data from a single field calculation to predict TL uncertainty resulting from source depth uncertainty, *b*) evaluate the performance of this technique in a variety of environments, and *c*) publish the results of this research to aid in the integration of this approach with the existing uBand algorithm.

APPROACH

The research approach for this project is to hypothesize, develop, and test computationally-efficient techniques for estimating the uncertainty inherent in acoustic TL calculations that arises from uncertain sound channel and environmental parameters. Rigorous (but computationally inefficient) direct- or Monte-Carlo simulations are used to determine the ground truth for all acoustic uncertainty scenarios and to evaluate the accuracy of various TL-uncertainty prediction techniques. Simulations in range-independent environments are performed with the modal-sum propagation model KRAKEN. Simulations in range-dependent environments are currently performed using RAMGEO, the computational foundation for the US Navy's Standard Parabolic Equation model (NSPE).

The range-dependent environments of current interest to NRL-SSC are sound channels with simple non-uniform sound speed profiles with upsloping or downsloping bathymetry over ranges up to 30 km at frequencies of 100 Hz to 1 kHz. Simulations are conducted in these environments, and the uncertainty predictions of the new *area statistics* approach are compared to direct simulations or Monte Carlo results.

WORK COMPLETED

Prior research applying the principle of reciprocity was successful for predicting TL uncertainty in range-independent environments, or at a single range of interest in range-dependent environments. Unfortunately, this technique is inefficient for predicting TL uncertainty bounds as a function of range in a range-dependent environment. Thus, for most of FY12, a second approach was pursued based on a combination of the adiabatic approximation, and TL calculations from RAMGEO. This approach had considerable potential due to its basis in acoustic wave-propagation physics, but a workable computational technique for extracting the TL uncertainty that results from source-depth uncertainty could not be developed, the primary problem being inversion of a system of non-linear algebraic equations. Thus, during FY13, a third approach was being pursued. It is based on collecting TL statistics from a single RAMGEO calculation in a range-depth area near the receiver location. This third approach is simpler and has a clear computational-efficiency advantage over the prior two approaches considered. It relies on sorting calculated TL values in a region near the field point of interest, and does not require any additional field calculations.

RESULTS

The TL uncertainty prediction scheme now under consideration has been named *area statistics* and it involves collecting, sorting, and sampling calculated TL values in a rectangular range-depth region near the location of interest. The technique is illustrated in Fig. 1. On the left is a small section of a range-depth TL calculation. The location of interest is shown as a black dot, and the range-depth region used for uncertainty estimation is shown as black rectangle. This rectangle has a height, W_z, of six standard deviations of source depth scaled by the ratio of the water column depth at the range of interest, $D(r)$, and the water column depth at the source, $D(0)$. The range-direction length of this rectangle, W_r, is two wavelengths. The N calculated TL values in this rectangle are sorted from smallest (index = 1) to largest (index = N). The lower and upper TL uncertainties are then determined from this sorted TL data by going downward to lower TL and upward to higher TL through a fixed percentage of the TL data that lies below and above, respectively, the predicted TL value at the point of interest. These lower and upper cutoff percentages, and the size of the rectangle are engineering parameters that need to be selected so that this approximate technique provides the best possible accuracy. The main effort for this project in FY13 has been to seek appropriate values for these parameter selections, and this parameter selection effort continues. When a suitable set of parameters has been found, a journal article on this topic will be submitted.

In this study, uncertainty predictions from area statistics are compared to direct simulations of source depth uncertainty from 25 RAMGEO field calculations (the original plus 24 additional field calculations). For comparison, the area statistics approach only requires the original field calculation; thus, it is orders of magnitude faster than direct simulations. Figure 2 shows a sound channel in which

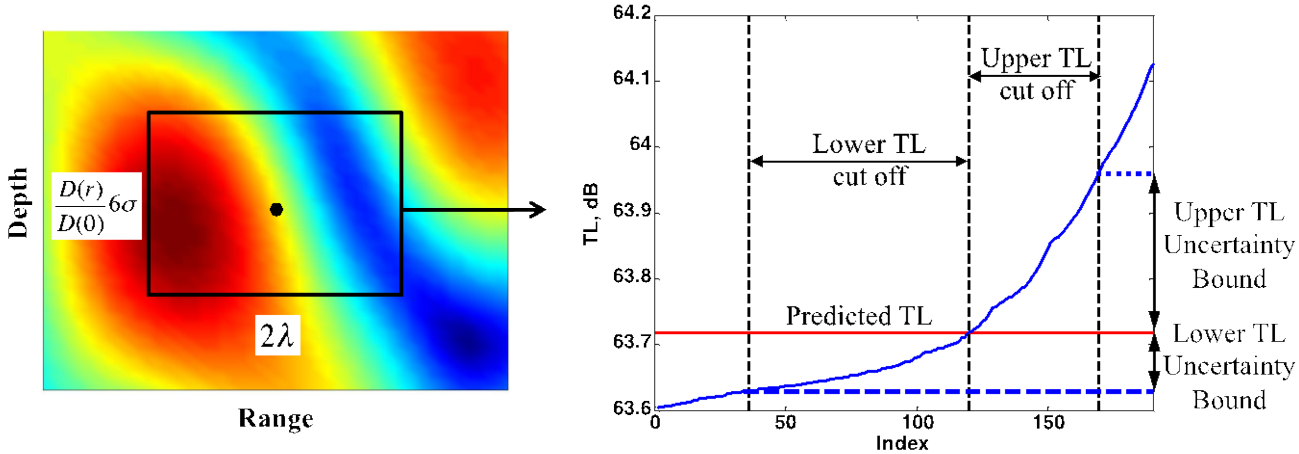

Figure 1. Schematic illustration of the area statistics technique. Here TL values in the range-depth rectangle shown on the left are sorted from lowest (index = 1) to highest TL value. In the example shown there are approximately 190 TL values in the region of interest and the predicted TL value lies at an index of 120. The lower and upper TL cut offs are percentage values used to determine the index values of the upper and lower uncertainty estimates. In this case, these index values are approximately 40 and 170.

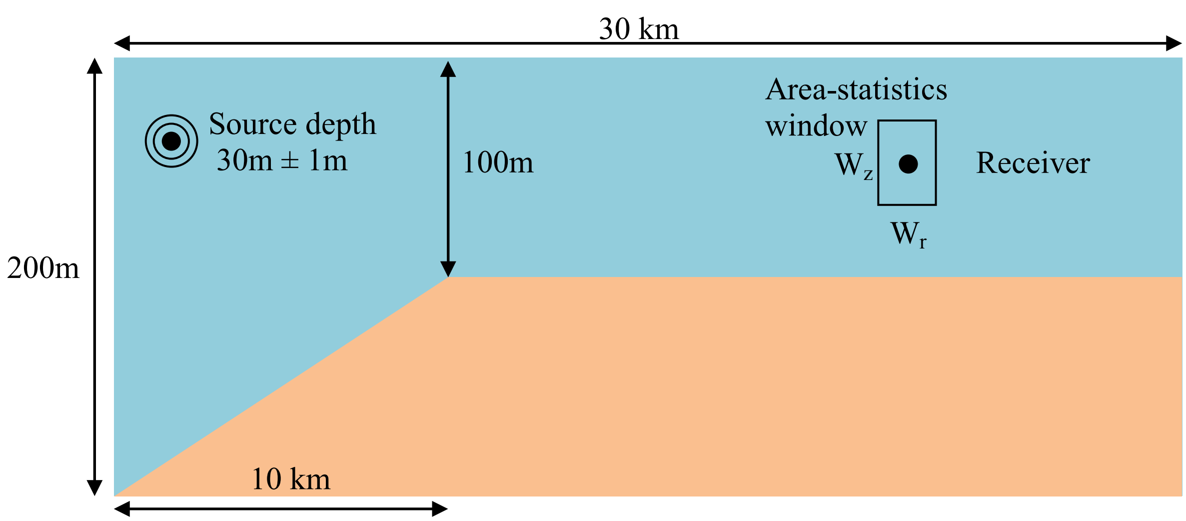

Figure 2. Sample range-dependent environment with uncertain source depth (not to scale). W_r and W_z are the range and depth dimensions, respectively, of the area-statistics window around the receiver.

these comparisons have been made. Here the source frequency and depth are 100 Hz and 30 m, respectively. The water-column sound speed is a constant 1500 m/s. The bottom sound speed, density, and absorption are 1700 m/s, 1.5 g/cm^3, and 0.5 dB/λ, respectively. The channel depth is 200 m at the source, and it slopes upward to a 100 m depth at a range of 10 km, where it becomes flat for the next 20 km. The source depth is uncertain, with a mean of 30 m and a standard deviation of 1 m. The range-averaged transmission loss is determined from RAMGEO at several receiver depths. Here the range-averaging interval is seven acoustic wavelengths (~100 m for the present case).

The uncertainty-bound comparisons are provided in Fig. 3 for a source depth of 50 m. The blue curves are from the area statistics calculations using the rectangle dimensions given above, and cutoff percentages of 50% for the lower uncertainty bound and 66% for the upper uncertainty bound. The confidence interval for both red and blue curves in this figure is ±3(standard deviations), 99.7%. When a smaller confidence interval is needed, linear scaling of the cutoff percentages has been found to be an adequate approach. Thus, the confidence interval for ±1(standard deviation), 68%, would be obtained by the same procedure with cutoff percentages of 17% for the lower uncertainty bound and 22% for the upper uncertainty bound, respectively.

The performance shown in Fig. 3 is typical of area statistics. The match between direct simulations and area statistics is better for the lower TL uncertainty bound. The upper TL uncertainty bound is more volatile for these single-frequency TL results. This is illustrated in Fig. 4 which shows the cross correlation coefficient between the area statistics and direct simulation results for different source depths, and the difference in root-mean-square (RMS) uncertainty between the area statistics and direct simulation results for different source depths, both computed over the full 30 km range. The cross correlation coefficient is consistently near 0.70 and RMS uncertainty differences are just a fraction of a decibel when the source is away from the ocean surface. These results show that accurately predicting TL uncertainty for sources close to the surface may require some modification of the area statistics technique.

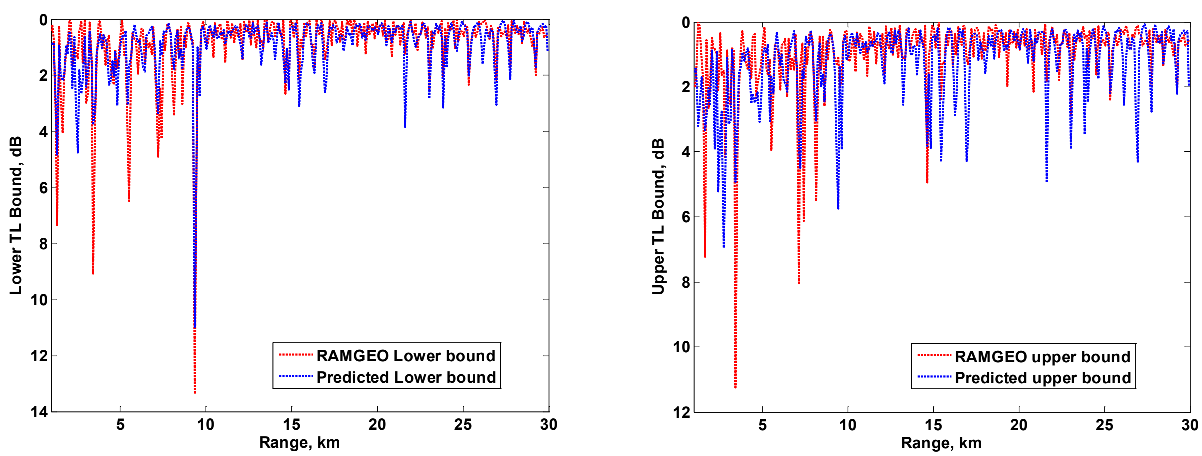

Figure 3. Comparisons of TL uncertainty bounds from area statistics (blue) and direct simulations (red). The left plot is for the lower TL bound and the right plot is for the upper TL bound. In both cases, the agreement is imperfect, but the trend is correct and many of the spikes are matched in location if not in amplitude.

IMPACT/APPLICATION

This project seeks to improve existing Navy TL prediction capabilities through collaborations with researchers at NRL-SSC to optimize acoustic uncertainty prediction algorithms. By addressing many uncertain environmental variables, and working to develop new techniques where current techniques lack accuracy or efficiency, the intended end result should be a robust and efficient computational tool for Navy-relevant transmission loss uncertainty prediction in imperfectly known ocean environments.

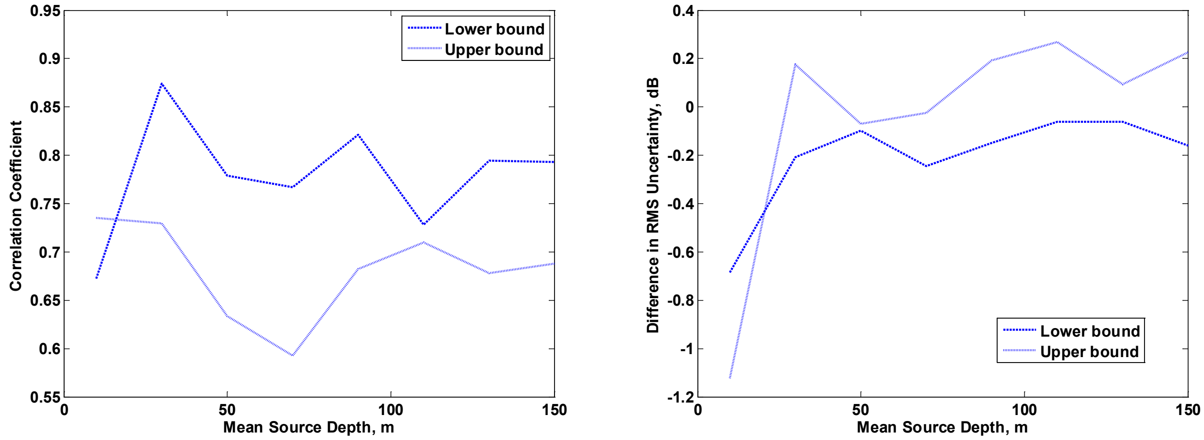

Figure 4. Cross correlation coefficient between the area statistics and direct simulation results for different source depths, and the difference in root-mean-square (RMS) uncertainty between the area statistics and direct simulation results for different source depths. The cross correlations coefficients are near 0.70 and the difference in RMS uncertainties is just a fraction of a dB when the source is away from the ocean surface.

TRANSITIONS

This project has a direct transition path. If successful, this project's results will feed into the uBand algorithm, that is now (or will soon be) a Navy-standard software tool for acoustic uncertainty prediction that is obtainable from the US Navy's Oceanographic and Atmospheric Master Library (OAML) under the Commander, Naval Meteorology and Oceanography Command (CNMOC).

RELATED PROJECTS

This project is a follow-up effort to past ONR-funded work at the University of Michigan on efficient prediction of acoustic uncertainty. In the past decade there has been a significant amount of ONR-funded research on acoustic uncertainty. Foremost among these was the Quantifying, Predicting, and Exploiting (QPE) Uncertainty program lead by Dr. James Lynch that emphasized acoustic experiments. In addition, NRL-DC has a sustained effort in this area focused on polynomial chaos and related techniques under the leadership of Dr. Steven Finette. The project described in this report more closely conforms to Naval applications of acoustic uncertainty prediction than the QPE program and is less computational and mathematical than the NRL-DC effort.

REFERENCES

[1] James, K.R., and Dowling, D.R. (2008) "A method for approximating acoustic-field-amplitude uncertainty caused by environmental uncertainties," *J. Acoust. Soc. Am.* Vol. 124, 1465-1476.

[2] James, K.R., and Dowling, D.R. (2011) "Pekeris waveguide comparisons of methods for predicting acoustic field amplitude uncertainty caused by a spatially-uniform environmental uncertainty," *J. Acoust. Soc. Am.* Vol. 129, 589-592.

HONORS AND AWARDS

Prof. Dowling was elected Fellow of the American Physical Society in November 2012.